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INCLUSION OF GUARANA BY-PRODUCTS AS ALTERNATIVE FEEDS IN DIETS FOR SLOW-GROWING BROILERS

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ABSTRACT

The problem of animal feeding in the Amazon region has faced significant challenges, particularly in the poultry industry, where feed costs account for approximately 70% of total expenses. This problem is aggravated by the dependence on grains, where 100% of feed raw materials are imported. This reality requires the search for alternative ingredients that reduce costs and increase profitability. By-products of guarana, an Amazonian fruit of economic and social importance, emerge as a promising option. Expanding the use of by-products and agricultural residues as alternative components in animal nutrition can represent an economically advantageous strategy, since these materials are often abundant and low-cost. Given the underutilized potential of guarana residues, this project proposes integrating these by-products into the diet of slow-growing broiler chickens, thereby optimizing nutrient collection, improving zootechnical performance, and reducing environmental impact, ultimately promoting more sustainable and economically viable animal production. Additionally, a literature survey on the management and production of slow-growing broiler chickens was conducted, along with a systematic review of the primary studies on alternative feeds in Brazil. It is worth mentioning that before including the by-products in the diet, a survey of the cellular cytotoxicity and total phenols of guarana and its by-products was conducted, as well as a survey on the production of guarana in the state of Amazonas, as well as an analysis of the economic viability of the by-products and a sensory analysis of the breast of slow-growing broiler chickens. In general terms, the results of this study demonstrate that the inclusion of guarana by-products in the diets of slow-growing broilers has the potential to significantly improve bird performance, increasing weight gain, improving feed conversion and providing a higher carcass yield, with cuts of higher commercial value. Its inclusion has proven to be economically viable and has achieved excellent acceptability among consumers. The inclusion of up to 10% guarana by-products in animal diets does not pose a risk of cell damage or death.

Keywords: Alternative feed; Poultry nutrition; *Paulinnia cupanna*; Sustainability.

RESUMO

O problema da alimentação animal na região amazônica tem enfrentado desafios significativos, especialmente na indústria avícola, onde os custos com ração representam aproximadamente 70% das despesas totais. Esse problema é agravado pela dependência de grãos, onde 100% das matérias-primas para ração são importadas. Essa realidade exige a busca por ingredientes alternativos que reduzam custos e aumentem a lucratividade. Os subprodutos do guaraná, uma fruta amazônica de importância econômica e social, surgem como uma opção promissora. Ampliar o uso de subprodutos e resíduos agrícolas como componentes alternativos na nutrição animal pode representar uma estratégia economicamente vantajosa, visto que esses materiais são frequentemente abundantes e de baixo custo. Dado o potencial subutilizado dos resíduos do guaraná, essa tese propõe a integração desses subprodutos na dieta de frangos de corte de crescimento lento, visando otimizar a absorção de nutrientes, melhorar o desempenho zootécnico e reduzir o impacto ambiental, promovendo uma produção animal mais sustentável e economicamente viável. Além disso, foi realizado um levantamento de literatura sobre o manejo e produção de frangos de corte de crescimento lento, e uma revisão sistemática sobre os principais estudos com alimentos alternativos no Brasil. Vale salientar que antes de incluir os subprodutos na dieta, foi realizado um estudo sobre a citotoxidade celular e fenóis totais do guaraná e seus subprodutos, e um levantamento sobre a produção de guaraná no estado do Amazonas, assim como a análise de viabilidade econômica dos subprodutos e análise sensorial do peito dos frangos de corte de crescimento lento. Em termos gerais, os resultados deste estudo demonstram que a inclusão de subprodutos do guaraná nas rações para frangos de corte de crescimento lento tem o potencial de melhorar significativamente o desempenho das aves, aumentando o ganho de peso, melhorando a conversão alimentar e proporcionando um rendimento de carcaça superior, com cortes de maior valor comercial, sua inclusão demonstrou ser viável economicamente e obteve excelente aceitabilidade pelos consumidores, e a inclusão de até 10% dos subprodutos do guaraná nas dietas de animais não possui risco de danos ou morte celular.

Palavras-chave: Alimento alternativo; Nutrição avícola; *Paulinnia cupanna;* Sustentabilidade

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LIST OF ACRONYMS

ABEF: Brazilian Association of Chicken Producers and Exporters

ABPA: Brazilian Animal Protein Association

ADF: Acid detergent fiber

ALB: Albumin

ANOVA: Analysis of Variance

AOAC: Association of Official Analytical Chemists

ASMMPW: Acid silage meal made of pirarucu waste

BA: Back

BE: Break-even

BR: Breast

CARB: Carbohydrate

CHO: Cholesterol

COR: Correlation

CR: Cassava residue

CV: Coefficient of variation

EMBRAPA: Brazilian Agricultural Research Corporation

CONAB: National Supply Company

°C: Celsius degree

CF: Crude fiber

CP: Crude protein

CS: Cassava scrapings

CSR: Cassava starch residue

CY: Carcass yield

DCR: Dry cassava residue

dL: Deciliter

DM: Dry matter

DR: Drumsticks

EE: Ether extract

ERI: Erithrocytes

FA: Fats

FAEA: Federation of Agriculture and Livestock of the State of Amazonas

FC: Feed conversion

FI: Feed intake

FO: Foot

F1: Phase 1

F2: Phase 2

°F: Fahrenheit degree

g: grams

GDP: Gross domestic product

GE: Gross energy

GFPE: Guavira fruit peel extract

GI: Gizzard

GLU: Glucose

GPEM: Guarana peel meal

GPUM: Guarana pulp meal

HE: Heart

HEMAT: Hematocrit

HEMOG: Hemoglobin

HSD: Honest Significant Difference

Hz: Hertz

IBAMA: Brazilian Institute of Environment and Renewable Natural Resources

IBGE: Brazilian Institute of Geography and Statistics

ICB: Institute of Biological Scinces

IDAM: Institute for Sustainable Agricultural and Forestry Development of the State of Amazonas

IFAM: Federal Institute of Education, Science and Technology of Amazonas

INMETRO: National Institute of Metrology, Quality and Technology

IU: International unity

Kg: kilogram

LI: Liver

MAPA: Ministry of Agriculture and Livestock

MCV: Mean curpuscular volume

MCH: Mean curpuscular hemoglobin

MCHC: Mean curpuscular hemoglobin concentration

ME: Metabolizable energy

MM: Mathematical model

MI: Minerals

MO: Moisture

NDF: Neutral detergent fiber

NE: Neck

N-NE: Non- nitrogenated extract

PCPUM: *Paullinia cupana* pulp meal

PCPM: *Paullinia cupana* peel meal

pg: Picograms

PICO: Pupulation, intervencion, control and observation

PPGCARP: Graduate Program in Animal Science and Fisheries Resources

PRISMA: Sistematic review and meta- analyses

PT: Proteins

SC: Search component

SEDECTI- AM: Amazonas State Secretariat for Economic Development, Science, Technology and Innovation

SPG: Participatory Guarantee System

SW: Slaughter weight

TH: Thighs

TP: Total proteins

TRI: Tryglicrides

TWBSM: Tambaqui waste biological silage meal

UFAM: Federal University of Amazonas

μm^3: Cubic micrometer

VIF: Variance, Inflation Factor

WG: Weight gain

WI: Wings

SUMÁRIO

ORGANIZATION OF THE THESIS

This thesis was developed between 2021 and 2025, comprising 9 interconnected chapters that integrate research and practical applications. Each stage is explored comprehensively, covering everything from poultry management and production, a survey of guarana production in the Amazon, characterization of guarana and its by-products, efficacy tests of guarana by-products in animal nutrition, economic and sensory analysis, and culminating in a booklet that summarizes alternative ingredients for sustainable poultry farming. Chapter 1 consists of a literature review on the management and production of slow-growing broiler chickens, which was adapted into a book chapter and subsequently published. Chapter 2 presents a systematic review on by-products used as alternative feeds in Brazilian poultry farming, published in the World's Poultry Science Journal (accepted for publication; impact factor: 3.9).

Chapter 3 addresses an econometric and market analysis of the guarana production chain in Amazonas; the manuscript was submitted to Innovation and Development (under evaluation; impact factor: 1.4). Chapter 4 discusses data on total phenols and cellular cytotoxicity of guarana and its byproducts; it was submitted to the journal ACS Food Science & Technology (impact factor: 2.8). Chapter 5 describes a field experiment that tested inclusion levels of guarana bark on performance, carcass yield, serum biochemistry, and meat quality of slow-growing chickens; published in Animal Production Science (impact factor: 1.2). Chapter 6 describes a field experiment that tested inclusion levels of guarana cake on performance, carcass yield, physiological analyses, and meat quality of slow-growing chickens; submitted to Animal Production Science (under evaluation; impact factor: 1.2).

Chapter 7 addresses the growth performance and economic viability of guarana by-products in diets for slow-growing broilers. The Brazilian Journal of Poultry Science published the article (impact factor: 1.1). Chapter 8 deals with data on the sensory analysis of broilers fed with guarana by-products. The article was submitted to Food Science and Technology (impact factor: 2.6). Chapter 9 is a primer, which provides a compilation of information on the use of alternative feeds for poultry farming in the Amazon. The primer is written in simple language and follows a didactic sequence, primarily aimed at small producers. The chapters follow the general structure of the thesis, with formatting adapted according to the guidelines of the scientific journals to which each work was submitted. The diversity of formats reflects the specific standards of each publication, maintaining academic rigor and methodological clarity

INTRODUCTION

Brazilian agribusiness has made significant progress since the mid-20th century, transforming production potential into food security through productivity gains (ABEF, 2021). The broiler chain stands out for its efficiency and leadership in exports (Schmidt & Silva, 2018), with production of 14.833 million tons in 2023 (ABPA, 2024). It has become one of the most consumed chicken meats worldwide (Guimarães et al., 2017), with production highlighted in large-scale systems that serve several markets (Silva et al., 2015). This success is attributed to technological advances, better feed conversion, genetics, and an efficient research and development system (Schmidt & Silva, 2018; Tremea & Silva, 2020). Its popularity is attributed to its high nutritional value, accessibility, and growing consumer preference for white meat (Vannier et al., 2022).

At the same time, alternative poultry farming represents an essential segment on Brazilian rural properties, providing value-added products (Silva et al., 2015). In the state of Amazonas, alternative poultry farming plays a significant role in the state's economy, offering sustainable production with social and agroecological appeal (Cruz et al., 2016), while promoting animal welfare (Lima et al., 2019; Ribeiro et al., 2022). This production system is consolidating, with a promising market (Raimundo et al., 2018) and is associated with Family Farming because it requires low investment, allows for simplified management, and provides quality protein (Cruz et al., 2013; Raimundo et al., 2018). These birds offer valuable sensory attributes (Morais et al., 2015) and improved climate adaptation compared to conventional production systems.

These systems can be economically viable for small farmers, contributing to income diversification and food security (Lima et al., 2019). However, profitability requires careful planning and management of production costs (Silva et al., 2019; Inácio et al., 2018), mainly due to the economic challenge of production costs, especially feed (Valentim et al., 2021; Cruz et al., 2016).

The problem of animal feed in the Amazon region has faced significant challenges, especially in the poultry industry, where feed costs account for approximately 70% of total expenses (Cruz et al., 2016). This problem is aggravated by the dependence on grains (De Souza et al., 2024), where 100% of feed raw materials are imported (Cruz et al., 2016; Valentim et al., 2021). This reality requires the search for alternative ingredients that reduce costs and increase profitability (Klinger et al., 2020). Research suggests that the use of local alternative ingredients can reduce production costs and promote sustainability in poultry farming (De Souza et al., 2024).

Agroindustrial by-products emerge as a strategic alternative for partially replacing corn and soybean meal (Ferreira et al., 2019; Gouveia et al., 2019), necessitating an evaluation of their nutritional efficiency (Santos et al., 2020). Previous studies have shown that such ingredients can reduce costs and improve meat quality without compromising performance (Gouveia et al., 2019). And by-products of guarana, an Amazonian fruit of economic and social importance (Ferreira et al., 2022), emerge as a promising option.

Guarana has become an essential raw material, with 70% destined for the production of soft drinks and energy drinks, while the remaining 30% is directed towards consumption in its natural form or processed by the nutraceutical and dermocosmetic industries (Schimpl et al., 2013; da Silva et al., 2017). Its dry seeds are rich in caffeine (2.41%-5.07%), theophylline (0.06%), theobromine (0.03%), total tannins (5.0%-14.1%), proteins (7.0%-8.0%), polysaccharides (30%-47%), sugars (6.0%-8.0%), fibers (3.0%), fatty acids (0.16%), total ash (1.06%-2.88%) and moisture (4.3%-10.5%) (Marques et al., 2019; Schimpl et al., 2013).

Brazil is the only country in the world that produces commercial guarana (EMBRAPA, 1995). In 2022, the state of Amazonas ranked second in the national production ranking, with 686 tons (CONAB, 2023). In this scenario, due to the high volume of guarana production, a substantial amount of waste is consequently generated (Stevens et al., 2018), the improper disposal of which poses a serious environmental problem (Coppola et al., 2021). Expanding the use of agricultural by-products and waste as alternative components in animal nutrition can represent an economically advantageous strategy, since these materials are often abundant and low-cost (Van Hal et al., 2019), in addition to transforming residual materials into high-quality nutritional products to serve as ingredients in feed formulations (Batalha et al., 2017).

However, despite the nutritional and economic advantages of agro-industrial waste derived from native Amazonian species (Chaves et al., 2024), strategies are needed to make better use of these resources (Gomes et al., 2017). In this context, given the underutilized potential of guarana waste, this project proposes integrating these by-products into the diet of slow-growing broiler chickens, aiming to optimize nutrient absorption, improve zootechnical performance and reduce environmental impact, promoting more sustainable and economically viable animal production.

OBJECTIVES

General Objective

Evaluate the effects of including guarana by-products (shell bran and cake bran) in diets for slow-growing broiler chickens.

Specific Objectives

1. Conduct a literature review on the management and production of slow-growing broiler;
2. Systematically review the scientific evidence on the inclusion of alternative feeds in poultry nutrition in Brazil;
3. Assess the structure of the guaraná value chain in the state of Amazonas, mapping its geographic distribution across microregions and applying econometric tools to analyze its production dynamics;
4. Evaluate the cytotoxicity, antioxidant activity, and total phenolic content of different guarana derivatives (powder, peel, pulp, and shell) to assess their safety and potential functional properties for application in animal nutrition;
5. Investigate the impacts of *Paullinia cupana* peel meal (PCPM) on the growth performance, meat quality, and hematological and serum biochemical parameters of slow-growing broilers;
6. Analyze the effects of *Paullinia cupana* pulp meal (PCPUM) on the performance, physiological parameters, and meat quality of slow-growing broilers;
7. Evaluate the growth performance and economic feasibility of slow-growing broilers fe diets containing increased levels of guarana by-products;
8. Investigate the effect of the inclusion of guarana by-products in diets of slow-growing broilers on the centesimal composition and sensory properties of the meat;
9. Develop a practical manual with alternative foods that can be used for poultry nutrition, using simple language to help small rural producers adopt these alternative foods and facilitate their application in everyday life.

REFERENCES

ABEF- Associação Brasileira dos Produtores e Exportadores de Frango. Relatório Anual 2021. Disponível em: https://abpa-br.org/wp-content/uploads/2021/04/ABPA_Relatorio_Anual_2021_web.pdf. Acesso em: 29 jun. 2025.

ABPA- Associação Brasileira de Proteína Animal. Relatório Anual 2024. Disponível em: https://abpa-br.org/wp-content/uploads/2024/04/ABPA-Relatorio-Anual-2024_capa_frango.pdf. Acesso em: 29 jun. 2025.

Batalha, O.S.; Alfaia, S.S.; Cruz, F.G.G.; Jesus, R.S.; Rufino, J.P.F.; Rocha, V.C. Digestibility and physico-chemical characteristics of acid silage meal made of pirarucu waste in diets for commercial laying hens. Acta Scientiarum. Animal Sciences, v. 39, p. 251, 2017. https://doi.org/10.4025/actascianimsci.v39i3.35112

Chaves, F.A.L.; Guimaraes, L.L.; Guimaraes, C.C.; Souza, L.S.S.; Rufino, J.P.F.; Pereira, A.M. Farelo de tucumã como alimento alternativo em dietas para frangos de corte de crescimento lento. Revista em Agronegócio e Meio Ambiente, v. 17, e11969, 2024.

CONAB - COMPANHIA NACIONAL DE ABASTECIMENTO. Análise mensal Guaraná – Agosto 2023. Disponível em: https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuario-e-extrativista/analises-do-mercado/historico-mensal-de-Guarana. Acesso em:04/04/2025.

Coppola, D.; Lauritano, C.; Palma Esposito, F.; Riccio, G.; Rizzo, C.; & de Pascale, D. Fish waste: From problem to valuable resource. Marine drugs, 19(2), 116. 2021.

Cruz, F. G. G., Rufino, J. P. F., Melo, R. D., Feijó, J. da C., Damasceno, J. L., & Costa, A. P. G. C. Perfil Socioeconômico da Avicultura no Setor Primário do Estado do Amazonas, Brasil. Revista Em Agronegócio E Meio Ambiente, *9*(2), 371–391. 2016. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Cruz, F. G. G.; das Chagas, E. O.; Botelho, T. R. P. Avicultura familiar como alternativa de desenvolvimento sustentável em comunidades ribeirinhas do Amazonas. Interações (Campo Grande), v. 14, n. 2, p. 197-202. 2013. https://doi.org/10.1590/S1518-70122013000200006

Da silva, G.S.; Canuto, K.M.; Ribeiro, P.R.V.; de Brito, E.S.; Nascimento, M.M.; Zocolo, G.J.; Coutinho, J.P.; & de Jesus, R.M. Perfil químico de sementes de guaraná (Paullinia cupana) de diferentes origens geográficas utilizando UPLC-QTOF-MS combinado com quimiometria. Pesquisa Alimentar Internacional, 102, 700-709. 2017.https://doi.org/10.1016/j.foodres.2017.09.055

De Souza, T.; Rufino, J.P.F.; Dias, P.G.; Souza, L.F.; Araújo, K.F.; Machado, N.J.B.Use of regional alternative feeds in poultry diets in the Amazon rainforest. Observatorio de la Economía Latinoamericana 22(12), 01-24. 2024. https://doi.org/10.55905/oelv22n12-287

EMBRAPA. A cultura do guaraná. 1995. Disponível em: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/162284/1/A-cultura-doguarana.pdf. Acesso em: 04/04/2025.

Ferreira, F.A.M.; Ferreira, B.B.; Bragança, V.A.N.; Lima, C.L.S.; Brasil, D.S.B. Guaraná (*Paullinia cupana Kunth*), marapuama (*Ptychopetalum olacoides Benth*.), genciana (*Gentiana lutea L.*), quassia (*Quassia amara L.*) e suas propriedades: uma breve revisão. Pesquisa, Sociedade e Desenvolvimento , *[S. l.]* , v. 2, pág. e21711224592, 2022. https://doi.org/10.33448/rsd-v11i2.24592

Ferreira, T.S.; Lana, S.R.V.; Lana, G.R.Q.; Madalena, J.A.; Silva, L.C.L.; Torres, E.C. Acerola residue in feed for quails. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 71(1): 259-266, 2019. https://doi.org/10.1590/1678-4162-9965

Gomes, V.D.S.; Silva, J.H.V.; Cavalcanti, C. R.; Fonseca, S.B.; Filho, J.J.; Neto, M.R.S.; silva, F.B. Utilização de enzimas exógenas na nutrição de peixes - Revisão de literatura. Arquivos de Ciências Veterinárias e Zoologia da UNIPAR, [S. l.], v. 19, n. 4, 2017. DOI: 10.25110/arqvet.v19i4.6106

Gouveia, A.B.; Moraes, P.L.; Marixara, S.S.J, Justina, S.W, Borges S.J, Alves S.S, et al. Coprodutos de frutas e carboidrases na alimentação de aves: revisão. Pubvet [Internet]. v.13, n.12, 2019. https://doi.org/10.31533/pubvet.v13n10a424.1-14

Guimarães, D.D.; Amaral, G.F.; Maia, G.B.S.; Lemos, M.L.F.; Ito, M.; Custódia, S. Suinocultura: estrutura da cadeia produtiva, panorama do setor no Brasil e no mundo e o apoio do BNDES. BNDES Setorial, Rio de Janeiro, n.45, p. 85-136, 2017.

Inácio, M.C.P.; Baldi, H.F.; Santos, C.F.; Oliveira, L.S.; Ferreira, C.E.C., Rezende, R.M.; Mendonça, A.T. Intensive system x extensive in the cattle breeding. Revista da Universidade Vale do Rio Verde ISSN: 1517-0276, vol. 16, n. 1. 2018. https://doi.org/10.5892/RUVRD.V16I1.4642

Klinger, A. C. K.; Toledo, G. S. P.; Falcone, D. B.; & Knob, A. N. Capim-elefante (Pennisetum purpureum) como suplemento em dietas para coelhos de corte. Brazilian Journal of Development, 6(9), 70275-70281, 2020.

Lima, K.F.; MATOS, M.B.; SOUZA, M.N. Produção de Aves em Sistema de Base Agroecológica. Revista Vértices, *[S. l.]*, v. 21, n. 2, p. 205–219, 2019. https://doi.org/10.19180/1809-2667.v21n22019p205-219

Marques, L. L. M., Ferreira, E. D. F., De Paula, M. N., Klein, T., & De Mello, J. C. P. Paullinia cupana: a multipurpose plant–a review. Revista Brasileira de Farmacognosia, v. 29, n. 1, p. 77-110, 2019. https://doi.org/10.1016/j.bjp.2018.08.007

Morais, J.; Ferreira, B.P.; Jacome, D.T.M.I.; Mello, R.; Breda, C.F.; Rorato, N.R.P. Curva de crescimento de diferentes linhagens de frango de corte caipira. Produção Animal, Cienc. Rural 45 (10), 2015. https://doi.org/10.1590/0103-8478cr20130867

Raimundo, E.K.M.; Evangelista, G.M.; Paulino, R.D.; Beltrão, L.G.C.; Barbosa, L.B.; SILVA, J.R. Exploração da avicultura caipira em regime de economia solidária: uma análise dos problemas e condicionantes ambientais da produção em uma cooperativa da Paraíba. Cadernos de Agroecologia – Vol. 13, N° 1, p. 7-12. 2018.

Ribeiro, R.A.; Silva, A.C.; Carvalho, E.K.O.; Silva, L.A.; Teixeira, B.S.A.S.; Silva, N.H. Produção sustentável de ovos em sistema cage free por híbridos embrapa 051 em pequenas propriedades; da granja a área industrial. Congresso Online Acadêmico de Medicina Veterinária, 1ª edição. 2022. https://doi.org/10.54265/hmbk5358

Schimpl, F.C.; Da Silva, J.F.; Gonçalves, J.F.; Mazzafera, P. Guarana: revisiting a highly caffeinated plant from the Amazon. J Ethnopharmacol. 2013 Oct 28;150(1):14-31. https://doi.org/10.1016/j.jep.2013.08.023

Santos, G.C.L., Neto, S.G., Bezerra, L.R., Medeiros, A.N. Uso de tortas na alimentação de vacas leiteiras: uma revisão. Braz. J. Anim. Environ. Res., Curitiba, v. 3, n. 1, p.89-113, jan./mar, 2020.

Schmidt, N.S.; Silva, C.L. Pesquisa e Desenvolvimento na Cadeia Produtiva de Frangos de Corte no Brasil. RESR, Piracicaba-SP, Vol. 56, Nº 03, p. 467-482, Jul./Set. 2018. https://doi.org/10.1590/1234-56781806-94790560307

Silva, R.J.; Silva, M.S.; Filho, A.M.S. Apoio à autonomia financeira e à promoção social de mulheres e jovens rurais no município de Inhapi, semiárido alagoano. Extifal. v.1, n.1, p. 29-34. 2015.

Silva, M.G.; Sousa, V.T.S.; Nascimento, D.C.; Pordeus, F.Q. Analysis of profitability in poultry: an evaluation of the poultry production sector at the IFPB-Campus Sousa. Agropecuária Científica no Semiárido, Centro de Saúde e Tecnologia Rural. v.14, n.4. 2018. https://doi.org/10.30969/acsa.v14i4.1069

Stevens, J. R.; Newton, R. W.; Tlusty, M.; & Little, D. C. The rise of aquaculture by-products:

Increasing food production, value, and sustainability through strategic utilisation. Marine Policy, 90, 115-124. 2018.

Tremea, F.T.; Silva, A.C. O setor avícola no Brasil e sua distribuição regional. Economia & Região, *[S. l.]*, v. 8, n. 1, p. 183–200, 2020. https://doi.org/10.5433/2317-627X.2020v8n1p183.

Valentim, J.K.; D'Ávila Lima, H.J.; Marques Bittencourt, T.; Matos e Silva, N.E.; De Castro Burbarelli, M.F.; Garófallo Garcia, R.; De Carvalho Pantoja, J.; Barbosa, D.K. Grãos Secos de Destilaria na Alimentação de Frangos de Corte. Ensaios e Ciência: Ciências Biológicas, Agrárias e da Saúde , *[S. l.]* , v. 1, pág. 44–49, 2021. https://doi.org/10.17921/1415-6938.2021v25n1p44-49

Van Zanten, H.H.E.; Herrero, M.; Van Hal, O.; Röös, E.; Muller, A.; Garnett, T.; Gerber, P.J.; Schader, C.; De Boer, I.J.M. Defining a land boundary for sustainable livestock consumption. Global Change Biology, v. 24, p. 4185-4194, 2018.

Vannier, L.R.; Tavares, E.R.; Pagani, M.M.; Cruz, A.G.; Teixeira, C.E.; Duarte, M.C.K.H.; Esmerino, E.A. Chicken meat – A study on consumption, attitudes and the Brazilian consumer behavior. The Journal of Engineering and Exact Sciences – jCEC, Vol. 08 N. 09. 2022. https://doi.org/10.18540/jcecvl8iss9pp14854-01e

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CHAPTER 1: Management and production of slow-growing broilers

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INTRODUCTION

In Brazil, poultry farming has become a significant and expanding economic activity in the market (Cielo et al. 2019). Within this sector, the production of slow-growing broilers has emerged as a promising choice for meat production in alternative systems. This model not only adds value to the product but also caters to a portion of the population that prioritizes animal welfare and the quality of the animal protein consumed, benefiting both small and medium-sized producers (Delgado and Bergamasco 2017), while not directly competing with fast-growing broilers used in industrial production systems (Araújo et al. 2011).

The production of slow-growing broilers in alternative systems represents only 3% of the Brazilian poultry market, with great growth potential (Del Castilho et al. 2013; Albino et al. 2014). This is not a large-scale practice (Almeida et al. 2013), being closely linked to family farming due to the low required investment, simple management, use of family labor, generation of supplemental income, and the provision of high-quality protein at a low cost (Cruz et al. 2013).

In this context, family farming plays an essential role in food security by preserving traditional knowledge in food production and managing natural resources sustainably. Furthermore, this production model fosters the local economy (FAO 2014) and contributes to retaining the population in rural areas (Cruz et al. 2013). It generates income for small producers, provides inputs for other crops, utilizes waste from agricultural crops, fruits, and vegetables, and serves consumers who value the origin of the products they consume (Cielo et al. 2019).

The main advantages of this system include easy management and low need for advanced technologies. However, it is crucial that producers adopt basic practices, from animal welfare to food safety, at the end of the chain (Santos et al., 2020). In Brazil, alternative systems of poultry farming began with the regulation of caipira poultry farming through Circular Letter No. 007/99 from the Division of Industrial Operations of the Department of Inspection of Animal-Origin Products, Ministry of Agriculture and Supply (Brazil 1999).

In these alternative production models, the operation can be either intensive or extensive, without limitations regarding the breeds used (Chagas 2010). It is divided into two main categories: "backyard free-range" characterized by extensive and minimally technician farming, aimed at self-consumption, with low productivity, lack of reproductive control, and entirely farm-based production cycles, and "commercial free-range," which involves semi-intensive farming with greater specialization and technification, using improved breeds for higher productivity in these systems, with a focus on medium-scale commercialization (Albuquerque; Reis 2022).

Brief history of domestic poultry

Archaeological studies show that the first domestic poultry (*Gallus gallus domesticus*) appeared in Asia, specifically in China, around 5,400 B.C. (Hirst 2019). The domestication of these birds began around 3,200 B.C., with two main purposes: For ornamentation and cockfighting. Birds that did not meet these uses were slaughtered for consumption. In the 16th century, cockfighting became popular in Europe, and breeders became very demanding regarding the strength and aggressiveness of the birds. With the banning of cockfighting in the 19th century, Europeans sought new ways to value these birds, leading to exhibitions that awarded the most attractive birds in terms of plumage, size, and the shape of combs and wattles. This period marked the beginning of the interest in exploiting these birds and, eventually, the development of poultry production (Gessulli 1999).

Redneck birds, originating from various parts of the world, were introduced to Brazil during the period of discovery (EMBRAPA 2007). These birds were raised freely around houses and fed primarily on food scraps and insects (Barbosa et al. 2007; Chagas 2010). For centuries, these birds played a significant role in Brazilian rural culture, accompanying the evolution of the Brazilian population (Tavares and Ribeiro 2007; Santana et al. 2020).

Genetically, domestic poultry originated from four distinct genealogical branches: American, Mediterranean, English, and Asian (Englert 1998). They descend from up to four main species of wild fowl (Jungle Fowl): *Gallus sonnerati* (Grey Jungle Fowl), *Gallus gallus* (Red Jungle Fowl), *Gallus lafayettei* (Ceylon Jungle Fowl), and *Gallus varius* (Green Jungle Fowl) (Moiseyeva et al. 2003).

Phylogenetic research indicates that the Red Jungle Fowl, originating from Southeast Asia, appears to be the closest ancestral species to modern poultry (Tixier-Boichard et al. 2011). Through various crossbreeding, including inbreeding, current poultry maintain similarities with the main ancestral breeds, reflected in their plumage, build and abilities (Barbosa 2007).

In Brazil, native poultry breeds are limited to small groups in backyard farms. This scenario is primarily the result of the replacement of these breeds by specialized industrial breeds, which occurred during the expansion of industrial poultry farming in the country, especially from the 1970s onwards (Moiseyeva et al. 2003; Barbosa et al. 2007; Tavares and Ribeiro 2007). Redneck breeds are known for their slow growth, being slaughtered at around two to six months, and when directed for laying, producing about 180 eggs per cycle (Figueiredo et al. 2008). They also stand out for their high adaptability to different regions and climates of Brazil and being less susceptible to diseases (Carvalho et al. 2020).

Main breeds or strains

Before addressing the main redneck breeds or strains, it is essential to clarify the difference between breeds and strains, with strains referring to the result of crossbreeding between two breeds or varieties. Redneck strains are known for their hardiness and for having higher productivity rates compared to traditional redneck breeds. However, they grow slower than commercial strains (Figueiredo et al. 2008). On the other hand, redneck breeds were developed to better adapt to redneck rearing systems, aiming to increase production and offer consumers products with specific characteristics in terms of taste and meat quality (Galvão Junior et al. 2010).

For an entrepreneur in the poultry sector, the main concern when starting the business is to choose the breed or strain that best suits the type of poultry farming they wish to implement. This choice is not simple, as there are many options, each with its own advantages and disadvantages. The decision should consider the available infrastructure, financial resources, available labor, the type of marketing of products and by-products, and, eventually, the option of subsistence farming (EMBRAPA 2007).

The main redneck or colonial breeds, as described by Cavalcanti (2019), are:

- **Gigante Negro de Jersey (Jersey Black Giant)**

The breed developed in New Jersey around the 1800s was created to meet the high demand for heavy chickens for broiler production destined for the New York market. There are two varieties of this breed, black and white, which are primarily used for meat. These birds are large, have a serrated comb and yellow skin, and produce brown-shelled eggs. The meat tends to have dark pigmentation due to the pigments in the legs that spread to the meat. The plumage is black, and the skin is yellow, with dual-purpose suitability for meat and eggs. It is the heaviest American breed, but it has some depreciation due to the dark pigmentation in the skin. Adult males weigh an average of 5.902 kg, and females 4.540 kg. The hens produce about 180 eggs in the first laying cycle, with an average weight of 60g.

- **Rhode Island Red**

Originating from the United States, the Rhode Island Red is a medium-sized breed producing meat and eggs. These birds have bright red plumage, a wide, long, deep body, and a medium-sized serrated comb. The body is robust, with brown plumage and black feathers on the tail, neck, and wings. Recently, this variety has been widely used to produce sexable hybrids based on color. The presence of a white or light spot on the wings of male chicks and its absence in female chicks allows for the identification of sexes with an accuracy rate of 80–90% right after hatching. Additionally, by crossing a rooster of this breed (genetically "gold" or non-barred) with hens that are genetically "silver" or barred, it is possible to distinguish the sex of the chicks by the color of their down. Many commercial laying hybrids result from crossbreeding between Rhode Island Red and Barred Plymouth Rock, producing many brown-shelled eggs.

● **New Hampshire**

The New Hampshire breed, also of American origin, is known for its hardiness and light brown plumage. This breed, which has yellow skin and produces brown-shelled eggs, was initially bred for broiler production but was later used in crossbreeding with other meat breeds. Currently, few breeders are still focused on this breed. New Hampshire played an important role in developing modern broiler hybrids due to its ability to produce many eggs with a high hatch rate. Similar to Rhode Island Red, the presence of a white or light spot on the wings of male chicks and its absence in females allows for sex identification with 80–90% accuracy right after hatching. When fully grown, males weigh an average of 3.632 kg and females 2.951 kg. The hens produce an average of 220 eggs in the first laying cycle, weighing 55g.

● **Plymouth Rock Barred**

The birds of this variety have feathers with white and black crossbars, giving them a gray appearance. The barred gene, which is sex-linked, influences the dosage of melanin, resulting in visual differences between males and females. Additionally, the black pigmentation on the females' toes ends abruptly, leaving the tip of each toe yellow. In contrast, the males have more irregular white spots on their heads and a less contrasting transition in the black color of their feet. These color pattern differences between the sexes vary among the breed's lines, requiring adjustments for accurate chick sexing. With the growing preference for white-shelled eggs, the popularity of this breed has declined. It is currently more commonly used as a female line in crossbreeding with Rhode Island Red roosters to produce autosexing chicks that, when grown, produce brown-shelled eggs. This type of crossbreeding has increased the breed's popularity.

● **Sussex**

Sussex is an English breed predominantly dual-purpose. It has a serrated comb, white skin, and brown-shelled eggs. The varieties include speckled, red, and white (light), with Light Sussex being the most popular. This breed is a good meat producer. In some European countries, white-skinned chickens are preferred. When fully grown, males weigh an average of 4.086 kg and females 3.178 kg. The hens produce an average of 180 eggs in the first laying cycle, weighing 55g.

- **Orpington**

Developed in England in the 1880s, the Orpington breed serves dual purposes (meat and eggs). It comes in black, yellow, white and blue varieties. These birds have a serrated comb, white skin, and brown-shelled eggs. When fully grown, males weigh an average of 4.540 kg and females 3.632 kg. The hens produce an average of 160 brown-shelled eggs, with an average weight of 55g.

- **Cornish**

The Cornish is an English meat breed with red, black, yellow and white varieties. It has a pea comb and yellow skin and produces brown-shelled eggs. It has a body structure different from other breeds, with shorter legs and a muscular chest. The meat production capabilities are highly valued in this breed, and it is commonly used in crossbreeding with hens of breeds such as Plymouth Rock Barred, Plymouth Rock White, New Hampshire, and hybrid lines. However, it produces few eggs, which are small in size and have low hatchability. When fully grown, males weigh an average of 4.086 kg and females 3.178 kg. The hens produce an average of 80 eggs in the first laying cycle, weighing 50g.



For the production of redneck broilers, the following lines are available on the market:

● **Caipira Pescoço Pelado (Naked neck redneck)**

This strain consists of hardy, easy-to-manage birds with red plumage and bare necks. The colors of the birds can vary between red, white, black, or brindle. They are ready for slaughter between 60 and 70 days of age, and the hens reach sexual maturity between 22 and 25 weeks, producing about 150 to 180 eggs per year. The egg production is relatively low, indicating that this line mainly focuses on meat production. Desired targets: weight of 1.90 kg at 63 days of age, with a feed consumption of 4.42 kg.

● **Caipira Pesadão (Heavy redneck)**

A rustic bird with red plumage and black tail feathers. It has proven productive efficiency and is well-received for sale at local markets. It offers excellent feed conversion and great meat yield after slaughter. The line is known for its good cut yield and weight gain, reaching up to 2.4 kg in around 56-68 days. It has good acceptability, adaptability to environmental conditions, and hardiness. Birds can achieve weights exceeding 4 kg.

● **Caipira Pesadão Misto Label Rouge (Mixed Label Rouge heavy redneck)**

This slow-growing bird is raised exclusively for slaughter, which can occur at 49 days with a weight of 2.00 kg, or at 63 days with a weight of 2.76 kg, consuming 4.10 kg and 6.46 kg of feed, respectively. Fed with balanced feed for broilers and raised outdoors, this line maintains the traditional characteristics of redneck chicken, producing firm and flavorful meat similar to the taste of game meat.

● **Caipira Pesadão Paraíso Pedrês (Paraíso Pedrês heavy caipira)**

Developed through crossbreeding various rustic breeds, this bird can reach 2.00 kg in 50 days or 2.35 kg in 56 days, consuming 4.28 kg and 5.43 kg of feed, respectively.

● **Caipira Colonial EMBRAPA 041 (EMBRAPA 041 colonial redneck)**

These yellow-colored birds are produced from crossbreeding dual-purpose (mixed) breeds. They can be slaughtered at 2.055 kg at 77 days or 2.445 kg at 91 days, consuming 6.202 kg and 7.89 kg of feed, respectively.

Production systems

According to Melo and Voltolini (2019), the rearing systems for these birds include intensive, free-range (or extensive), and semi-extensive (partially free-range or part of the rearing cycle). The region's extensive and semi-extensive systems are the most commonly used for rearing adapted chickens. In the intensive system, the birds are kept in total confinement in closed barns, which is more typical of other regions and larger-scale productions, making it financially unfeasible for family farmers, especially due to local climatic conditions. In family farming, extensive and semi-extensive systems are preferred, where various materials can be used for building fences and poultry facilities, as long as they meet the minimum requirements for proper rearing of the birds.

In Brazil, the legislation for alternative poultry production, free-range, capoeira, or colonial production, is based on Normative Instruction No. 007, dated May 17, 1999 (Brasil 1999), which guides producers who wish to regulate alternative poultry production. According to this norm, some measures must be followed: the producer should not use animal-derived ingredients in the feed, the stocking density should be 7 birds/m² in the covered area and at least 1m² for 4 or 5 birds in the pasture area. Additionally, the birds must stay in the rearing environment for at least 85 days before slaughter. Organic poultry production must follow Law No. 10.831, published in December 2003, regulated by Decree No. 6.323 of December 27, 2007 (Brasil 2007).

Within the free-range style poultry rearing systems, we can find the following designations:

● **Green chicken system:** The term "green chicken" generally refers to chickens raised sustainably and ecologically, with an emphasis on animal welfare and environmentally responsible production. These chickens are fed with antibiotic-free and hormone-free feed, often raised outdoors, which allows for more natural and healthy growth. The goal is to offer a high-quality product with better taste and nutritional value while minimizing environmental impact and promoting more sustainable agricultural practices. Green chicken is an increasingly popular choice among consumers concerned with health and sustainability.

● **Free-range system:** The free-range or colonial poultry rearing system is a traditional method that favors rearing in conditions closer to the natural environment. The birds are kept free-range, with access to pasture and natural foods such as insects and grains, supplemented by balanced feed. This system is characterized by simpler and less intensive management, allowing the birds to exhibit natural behaviors, contributing to animal welfare. The result is meat with a distinctive flavor, appreciated texture, and quality, and it is a practice that values local culture and sustainability, often associated with organic production and environmental respect.

● **Organic system:** In the organic production system, the use of growth promoters is prohibited. The diet consists exclusively of grains and vegetables grown organically, meaning without the use of chemical pesticides and fertilizers. For commercialization, the products must have certification from the Ministry of Agriculture, Livestock, and Supply (MAPA) and accreditation from the National Institute of Metrology, Standardization, and Industrial Quality (INMETRO), ensuring that the production process follows organic production standards (MAPA 2008). To obtain certification, producers must hire a certifying agency approved by MAPA and accredited by INMETRO, characterizing the Certification by Audit System.

There are two more accessible ways for small producers to obtain organic certification:

a) Participatory Guarantee System (SPG): This system involves collective production, where groups or associations register with MAPA and commit to producing organically, with commercialization restricted to fairs.

b) Social Control of Direct Sales: Aimed at family farming, where certification is not mandatory if the producer is associated with a social organization registered with an official inspection body.

General management

To practice poultry farming, the producer needs to invest in appropriate infrastructure to facilitate chicken rearing. According to Barbosa et al. (2007), Chagas (2010), and Raimundo et al. (2018), this involves:

a) Facilities: When birds are kept free-range, various problems may arise, but proper facilities can mitigate them. With them, the producer can better control hygiene and sanitation, prevent diseases, protect the birds from predators, and ensure good egg production, all essential factors for successful rearing.

b) Site selection: It is recommended that the chicken coop be built close to the producer's house. The site should be dry, well-ventilated, and with minimal slope to avoid water puddles. It is important for the area to have vegetation, such as brushwood, and preferably trees for shading. This vegetation will be a favorable habitat for insects and worms, which will serve as a supplementary protein source for the birds. The ideal orientation for the poultry house is east-west. This way, the sun crosses the building through the highest part of the roof, avoiding an increase in internal temperature during the warmer periods of the year.

c) Fencing: To better control the flock, a fence around the chicken coop, with the area depending on the number of birds, is necessary. Inside the fenced area, there should be space for fruit trees or other trees that provide shade and bird protection. Ideally, there should be two separate pens to allow rotation of the birds, facilitate management and periodic cleaning of the unused coop, and allow vegetation to rest.

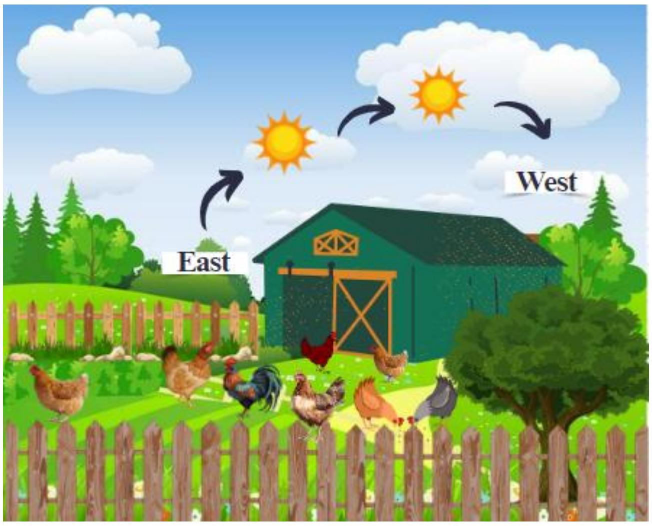

Figure 1. Correct orientation for constructing the poultry house in a fenced environment.

d) Perches: Perches, where the birds sleep, should be built securely and without risks of injuring the birds' feet, preferably at the back of the coop, which is more isolated. Perch rows should be spaced about 40 cm apart. The height of the perches can vary between 40 and 60 cm from the floor, with a width of 5 cm and a height of 2 cm.

e) Nests: It is recommended that nests be made of wood and measure 30 cm in width, height, and depth. They should be placed on wooden stands 50 cm above the floor, with a perch 10 cm from the nest entrance to facilitate bird access. Each nest should accommodate a maximum of four hens and be located in the darker parts of the coop to prevent the birds from staying in the nest when not laying eggs.

f) Nest bedding: Corn straw, wood shavings, or dry grass can be used to cover the nests as long as proper hygiene and sanitation are maintained.

g) Feeders: Feeders can be made from galvanized sheet metal or PVC pipes four to six inches in diameter, cut longitudinally with end barriers. Alternatively, they can be made from wood, with dimensions of 10 cm in height and 15 cm in width.

h) Drinkers: Drinkers can be made like the feeders, using galvanized sheet metal or PVC pipes four to six inches in diameter, cut longitudinally with end barriers. Any other waterproof material can also be used.

i) Feeding: The feed should be balanced to meet the birds' nutritional needs. Other types of food can be replaced, depending on the property's availability. It is crucial to follow each step of the poultry management process in family farms to ensure good control of growth and health in the coop, thus achieving the desired results.

REFERENCES

Albino, L.F.T., Carvalho, B.R., Maia, R.C., Barros, V.R.S.M. (2014). Galinhas Poedeiras: Criação e Alimentação. Viçosa, Minas Gerais: Aprenda Fácil.

Albuquerque, M.F., Reis, E.M.B. (2022). Viabilidade econômica na produção de frango de corte de crescimento lento em Rio Branco/Acre. Ciência Animal, 32(4), 20-28.

Almeida, E.C.J., Carneiro, P.L.S., Wenceslau, A.A., Farias Filho, R.V., Malhado, C.H.M. (2013). Características de carcaça de galinha naturalizada Peloco comparada a linhagens de frango caipira. Pesquisa Agropecuária Brasileira, 48(11), 1517-1523. https://doi.org/10.1590/S0100-204X2013001100013

Araújo, W.A.G., Albino, L.F.T., Sakomura, N.K., Paulino, P.V.R., Campos, A.M. Meat quality in “in door” and “out door” production systems of poultry and swine. Open Journal of Animal Sciences, 1(3), 75-88. https://doi.org/10.4236/ojas.2011.13010

Barbosa, F.J.V., Nascimento, M.P.S.B., Diniz, F.M., Nascimento, H.T.S., Araújo Neto, R.B. (2007). Sistema alternativo de criação de galinhas caipiras. EMBRAPA MeioNorte. Sistema de Produção.

Brasil. (1999). Instrução Normativa nº 7, de 17 de maio de 1999. Estabelece as normas de produção, tipificação, processamento, envase, distribuição, identificação e de certificação da qualidade para os produtos orgânicos de origem vegetal e animal. Brasília, DF: Diário Oficial da União, Poder Executivo, 19 mai. 1999. Seção 1, p.11.

Brasil. (2007) Decreto nº 6.323, de 27 de dezembro de 2007. Regulamenta a Lei nº 10.831, de 23 de dezembro de 2003, que dispõe sobre a agricultura orgânica, e dá outras providências. Brasília, DF: Diário Oficial da União, Poder Executivo, 28 dez. 2007. Seção 1. p. 2.

Carvalho, D.A., Sarmento, J.L.R., Almeida, M.J. (2020). Conservação uso e melhoramento de galinhas caipiras. Ponta Grossa (PR): Atena.

Cavalcanti, F.A.V.R. (2019). Avicultura caipira. Natal (RN): SEBRAE.

Chagas, J.P. (2010). Galinha Caipira Moderna: Orientações para Criação em Porto Velho – RO. Porto Velho: EMATER (RO).

Cielo, I., Rocha Júnior, W.; Canevesi, F. (2019). Importância Socioeconômica da Integração Avícola para os Produtores da Mesorregião Oeste do Paraná. Desenvolvimento em questão, v. 17, n 49, p. 329-347,

Cruz, F.G.G., Chagas, E.O.; Botelho, T.R.P. (2013). Avicultura familiar como alternativa de desenvolvimento sustentável em comunidades ribeirinhas do Amazonas. Interações (Campo Grande), v. 14, n. 2, p. 197-202.

Del Castilho, C.C., Santos, T.T., Rodrigues, C.A.F., Torres Filho, R.A. (2013). Efeitos do sexo e genótipo no desempenho e características de produção de frangos de corte ao ar livre. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, v. 65, n. 5, p. 1483-1490. https://doi.org/10.1590/S0102-09352013000500029.

Delgado, G.C., Bergamasco, S.M.P.P. (2017). Agricultura familiar brasileira: desafios e perspectivas de futuro. Disponível em: https://www.cfn.org.br/wp-content/uploads/2017/10/Agricultura_Familiar.pdf. Acesso em: 27 jul. 2024.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. (2007). Criação de galinhas caipiras. Brasília (DF): EMBRAPA Meio Norte, EMBRAPA Informação Tecnológica.

Englert, S.I. (1998). Avicultura: tudo sobre raças, manejo, alimentação e sanidade. Guaíba: Agropecuária.

FAO - Food and Agriculture Organization of the United Nations. Ano Internacional da Agricultura Familiar (Artigo). Organização das Nações Unidas para a Alimentação e a Agricultura. ONU, 2014. Disponível em: http://www.fao.org/brasil. Acesso em: 27 jul. 2024.

Figueiredo, E.A.P., Schmidt, G.S., Ledur M.C., Ávila, V.S. (2008). Raças e linhagens comerciais de galinhas (Artigo). Brasília (DF): EMBRAPA- Parque de Estação

Biológica.

Galvão Junior, G.B., Bento, E.F., Souza, A F. (2010). Sistema alternativo de produção de aves (Cartilha). Panguaçu: IFRN/RN.

Gessulli, O.P. (1999). Avicultura Alternativa: sistema “ecologicamente correto” que busca o bem estar animal e a qualidade do produto final. Porto Feliz: OPG Editores.

Hirst, K.K. (2019). The Domestication History of Chickens (Gallus domesticus). Disponível em: https://www.thoughtco.com/the-domestication-history-of-chickens-170653. Acesso em: 27 jun. 2024.

MAPA - Ministério da Agricultura, Pecuária e Abastecimento. Aves, 2008. Disponível em: http://www.agricultura.gov.br/animal/especies/aves. Acesso em: 27 jul. 2024.

Melo, R.F., Voltolini, T.V. (2019). Agricultura familiar dependente de chuva no Semiárido. Petrolina (PE): EMBRAPA Semiárido.

Moiseyeva, I.G., Romanov, M.N., Nikiforov, A.A., Sevastyanova, A.A., Semyenova, S.K. (2003). Evolutionary relationships of Red Jungle Fowl and chicken breeds. Genetics Selection and Evoltion, 35, 403. https://doi.org/10.1186/1297-9686-35-5-403

Raimundo, E.K.M., Evangelista, G.M., Paulino, R.D., Beltrão, L.G.C., Barbosa, L.B., Silva, J.R. (2018). Exploração da avicultura caipira em regime de economia solidária: uma análise dos problemas e condicionantes ambientais da produção em uma cooperativa da Paraíba. Cadernos de Agroecologia, 13(1), 7-12.

Santana, M.H.M., Lima, M.C.D., Figueiredo Junior, J.P., Santos, E.G., Santana, A.M.M.A., Nascimento, J.B. (2020). Diagnóstico socioeconômico e produtivo da avicultura caipira no estado do Acre. Revista de Agroecologia no Semiárido, 4(5), 10-22. http://dx.doi.org/10.35512/ras.v4i5.4380

Santos, M.B., Cunha, F.S.A., Santos, J.S., Albuquerque, J.G.S.S., Oliveira, A.T. (2020). Análise econômica da produção de frango de corte caipira em dois municípios do médio sertão de Alagoas, Nordeste do Brasil. Diversitas Journal. 5(3), 2129-2139. https://doi.org/10.17648/diversitas-journal-v5i3-1085

Tavares, L.P., Ribeiro, K.C.S. (2007). Desenvolvimento da avicultura de corte brasileira e perspectivas frente à influenza aviária. Organizações Rurais & Agroindustriais, 9(1), 79-88

Tixier-Boichard, M., Bed'hom, B., Rognon, X. (2011). Chicken domestication: from archeology to genomics. Compets Rendus Biologies, 334(3), 197-204. https://doi.org/10.1016/j.crvi.2010.12.012

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CHAPTER 2: Potential of Alternative Feeds in Poultry Nutrition: A Systematic Review

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Abstract

Brazil is the world leader in poultry production but faces high feed costs, which account for up to 75% of the sector's expenditure. Agro-industrial byproducts are sustainable alternatives because they are affordable and rich in nutrients. This study seeks to systematically review the scientific evidence on the inclusion of alternative feeds in poultry nutrition in Brazil. The searches were conducted in the Scopus, Web of Science, Scielo and PubMed databases, resulting in 187 studies, of which only 28 were considered adequate. The highest percentage of studies is concentrated in the north region at 53.6%, the south region at 21.4%, the northeast at 17.9% and the central-west region at 7.1%. The agro-industrial by-products analyzed, such as babassu pie and Guarana peel meal, have relevant nutritional value, standing out for their high content of gross energy, proteins, fibers and minerals. Cassava starch by-products and tambaqui waste biological silage meal showed high digestibility; tucumã meal had the highest triglyceride concentration (266.91 mg dL-1) with 1.77% inclusion. Guarana peel meal and fish waste oil showed reducing effects on the lipid profile at higher inclusion levels. Agro-industrial by-products have great potential as alternative ingredients in poultry diets, but their application must be carefully adjusted to maximize benefits and avoid negative impacts on bird performance.

Keywords: Agro-industrial by-products; Circular economy; Digestibility; Performance; Poultry Farm.

INTRODUCTION

Brazil has become a global leader in poultry production and exports (Tremea; Silva, 2020). The country is the world's largest exporter of chicken meat and the third-largest producer worldwide (Piccolo et al., 2024). This success is attributed to technological advances, improved feed conversion, and genetics of the animals (Tremea; Silva, 2020). The poultry sector has been growing, driven by public policies since the 1970s, with egg production projected to reach 56 billion units by 2024 (Piccolo et al., 2024). The global relevance of these products is due to consumer preference for their practicality, nutritional value and wide availability as a protein source. However, the factor that most contribute to this preference is the favorable cost-benefit ratio, making these products competitive compared to other protein sources of animal origin (Maquiné et al., 2024; Santos et al., 2024; Guimarães et al., 2025).

A statistical forecast suggests a 35.14% expansion in egg production from 2022 to 2030 (Junior et al., 2023). Despite these advances, feed represents approximately 75% of costs in the poultry industry, with corn and soybean meal being the main ingredients in the diets (Sanches et al., 2023). However, fluctuating prices, competition with other crops, and growing human demand make it necessary to seek feed alternatives that reduce costs without compromising the poultry's nutritional quality and production efficiency (Malhado et al., 2021). In this context, the use of agro-industrial byproducts emerges as a viable and sustainable solution to mitigate high costs and reduce dependence on traditional ingredients (Aguilar-Rivera & Debernardi-Vázquez, 2018; Almaraz-Sánchez et al., 2022).

Brazil, due to its vast agro-industrial production, generates significant volumes of by-products that are often discarded due to lack of knowledge about their possibilities for reuse (Siqueira et al., 2022; Nascimento Filho; Franco, 2015). It's come from the processing of cereals, fruits, vegetables and products of animal origin, produced at different stages of the production chain, from harvesting to storage and distribution. (Sharma et al., 2020; Gaur et al., 2020). The growth in fruit production in 2023 increased the generation of by-products in the country (Lazzari et al., 2021). These by-products are particularly relevant due to their low cost, wide availability and richness in bioactive compounds, being an excellent nutritional source for poultry (Correddu et al., 2020).

The processing of animals such as fish, cattle and pigs generates large quantities of by-products, corresponding to approximately 45%, 38% and 20% of the live weight of these animals, respectively. These by-products, which include heads, viscera, bones and scales, can be reused for several specific situations (Corioletti et al., 2022; Limeneh et al., 2022). The composition of these wastes varies according to the animal species; the use of these byproducts in animal feed has a double benefit: it promotes the valorization of waste that would otherwise be discarded and provides an alternative source of nutrients, contributing to the circular economy in the agro-industrial sector (Vastolo et al., 2022).

Including by-products in animal feed has proven to be a promising strategy (Sasu et al., 2014; Stefanello et al., 2019), numerous studies have been carried out on the reuse of by-products as alternative ingredients in poultry farming (Santos et al., 2024; Silva et al., 2015; Costa et al., 2018; Guimarães et al. 2025) and have shown that these by-products can be incorporated into poultry diets with a double benefit: significant reduction in production costs and maintenance of zootechnical performance (Falcone et al., 2020; Tripathi et al., 2019).

However, it is necessary to consider factors such as seasonality, nutrient distribution, and possible variations in the composition of byproducts (Salami et al., 2019; Halmemies et al., 2018). Depending on the type of byproduct used, adjustments in the feed formulation are essential to ensure adequate nutritional balance and avoid negative impacts on bird performance (Gouveia et al., 2020). This approach reduces production costs and develops a resilient poultry industry that is less dependent on conventional ingredients (Georganas et al., 2023; Gouveia et al., 2020). Considering the current scenario and the growth prospects for poultry production, it is essential to review and compile scientific evidence that supports the inclusion of byproducts in poultry diets. This study seeks to systematically review the scientific evidence on the inclusion of alternative feeds in poultry nutrition in Brazil.

MATERIALS AND METHODS

The authors (Santos, A. N. A. and Oliveira, A. T.) performed the Systematic Review in four sequential stages: study selection criteria, focus question, information sources and data curation and risk of bias assessment.

Study selection criteria

The first stage of the search was a preliminary selection and independent identification of abstracts and titles of articles. Abstracts were removed when the articles did not present associations between poultry farming, agro-industrial waste and alternative feed.

Focus question

The central question was formulated according to the population, intervention, control and observation (PICO) method and the following question was formulated: "What are the primary sources of used as alternative ingredients in poultry feed?

To answer this question, the following secondary questions were formulated:

(a) In which regions of Brazil are the primary studies on the subject?

(b) What are the nutritional and productive benefits of including alternative feeds in poultry diets?

(c) How does including these alternative feeds affect the digestibility and productive performance parameters such as meat and eggs?

(d) How does the addition of alternative feeds to the diet influence biochemical parameters?

Information sources and data curation

The research was carried out on the Web of Science, Scopus, Scielo and PubMed platforms in October 2024. Three “Research Components” were defined:

● Search component 1 (SC1)

– “poultry farming” OR “broiler chickens” OR “laying hens” OR “Gallus gallus domesticus”

● Search component 2 (SC2)

– “fruit peel” OR “agro-industrial residue” OR “alternative feed” OR “fruit exhaustion”

● Search component 3 (SC3)

– "poultry nutrition" OR "chicken feed" OR "balanced feed" OR "Brazil"

After selecting the search component, the boolean operator "AND" was used to cross-combine SC1, SC2, and SC3 and obtain results. The search was limited to english articles published between 2013 and 2025. Editorials, letters, reviews, mini-reviews and theses were excluded. Subsequently, the articles selected from an initial reading of the titles and after reading the abstracts were imported and read in full, with all relevant data extracted and entered into a microsoft excel spreadsheet for evaluation supports the results with the preferred reporting items for systematic review and meta-analyses (PRISMA) (Page et al., 2021).

Risk of bias assessment

Possible sources of bias include the inclusion/exclusion criteria, the database chosen, the date, the language, the number of articles and the types of articles selected for this study.

RESULTS

Literature Search

In the initial identification phase, 187 scientific articles were found in the databases, 6 in Scopus and 181 in Web of Science. Searches were also carried out in the Scielo and PubMed databases, but no relevant articles were found (Figure 1). Of these 187 articles, 7 were duplicated or triplicated and were immediately excluded, resulting in 180 remaining articles. These were analyzed in the second stage (screening) regarding titles and keywords, 72 articles were excluded because they needed to contain the search components before reading the abstracts. Articles presenting information about other animals and countries not part of the study were also excluded from this stage (n= 25).

The remaining articles (n= 83) were thoroughly evaluated, and only 26 were considered suitable for use in this review, as they reported on the use of agro-industrial waste of animal and vegetable origin and other alternative feeds for poultry farming, according to the Focus Questions. Thus, all 57 articles were excluded for not meeting the inclusion criteria. Subsequently, 2 articles containing essential information, such as data on alternative feeds in poultry farming, were added. Therefore, 28 articles were compiled for this review.

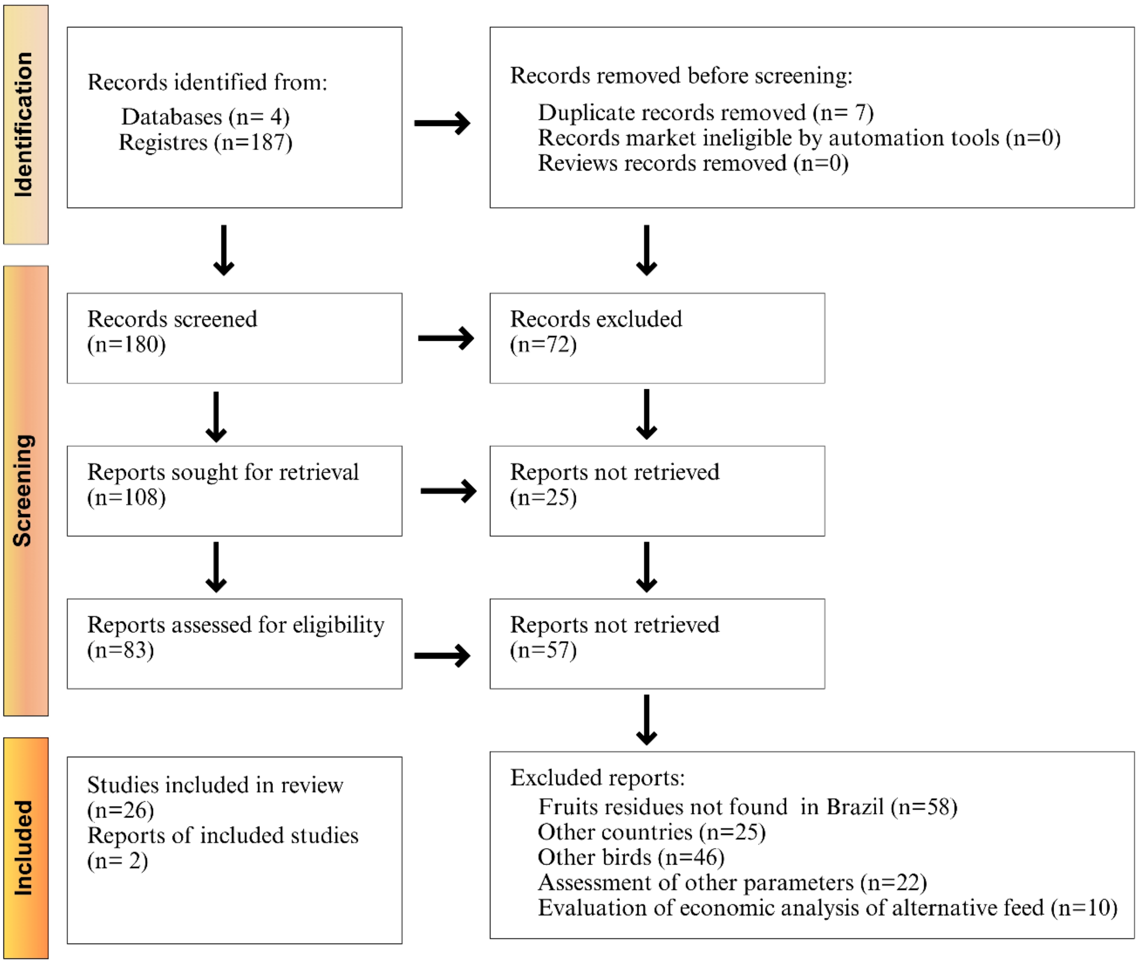

Figure 1. PRISMA flow diagram displays the literature search results (Scopus, Web of Science, PubMed e Scielo).

Distribution of studies in Brazil

Studies on alternative feeds for poultry revealed an uneven distribution among Brazilian regions (Fig. 2). The North region was responsible for most of the studies (53.6%), followed by the South (21.4%), Northeast (17.9%) and Central-West (7.1%) regions; no studies were found in the Southeast region. The states of Amazonas, Pará and Tocantins, both belonging to the North region of Brazil, obtained 12, 1 and 2 studies, respectively. The state of Paraná, belonging to the South region, obtained 6 studies; in the states of Ceará and Bahia, belonging to the Northeast region, 4 and 1 study were found, respectively. The state of Mato Grosso do Sul, located in the Central-West region of Brazil, presented 2 studies.

In total, 25 agro-industrial residues of animal and vegetable origin were found in the studies as potential feed alternatives in poultry farming (Table 1). Among the agro-industrial by-products most frequently studied in different regions of Brazil, three deserve special attention: the by-product of cassava (*Manihot esculenta Crantz*, 1766), the by-product of sunflower oil extraction (*Helianthus annuus L.*, 1753) and the by-product of cashew nut processing (*Anacardium occidentale L.*, 1753). The North region leads the studies on the subject, with a total of 11 residues with the potential to be used as alternative feed in poultry farming, followed by the Northeast region, the South region and the Central-West region.

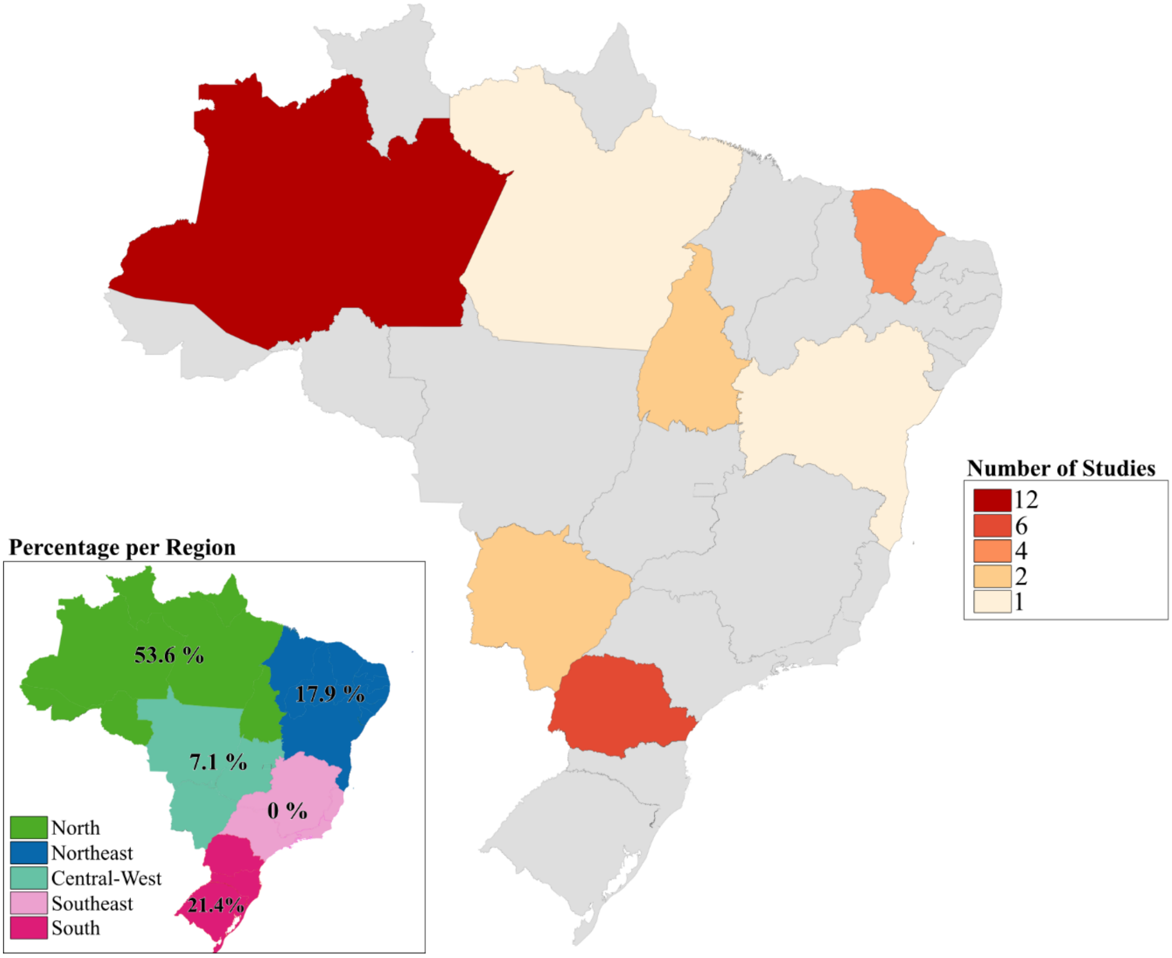

Figure 2. Occurrence of studies on alternative feed in Brazil.

The analysis of the studies revealed that most of the research is focused on broilers (53.6%), representing the majority of the studies evaluated (Fig. 3). Next, studies involving laying hens (42.8%) were identified, with significant importance due to egg production. On the other hand, research with quails showed less representation (3.6%), with only one study registered.

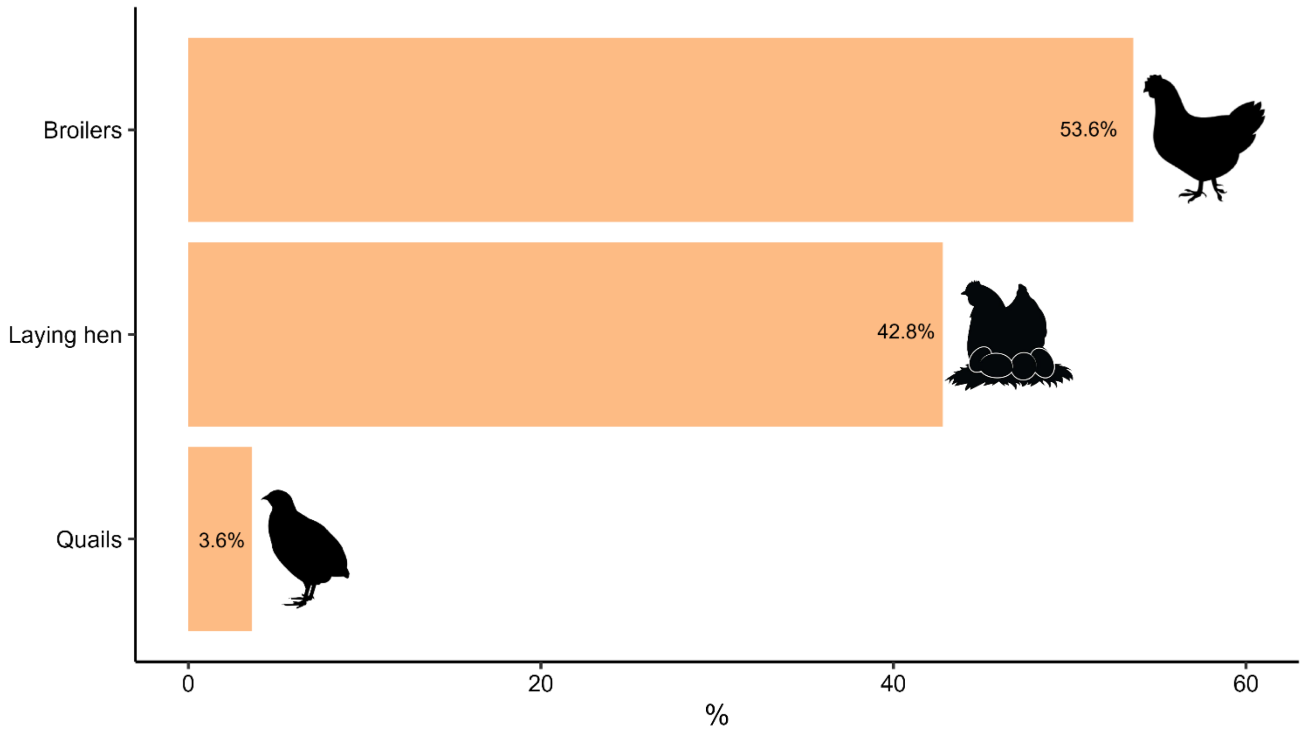

Figure 3. Percentage of studies with production birds.

Table 1. Regions of Brazil, states of Brazil and residues used as an alternative ingredient in poultry farming.

Regions of Brazil	Waste used as an alternative ingredient in poultry farming				
	Broiler chicken			Laying hen	Quails
North	**Amazonas** • Waste from the extraction of tucumã pulp • Guarana peel	**Pará** • Cassava scrapings and cassava starch residue	**Tocantins** • Moringa • Residue from the processing of babassu coconut	**Amazonas** • Açaí residue (pit + peel) • Fish waste oil • Black pepper • Tambaqui processing waste (viscera, gills, scales and fins) • Pirarucu processing waste • Cara	
Northeast	**Ceará** • Cashew nut processing waste • Waste from the extraction the oil from the sunflower seeds	**Bahia** • Pequi • Epicarp and endocarp of jucara		**Ceará** • Cashew nut processing • Waste Leucaena leaf • Waste from the extraction the oil from the sunflower seeds	
Central-West	**Mato Grosso do Sul** • Dry cassava residue • Residue from the extraction of oil from macauba pulp				**Mato Grosso do Sul** • Dry cassava residue
South	**Paraná** • Waste from the processing of citrus fruits • Guavira • Waste from the extraction the oil from the sunflower seeds				

	• Dehydrated cassava starch residues	

Chemical composition

Table 2 presents the results of the centesimal composition of the alternative feeds in the studies. Among the diets analyzed, animal by-products such as acid silage meal made of pirarucu waste (ASMMPW) (Arapaima gigas Schinz, 1822) (40.05%) and tambaqui waste biological silage meal (TWBSM) (Colossoma macropomum Cuvier, 1818) residue (33.29%) presented higher levels of crude protein (CP).

In addition to protein levels, the analysis of carbohydrates and crude fiber (CF) also reinforces the potential of these alternative feeds. For example, the guarana peel meal (GPEM) (Paullinia cupana Kunth, 1821) presented a high value of CF, (44.04%). At the same time, cassava shavings stood out in the fractions of neutral detergent fiber (NDF) and acid detergent fiber (ADF). These characteristics are essential since including fibers in adequate levels contributes to the balance of the intestinal microbiota and better use of nutrients by the birds.

The minerals present in the alternative feed also presented significant values, such as Sunflower cake (26.6%) and TWBSM (14.37%). Regarding the ether extract, fish waste oil presented the highest percentage (99.06%), followed by TWBSM (33.65%), ASMMPW (26.81%) and Sunflower cake (15.52%).

Another fundamental aspect analyzed was the feed's gross energy (GE) and metabolizable energy (ME). GPEM stood out as the primary source of GE, TWBSM, ASMMPW, acai meal (Euterpe oleracea Mart. 1824), babassu pie (Attalea speciosa Mart. 1826) presented significant values. In the case of ME, GPEM remained the highlight, reaching 4,227.20 kcal kg-1, evidencing its efficiency in providing energy for animal metabolism.

Table 2. Chemical composition of alternative feed.

Alternative feed	**Variables**										
	DM (%)	CP (%)	CARB %	MI (%)	CF (%)	NDF (%)	ADF (%)	EE (%)	N-NE%	GE (kcal kg^{-1})	ME (kcal kg^{-1})
Acai meal	89.12	5.25	-	6.64	25.30	-	-	4.12	58.69	5389.16	2838.18
Acid silage meal made of pirarucu waste	84.16	40.05	7.97	9.31	-	-	-	26.81	-	5771.49	3253.01
Babassu pie	-	21.26	-	-	29.21	58.63	30.64	-	-	4556	2268
Cara flour	95.54	2.65		3.23	2.69	7.45	3.64	0.31	86.66	3730.73	3489.81
Cassava starch residue	19.04	8.47	-	1.1	-	4.23	40.14	2.98	-	-	-
Cassava scrapings	24.16	6.08	-	5.17	-	41.84	39.91	1.92	-	-	-
Dehydrated cassava starch residues	88	1.12	-	-	-	-	-	-	-	-	-
Dehydrated citrus pulp	87.04	9.62	-	-	-	19.79	36.93	6.01	-	-	-
Dried cassava residue	89.86	1.12	60.73	1.53	13.57	38.22	20.82	0.31	-	-	1703
Fish waste oil	-	-	-	-	-	-	-	99.06	-	-	-
Guarana peel meal	89.11	18.72	26.55	5.33	44.04	61.34	33.33	-	-	6752.61	4227.20
Macauba meal	85.60	4.14	-	-	28.54	-	-	1.20	-	-	3952
Sunflower cake	92.81	19.31	-	26.6	-	439.5	289.6	15.52	-	-	-
Tambaqui waste biological silage meal	96.28	33.29	-	14.37	1.36	-	-	33.65	13.63	5666.07	-
Tucumã meal	89.78	9.33	-	4.49	14.63	53.98	38.63	12.66	-	-	3267

DM= Dry matter; CP= Crude protein; CARB= Carbohydrate, MI= Minerals; CF= Crude fibre; NDF= Neutral detergent fiber; ADF= Acid detergent fiber; EE= Ether extract; N-NE= Non-nitrogenated extract; GE= Gross energy; ME= Metabolisable energy.

Main parameters evaluated

The main parameters analyzed in studies on alternative feeds for laying hens are listed in Table 3. Acai meal was investigated with a focus on digestibility, while ASMMPW was analyzed in relation to productive performance, egg quality, apparent digestibility and energy metabolism. Black pepper (*Piper nigrum* L., 1678) was studied due to its effects on performance, egg quality and biochemical parameters. Other ingredients, such as cashew nut meal and cara flour, were analyzed, considering their impact on productive performance, egg characteristics and digestibility. Leucena leaf hay (*Leucaena leucocephala*, (Lam.) de Wit.), 1759) stood out in studies of digestibility and productive performance, while fish waste oil was widely researched regarding egg quality and sensory characteristics, serum biochemical profile, digestibility and ME. Furthermore, TWBSM was evaluated regarding digestibility, energy metabolism, performance, egg quality, and biochemical parameters.

On the other hand, research involving broilers (Table 3) focused mainly on the effects of alternative feeds on productive performance, carcass characteristics and meat quality. Babassu pie was evaluated, considering zootechnical performance, organ biometry, and feed costs, while cashew nut meal was investigated for its chemical characteristics, such as breast meat and abdominal fat color. Cassava residue (CR), including dry cassava residue (DCR), cassava scrapings (CS) and cassava starch residue (CSR), were analyzed for carcass yield, meat quality, digestibility, gastrointestinal tract characteristics, and aspects such as leg pigmentation and litter moisture.

Dehydrated citrus pulp, in turn, was studied in terms of intestinal morphometry, the relative weight of organs of the gastrointestinal tract, meat quality, and lipid oxidation. GPEM presented essential results regarding performance, carcass characteristics and serum biochemical profile, while guavira fruit peel extract (GFPE) (*Campomanesia adamantium* (Cambess.) O. Berg, 1856) was analyzed considering carcass yield and meat quality. Macauba meal (*Acrocomia aculeata* (Jacq.) Lodd. ex Mart., 1824) was also studied in terms of performance and carcass characteristics, and Moringa leaf flour was evaluated in relation to the biometry of digestive organs, productive performance and meat color.

Specific studies also highlighted the use of pequi waste extract (*Caryocar brasiliense* Cambess, 1828) and juçara waste extract (*Euterpe edulis* Martius, 1824), focusing on the antioxidant capacity of the extracts to control the oxidation of chicken meat. Sunflower meal and cake were analyzed in relation to zootechnical performance, carcass yield, intestinal morphology, nutrient retention, energy metabolism and economic viability.

Finally, about quails (Table 3), a single study was found that addressed the use of CR. In this study, the performance of the birds, the weight of the organs of the gastrointestinal tract, the intestinal morphometry and the quality of the eggs were evaluated. Despite the limited number of studies involving this species, the results reinforce the viability of using agro-industrial byproducts in different poultry production systems.

Table 3. Parameters evaluated in the studies.

Animal category	Alternative feed	Parameters evaluated	Author
Laying hen	Acai meal	Digestibility	Rufino et al. (2020)
	Acid silage meal made of pirarucu waste	Performance and egg quality	Batalha et al. (2018)
	Acid silage meal made of pirarucu waste	Apparent digestibility and energy metabolism	Batalha et al. (2017)
	Black pepper	Performance, egg quality and biochemical parameters	Melo et al. (2016)
	Cara flour	Apparent digestibility and energy metabolism	Melo et al. (2015)
	Cashew nut flour	Performance and characteristics of eggs	Cruz et al. (2015)
	Leucaena leaf hay	Performance and digestibility	Oliveira et al. (2014)
	Tambaqui waste biological silage meal	Performance, hematological and plasma biochemical parameters, and quality of the eggs.	Guimarães et al. (2025)
	Tambaqui waste biological silage meal	Apparent digestibility and energy metabolism	Guimarães et al. (2019)
	Fish waste oil	Performance, egg quality and sensory characteristics	Brelaz et al. (2019)
	Fish waste oil	Serum biochemical profile	Brelaz et al. (2021)
	Fish waste oil	Digestibility, ME	Brelaz et al. (2024)
Broiler chicken	Cashew nut meal	Chemical characteristics of breast meat and abdominal fat color	Lopes et al. (2013)
	Cassava residuos (Cassava scrapings and cassava starch residue)	Digestibility, performance, organoleptic characteristics and meat quality	Vieira et al. (2022)
	Dehydrated cassava starch residues	Performance, litter moisture, gastrointestinal tract characteristics, leg pigmentation, carcass quality	Picoli et al. (2014)
	Dehydrated citrus pulp	Intestinal morphometry, relative weight of gastrointestinal tract organs, and meat quality and lipid oxidation	Diaz-Vargas et al. (2019)
	Dry cassava residue	Carcass yield, cuts and meat quality	Almeida et al. (2020b)
	Guarana peel meal	Performance, carcass characteristics and serum biochemical profile	Santos et al. (2024)
	Guavira fruit peel extract	Performance, carcass yield and meat quality	Lohmann et al. (2021)
	Macauba meal	Performance and carcass characteristics	Ferreira et al. (2019)
	Moringa leaf flour	Performance, carcass characteristics, digestive organ biometrics and	Vásquez et al.

		meat color	(2024)
	Pequi waste extract and juçara waste extract	Antioxidant capacity of extracts of waste from the processing of native Brazilian fruits for the inhibition of oxidation in chicken meat	Frasao et al. (2018)
	Sunflower meal	Performance, intestinal morphometry and carcass characteristics	Oliveira et al. (2016)
	Sunflower cake	Zootechnical performance, carcass yield and intestinal morphology	Berwanger et al. (2017a)
	Sunflower cake	Performance, body composition, nutrient retention, energy metabolism and economic viability	Souza et al. (2020)
	Tucumã meal	Performance, carcass characteristics and serum biochemical profile	Costa et al. (2018)
Quail	Dried Cassava Residue	Performance, gastrointestinal tract organ weight, intestinal morphometry and egg quality	Almeida et al. (2020a)

Digestibility

The digestibility data from the studies analyzed with broilers and laying hens are presented in Table 4. CSR (inclusion of 30 g kg^{-1} CSR) in the feed; in the feed presented superior digestibility for both apparent metabolizable energy and apparent metabolizable energy corrected by nitrogen balance compared to CS (inclusion of 30 g kg^{-1} CS), in diets t broilers. Similarly, TWBSM, with 5% inclusion, the laying hens presented better nutrient utilization than those fed the control diet.

On the other hand, ingredients such as fish waste oil (0 and 3.5%) and cashew nut meal (0, 5, 10, 15, 20 and 25%) did not present significant differences in the control diet for all variables analyzed, showing that, although they do not compromise digestive performance, they also do not promote significant gains to laying hens. However, the negative impact of high inclusion levels was evident in some ingredients, such as moringa leaf flour to broilers, used in 20% of the diet, and sunflower cake to laying hens, with inclusions ranging from 60 to 300 g kg^{-1}, highlighting the need for adjustments in the proportions of these ingredients in diet formulation. In contrast, the experimental diet containing 25% cara flour in diets to laying hens showed higher digestibility coefficients for dry matter, non-nitrogenous extract and ether extract, evidencing its efficiency as a viable alternative.

Table 4. Digestibility results.

Animal category	Alternative feed	Inclusion levels	Relevant results
Laying hen	Acai meal	(0 and 25%)	The inclusion of 25% showed better utilization of CP, non-fiber carbohydrates and mineral matter.
	Acid silage meal made of pirarucu waste	(0 and 3%)	3% ASMMPW showed better use of ether extract and mineral matter.
	Cara flour	(0 and 25%)	The inclusion of 25% obtained better digestibility coefficients of dry matter, nitrogen-free extract and ether extract.
	Cashew nut meal	(0, 5, 10, 15, 20 and 25%)	There was no significant difference with the different levels of inclusion.
	Fish waste oil	(0 and 3.5%)	Had no effect on the digestibility of dry matter, CP, mineral matter, CF and non-nitrogenous extract.
	Leucaena leaf hay	(0, 5 and 10%)	There was no significant effect on the rates of Coefficient of nitrogen digestibility, Apparent metabolizable energy and Apparent metabolizable energy corrected for nitrogen.
	Sunflower cake	(0, 60, 120, 180, 240 and 300 g kg^{-1} of SC)	60 to 300 g kg^{-1} promoted a linear reduction in the metabolizable coefficients and ME values of the diets.
	Tambaqui waste biological silage meal	(0 and 5%)	Showed better nutrient utilization than those fed the control diet.
Broiler	Cassava residues (CS and CSR	(30 g kg-1 CS in the feed; inclusion of 30 g kg-1 CSR in the feed; and control)	The digestibility of CSR was higher for the variables apparent metabolizable energy and apparent metabolizable energy.
	Moringa leaf flour	(0 and 20%)	The highest triglyceride concentration (266.91 mg dL-1) was obtained at the inclusion level of 1.77%.

Performance

Table 5 presents studies on the performance of broilers using different alternative feeds. Babassu cake, GFPE (314 and 219 mg kg-1) and GPEM (10% inclusion) showed positive weight gain and feed efficiency results, indicating their potential as effective alternative additives. However, ingredients such as CSR and macaúba bran showed inferior performance when used in high proportions.

On the other hand, CR and moringa leaf flour did not significantly influence the productive performance of the birds, suggesting that they can be used as partial substitutes without compromising the results. Another relevant point was the positive effect of enzyme supplementation in diets containing sunflower meal. The addition of enzymes improved digestibility coefficients and bird performance.

Table 5. Main results on the performance of broiler.

Alternative feed	Broiler
	Results found
Babassu pie	The substitution of soybean meal with babassu pie influenced (P<0.05) the weight gain (WG), feed conversion (FC), water intake and weight of the broilers of 21 days of age, with no effect (P>0.05) on feed intake (FI).
Cassava residues	Feed intake, average weight and weight gain did not vary significantly between treatments, as well as carcass yield, breast yield and viscera.
Cassava starch residue	A comparison of the different levels of CSR inclusion with the control treatment showed lower weight gain and higher feed conversion (P<0.05) at inclusion levels above 4 %.
Guavira fruit peel extract	314 and 219 mg kg^{-1} resulted in greater weight gain and better feed conversion rate. With the inclusion of 500 mg kg^{-1} the broiler achieved greater gain and weight.
Macauba meal	Macaúba meal levels did not influence (P>0.05) animal performance in the periods from 29 to 56 and 57 to 85 days. An influence (P<0.05) of macaúba meal levels was observed during the accumulated experimental period (1 to 85 days).
Moringa leaf flour	The inclusion of the Moringa leaf in the feed of slow-growing chickens did not influence (P>0.05) carcass yield, nor the breast, thigh, drumstick and wing.
Guarana peel meal	The 10% inclusion level of PCPM providing better cumulative weight gain and feed efficiency results.
Dry cassava residue	No interaction(P>0.05) was observed between enzyme addition and dry cassava residue (DCR) levels for the carcass and portion yield,or abdominal fat variables
Sunflower cake	Diets containing 180, 240 and 300 g kg-1 of Sunflower cake (SC) increased their feed intake (0 g kg-1 of SC), and only those receiving 300 g kg-1 of SC showed a worse in feed conversion values.
Sunflower cake	Supplementation of exogenous enzymes to the diets did not improve the performance of the birds in the period 1 to 21 days of age (P>0.05).
Sunflower meal (SM) inclusion with or without multienzyme complex supplementation	The influence of the exogenous enzymes on performance parameters observed during the initial phase were observed from 1 to 42 d of age, with increases of 2.65 and 3.50% for weight gain and feed intake, respectively.
Tucumã meal	Differences were observed (P<0.05) in feed intake with the highest feed intake (4.35 kg/bird) from inclusion of 4.47% of tucumã meal in the diets.

The performance results of laying hens and quail, organized in Table 6. The inclusion of ASMMPW in diet of laying hens showed superior results were observed in feed intake, egg production, feed conversion and egg mass results of laying hens fed, feed intake showed quadratic effect with great intake of 111.14g/bird/day in inclusion level of 0.75%. On the other hand, cashew nut meal inclusion in the diet of laying hens did not influence feed consumption and egg weight, at levels above 5% it promoted a linear reduction in egg laying and egg mass, and feed conversion worsened linearly.

The inclusion level of 2,00% of fish waste oil presented more balanced results than other inclusion levels. High levels of sunflower cake (180, 240 and 300 g kg-1) increased their feed intake compared to those consuming the control diet (0 g kg-1 of SC) and 10% leucaena leaf hay did not affect significantly ($p > 0.05$) the variables evaluated diet intake, weight gain, feed conversion, ingestion of metabolized energy and ingestion of CP.

Regarding quail performance, internal egg quality, and yolk color were unaffected ($p > 0.05$) by dietary DCR inclusion. However, increasing DCR levels led to a linear rise in gizzard and small intestine relative weight, no differences ($p > 0.05$) were observed in villus height, crypt depth, or their ratio in the small intestine segments.

Table 6. Main results on the performance of laying hens and quail.

Alternative feed	Laying hen Results found
Acid silage meal made of pirarucu waste	Differences ($p<0.05$) were observed in feed intake, egg production, feed conversion and egg mass results of laying hens.
Black pepper	There were no significant differences ($p > 0.05$) between the means of the productive performance variables.
Cashew nut meal	The inclusion in the diet did not influence feed consumption and egg weight, at levels above 5% it promoted a linear reduction in egg laying and egg mass, and feed conversion worsened linearly.
Leucaena leaf hay	The inclusion of leucaena leaf hay in the diet did not affect significantly ($p > 0.05$) the variables evaluated diet intake, weight gain, feed conversion, ingestion of metabolized energy and ingestion of CP.
Fish waste oil	The inclusion level of 2,00% of fish waste oil presented more balanced results than other inclusion levels. Differences were not observed ($p>0.05$) in all variables analysed.
Alternative feed	**Quail**
Dried cassava residue	There was a linear increase ($p<0.05$) for the relative weight of the gizzard and the small intestine with increased dietary levels of the residue. The different levels of the residue did not change ($p>0.05$) the values of villus height, crypt depth, and villus height/crypt.

Serum biochemical

The results of the serum biochemistry are shown in Table 7. The inclusion of tucumã meal in broiler diets showed a higher concentration of triglycerides (266.91 mg dL-1) with 1.77% inclusion. On the other hand, the use of GPEM in broiler diets reduced the concentration of triglycerides, especially when used at higher inclusion levels (10%). Black pepper showed a slight reduction in the ideal level of triglycerides, with 259.08 mg dL-1, with an inclusion of 0.78% in the diets of laying hens, in addition, fish waste oil reduced the concentration of triglycerides in laying hens at the highest inclusion levels.

Table 7. Main results on serum biochemical parameters of broiler and laying hens.

Animal category	Alternative feed	Parameters evaluated	Results found
Laying hen	Black pepper	Glucose, triglycerides, cholesterol and pH	The best level of triglycerides (259.08 mg dL^{-1}) was observed at the level of 0.78% inclusion.
	Fish waste oil	Triglycerides, total cholesterol, glucose, total proteins, albumin, globulins and uric acid	The inclusion of 3.5% fish waste oil reduced the concentration of triglycerides in the blood of laying hen.
Broiler	Guarana peel meal	Total proteins, triglycerides, cholesterol, albumin	The triglyceride concentration was significantly increased with the inclusion of Paullinia cupana peel meal in the diets.
	Tucumã meal	Glucose, triglycerides, cholesterol and pH	The highest triglyceride concentration (266.91 mg dL-1) was obtained at the inclusion level of 1.77%.

DISCUSSION

Distribution of studies in Brazil

These data indicate (Fig. 2) that research on alternative feeds in poultry farming is relevant in the states of Amazonas (42.9%). The importance of these studies in the region is particularly evident, given the significant impact of logistics on the cost of inputs for poultry farming. The difficulty of transportation and the distance from production centers increase the price of the final product, making it essential to develop local solutions for animal feed. Cruz et al. (2016) state that the limited resources and the high cost of raw materials make the state of Amazonas particularly unfavorable since 100% of the raw materials used to manufacture balanced feeds come from other regions. Klinger et al. (2020), which highlights the importance of searching for alternative ingredients to reduce feed costs and increase the poultry farmer's profit margin. Using these ingredients also prevents agro-industrial waste from being discarded into nature, reducing environmental impacts (Valentim et al., 2021).

Among the seven Brazilian states that presented studies related to the topic, three are located in the North region, two in the Northeast region, one in the Central-West region and two in the South region. The North region leads the studies on the topic (Table 1). Cruz et al. (2016) state that feed accounts for approximately 70% of the total production cost, and in the Amazon region, these costs can be amplified due to logistical problems and dependence on grains produced in the other areas, directly impacting the final cost of the product. This situation is evidenced by Rufino et al. (2015) and Cruz et al. (2016), who identified the Amazon as the leading Brazilian region where all the challenges mentioned are most pronounced. In poultry and swine diets, alternative feed ingredients can partially replace traditional dietary components, such as soybean meal and corn (Sanches et al., 2023).

Of the total number of studies analyzed, it was observed that most of the research (Fig. 3) was focused on broilers, which may be related to the growing development of this production chain. National poultry farming records continuous growth in broiler production, a factor that drives global economies and consolidates the product as the country's leader in exports (ABPA, 2024; Schmidt & Silva, 2018).

Secondly, studies on the nutrition of laying hens were identified, which are of significant importance due to the large number of eggs produced in Brazil. According to ABPA (2024), the average egg consumption in Brazil is 242 eggs per capita per year, reflecting a constant increase in recent decades. Eggs are widely recognized as one of the most complete feed in the human diet, standing out for their rich nutritional composition, which includes vitamins, minerals, fatty acids and proteins (Kusum et al., 2018; Eddin et al., 2019).

On the other hand, studies involving quails were less representative, with only one study registered, possibly due to their smaller market share than the different categories. Although quails stand out for their high productivity, such as the early start of laying, around the 40th day of life, and an average of 300 eggs in the first year (Santos Bourdon et al., 2023), there is a notable lack of information in the national literature on the nutrition of these birds (Benivente et al., 2022).

Chemical composition

Alternative animal-based feed such as TWBSM and ASMMPW have higher levels of CP, followed by by-products of plant origin, among which we can highlight babassu pie, sunflower cake and GPEM (Table 2). According to Toldrá et al. (2016); Lynch et al. (2017), many by-products are rich sources of proteins, lipids and biomolecules, and can add value in certain cases.

CS and GPEM, in turn, obtained the highest values for the fibrous fractions NDF and ADF. This can be attributed to the fact that the scrapings are obtained from the entire cassava root, including part of the outer layers, which are naturally rich in insoluble fibers, such as cellulose, hemicellulose, and lignin. Araújo et al. (2017) found NDF and ADF values for raw cassava peel of 42.95% and 28.76%, respectively. These residues can also contain more than 10% CF (Amorim et al., 2015; Parente et al., 2018). Santos et al. (2024) also found high NDF and ADF values for GPEM. In another context, Cândido et al. (2017) evaluated the composition of fish silage and obtained 39.01% CP, 29.78% ether extract, 14.45% mineral matter and 30.69% dry matter, values similar to those found in TWBSM.

Moringa leaf flour, widely researched as an alternative in animal feed, stands out for its low production cost and high efficiency of use. All plant parts can be used, including leaves, fruits and seeds (Marinho et al., 2016; Cohen-Zinder et al., 2016; Babiker et al., 2017). Guzmán-Maldonado et al. (2020) highlight that Moringa oleifera leaves contain 21.7 g of protein, 10 g of fat, 16 g of fiber and 48 g of carbohydrates per 100 g, in addition to 1,908.71 mg of tannins and 2,859.44 mg of flavonoids, polyphenols with high antioxidant potential, contributing to several beneficial functions in the body.

In addition, babassu pie, with a protein content of 21.26%, has proven to be a viable alternative to replace conventional and high-cost inputs in animal supplementation due to its nutritional properties (Freitas et al., 2014). According to Table CQBAL 4.0 (2020), babassu pie has 19.27% CP, 90.75% dry matter and high levels of NDF (71.41%) and ADF (39.66%), making it an effective alternative to reducing feed costs without compromising the nutritional value of diets.

The sunflower cake presented CP levels of 19.31% and ether extract of 15.52%, with variations in the values observed by Berwanger et al. (2014), who identified 24.37% CP and 23.80% ether extract. These variations can be attributed to the nutritional composition of the byproduct, with a high content of NDF and a lower concentration of GE, which directly impacts the energy value available in the diet. According to Rostagno et al. (2017), the fiber content in the sunflower cake is composed mainly of insoluble non-starch polysaccharides, such as rhamnose, arabinose, xylose, mannose, galactose and uronic acid.

Finally, the GPEM stood out with the highest levels of CF and GE, reaching 6,752.61 kcal kg-1 (Table 2). ME, which is the energy available for animal metabolism after losses in the digestive process, was also more significant in GPEM, reaching 4,227.20 kcal kg-1. However, the high fiber content of GPEM (Santos et al., 2024) limits its inclusion in diets for non-ruminants, and its use in low concentrations is recommended to avoid impacts on animal performance (He et al., 2015; Rufino et al., 2021).

Main parameters evaluated

The main parameters evaluated in studies on broilers and laying hens include performance, digestibility, carcass yield, egg quality and biochemical parameters (Table 3). Before being included in animal feed, the alternative ingredients requires careful evaluation of their chemical composition, digestibility and potential antinutritional factors to develop cost-effective diets without compromising animal performance (Brandão et al., 2023).

Digestibility

CSR showed significantly higher digestibility for apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance than CS (Table 4), evidencing greater energy efficiency. Cassava is a promising energy source for poultry diets due to its high starch content and high digestibility, which are higher than those found in many cereal grains (Bakare et al., 2021). According to Sakomura et al. (2014), CR has higher digestibility of ingested energy than shavings, which can be attributed to the higher content of ether extract, resulting in an additional caloric effect. However, the low digestibility of CP in cassava diets reflects a lower availability of nutrients for the animals, and changes in feed composition can impact the acceptance and consumption of diets, especially for slow-growing broilers (Chukwukaelo et al., 2018).

On the other hand, the inclusion of acai meal, which increases the fiber content in the diets, favored the efficiency in using nutrients. This positive effect of fibers can be explained by the impact on the development and functionality of the gizzard, promoting more excellent mechanical activity of grinding and retention of the feed until it reaches particles of ideal size, (Rufino et al., 2017). Including up to 10% of acai meal, with 4.50% fiber, promoted balance in energy and protein consumption, directly impacting performance, especially the laying rate (Rufino et al., 2021). Although historically seen as antinutritional (Mateos et al., 2012; Rufino et al., 2021), its balanced inclusion demonstrates benefits in digestive physiology and in the modulation of the intestinal microbiota, this effect also promotes improvements in zootechnical performance (Goulart et al., 2016; Mateos et al., 2012; Rufino et al., 2021).

TWBSM (with 3% inclusion) demonstrated superior results in energy and nutritional digestibility, suggesting its viability as a substitute in poultry diets. Batalha et al. (2017, 2018, 2019) observed that up to 3% ASMMPW provided good nutrient digestibility and considerable energy potential. Guimarães et al. (2019) also observed the viability of TWBSM as a source of energy and protein, with good digestibility at up to 5% levels.

However, the inclusion of ingredients such as moringa leaf flour (20%) and sunflower cake (60 to 300 g kg-1) resulted in negative impacts, highlighting the importance of adjusting the proportions in diet formulation. Sebola et al. (2017) reported that the inclusion of moringa leaf flour had no significant impact on the digestibility of the Potchefstroom Koekoek and Ovambo lines but indicated a reduction in digestibility in the Black Australorp line. Oliveira et al. (2020) evidenced that Moringa oleifera has potential in animal feed, offering high nutritional value and bioactive compounds to improve performance and digestibility.

According to Berwanger et al. (2017a), sunflower meal contains non-starch polysaccharides such as cellulose and lignin, which are not degradable by digestive enzymes and may reduce nutrient availability. Rostagno et al. (2017) indicated that the fibrous fraction present in sunflower meal may reduce the efficiency of nutrient absorption, depending on the inclusion levels. Finally, 25% cara flour in the experimental diet promoted a significant increase in the digestibility coefficients of dry matter, non-nitrogenous extract and ether extract, indicating its potential as a viable alternative ingredient.

Performance

The results on the performance of broiler chickens are shown in Table 5. The inclusion of babassu pie, GFPE and GPEM demonstrated positive effects on weight gain and feed efficiency, indicating the potential of these inputs as alternative feed.In studies carried out, Silva et al. (2015) did not observe negative impacts on weight gain and feed conversion by replacing up to 30% of soybean meal with babassu cake, which suggests that this ingredient can be used without compromising bird performance.

Furthermore, guavira is rich in bioactive substances such as ascorbic acid and phenolic compounds and has shown positive effects on poultry health, promoting antioxidant, antimicrobial and immunostimulant functions (Viecili et al., 2014; Capeletto et al. 2016). These compounds can improve the digestive performance of poultry and modulate their immune response (Kamboh et al., 2015), in addition to preserving meat quality by reducing lipid oxidation during processing (Jiang; Xiong, 2016). Similarly, GPEM, when included in diets for slow-growing broilers, has shown positive effects on weight gain and feed efficiency despite its high fiber content (Santos et al., 2024).

In contrast, CR and moringa leaf flour did not significantly influence bird performance, although they are viable as partial substitutes for conventional ingredients without negatively affecting production results. Silva; Silva (2021) highlight that whole CS, due to their low protein content and deficiency in essential amino acids such as methionine and tryptophan, require nutritional adjustments for their proper use. However, this ingredient has a high content of lysine, an essential amino acid for bird growth. Similarly, the inclusion of moringa leaf leaves in diets did not significantly affect bird performance (Macambira et al., 2018). However, Hassan et al. (2016) observed that higher levels of moringa leaf inclusion improved both weight gain and feed conversion. Variations in processing methods, nutritional management, and genetic characteristics of the birds studied can explain these divergent results.

Malhado et al. (2021) concluded that the inclusion of 12% barley residue in diets for Label Rouge broilers (49-90 days) did not affect weight gain, feed conversion, and carcass yield. Similarly, Santos et al. (2024) reported that 10% Paullinia cupana hull bran provided the best results for slow-growing birds, with gains in productive performance, meat quality, and yield of prime cuts such as breast, thigh, and drumstick. Corroborating with . Holanda et al. (2015) found that the inclusion of up to 48% of whole cassava bran in the diet of free-range chickens did not affect the yield of commercial cuts, viscera or zootechnical performance. However, Chaves et al. (2024) observed that 15% tucumã bran in the initial phase did not alter consumption, but reduced weight gain and feed efficiency in both phases, indicating possible impairment in nutrient utilizationConversely, Costa et al. (2018) observed that increasing levels of babassu flour in diets improved the weight and productive efficiency of chickens, but identified a reduction in these parameters after 25% inclusion

The performance results of laying hens and quails (Table 6) prove the potential of these alternative feeds. Significant results were observed with an increase in egg production, feed conversion and egg mass of laying hens with diets containing ASMMPW . The results also indicate that the inclusion level of 2.00% of residual fish oil presented more balanced results. Alemayehu et al. (2015) indicated that including fish meal and oil in the diets of chickens and quails resulted in a significant increase in yolk height, which suggests the positive effect of alternative ingredients on egg quality. Scherr et al. (2014) associated this effect with the high content of essential fatty acids, such as omega-3 and omega-6, present in fish waste, which can improve the final product's quality. Silva et al. (2017) also reported an increase in bird feed consumption with the inclusion of fish byproduct meal in the diets, evidencing the positive impact of these ingredients on feeding behavior. Nogueira et al. (2014) associated this increased consumption with ingredients of animal origin, which are known to enhance the palatability of diets. This effect can be explained by the natural preference of birds for feed with moderate to high lipid levels, which act as positive sensory modulators, stimulating voluntary consumption and, consequently, favoring the productive performance of birds.

The inclusion of black pepper, cashew nut meal and leucaena leaf hay in the diet of laying hens did not significantly influence (P>0.05) the productive performance. However, diets with 180 to 300 g kg^{-1} of sunflower cake linearly decreased (P<0.05) the feed intake, although the dosage of 300 g kg^{-1} impaired the feed conversion. There was a linear increase (P<0.05) for the feed intake and feed conversion after the inclusion of 60 g kg-1 of sunflower cake in the diet. Pinheiro et al. (2012) reported the importance of evaluating the positive or negative effects on productive performance when including alternative feed with phytogenic compounds in the poultry diet. Regarding cashew nut flour, Soares et al. (2007) observed that its quality is variable, with tannin levels around 0.26%; however, this percentage may increase with processing. Cruz et al. (2015) suggests that protein manipulation by burnt almonds and tannin levels may reduce egg production and worsen feed conversion.

The addition of sunflower cake and leucaena leaf hay can reduce intake and worsen feed conversion in pullets, due to the high fiber content (Souza et al., 2020) and the presence of antinutritional factors such as mimosine and tannins in leucaena leaf (Oliveira et al., 2014). However, Abdallah et al. (2015) observed that up to 140 g/kg of sunflower cake improved weight gain and body mass in pullets aged 11 to 19 weeks.

The inclusion of DCR in quail diets did not significantly affect performance, internal egg quality, or yolk color, but promoted a linear increase in the relative weight of the gizzard and small intestine without altering the height of the intestinal villi. This result is in line with the observations of Duarte et al. (2013), who highlight the greater ability of quails to utilize fibrous feeds compared to broilers, thanks to the morphophysiological characteristics of their gastrointestinal tract, such as the higher digestive passage rate (Wils-Plotz; Dilger, 2013). Although fiber inclusion can influence the characteristics of the intestinal villi (Almeida et al., 2020a), in this study no significant changes were observed, noting that the tested DCR levels maintained the balance between digestibility and nutritional utilization.

Brunelli et al. (2012) found that the inclusion of 30% defatted corn germ meal in laying hens did not affect performance, but reduced yolk pigmentation. At the same time, vegetable oils increased egg weight and yolk percentage in young hens (Oliveira et al., 2010). On the other hand, the inclusion of up to 5.7% detoxified castor bean meal improved performance without compromising egg quality (Bueno et al., 2014).

Serum biochemical

Tucumã bran provided the highest concentration of triglycerides (266.91 mg dL-1) with 1.77% inclusion in diets to laying hen (Table 7), while black pepper showed a slight reduction in the optimal level (259.08 mg/dL) with 0.78% inclusion in diets to laying hen. GPEM (10%) and fish waste oil (3.5%) reduced the concentration of triglycerides, decreasing the potential to improve the lipid profile in broiler. The results showed that alternative ingredients modulate serum biochemical parameters in birds, as demonstrated by Melo et al. (2016), who associate changes in diet with metabolic changes, even if subtle.

In broilers' metabolism, triglycerides from the digestion and absorption of fatty acids are mainly processed in the intestinal mucosa and liver. However, excessive elevations in the concentrations of these lipids can compromise metabolic efficiency, resulting in reduced zootechnical performance (Zhou et al., 2020; Hu et al., 2021). Thus, adequate control of the intake of ingredients that impact the lipid profile is essential to optimize the growth and health of birds.

Including up to 25% of tucumã byproduct meal in broiler diets did not compromise the serum biochemical parameters of the broilers. However, it presented significant changes in the broilers' blood pH, suggesting a specific physiological impact of this ingredient on the acid-base balance. Deviations in this balance can compromise fundamental metabolic processes, resulting in reduced physiological efficiency and negatively affecting animal productivity (Melo et al., 2016). An imbalance in the electrolyte system can harm the growth, health, and zootechnical performance of birds, and it is becoming a critical factor to be considered in studies that evaluate the effect of alternative ingredients in diets (Maia et al., 2024; Souza et al., 2015).

Studies carried out by Gutiérrez Castro & Matus (2019) demonstrate that the inclusion of Tithonia diversifolia flour up to 15% does not alter blood parameters in broilers. Morais et al. (2023) tested cinnamon, oregano and annatto (2%) in 42-day-old broilers, and annatto stood out for improving the calcium/phosphorus ratio and plasma protein without altering cholesterol. At the same time, Carrijo et al. (2005) found that garlic powder, the inclusion of up to 1%, did not alter lipid ranges. Although alternative foods can replace traditional diets, their adoption depends on accessibility and animal adaptation (Sanches et al, 2023).

CONCLUSION

The inclusion of agro-industrial waste in poultry diets has been widely studied in the northern regions of Brazil, seeking alternatives that reduce costs and promote sustainability. This waste offers relevant nutritional and productive benefits, such as providing proteins, lipids and bioactive compounds, and contributes to the circular economy by reusing byproducts that would otherwise be discarded. Studies show that waste such as babassu cake, guarana peel meal and cassava waste can improve poultry's digestibility and productive performance, increasing weight gain, feed conversion and meat and egg production. However, excessive use of these ingredients can impair nutrient absorption, requiring an adequate nutritional balance in the formulations.

The inclusion of waste also affects poultry's biochemical parameters, especially the acid-base balance. Ingredients such as tucumã meal and residual fish oil have shown positive effects in reducing triglycerides, promoting a healthier metabolism. In summary, agro-industrial residues have great potential as alternative ingredients in poultry diets, but their application must be carefully adjusted to maximize benefits and avoid negative impacts on bird performance.

Declarations Conflict of interest

The authors have no concerns of interest that are relevant to the content of this article.

Human and animal rights

This article contains no studies with human participants or animals performed by any of the authors.

REFERENCES

Abdallah AG, Beshara MM, Ibrahim AF (2015) Effect of different levels and sources of dietary fiber on productive and economical performance in local laying hens: 1-during growing period and subsequent laying performance. Egypt. Poult. Sci. J. 35, 367–398.

ABPA – Brazilian Association of Animal Protein. Annual report 2024. Available online: https://abpa-br.org/wpcontent/uploads/2024/04/ABPA-RelatorioAnual-2024_capa_frango.pdf. (Accessed on 01January 2025).

ABPA- Brazilian Animal Protein Association. Annual Report 2023. Available online: https://abpa-br.org/wp-content/uploads/2023/04/Relatorio-Anual-2023.pdf. (Accessed on 02 January 2025). [in Portuguese]

Aguilar-Rivera N, Debernardi-Vázquez, TJ (2018). Sustainable Development for Farmers Transforming Agro-industrial Wastes into Profitable Green Products. In: Leal Filho, W., Noyola-Cherpitel, R., Medellín-Milán, P., Ruiz Vargas, V. (eds) Sustainable Development Research and Practice in Mexico and Selected Latin American Countries. World Sustainability Series. Springer, Cham. Pp 53–75. 10.1007/978-3-319-70560-6_4

Alemayehu Y, Urge M, Getu A (2015) Effects of levels of inclusion of locally processed fish waste meal in the diets of white leghorn layers on performance parameters, hatchability, economics, egg production and egg quality. Iranian Journal of Applied Animal Science;5(3):689 698.

Almaraz-Sánchez V, Amaro-Reyes A, Acosta-Gallegos JA, Mendoza-Sánchez M (2022) Journal of Chemistry Volume 2022, ID 3656932, 13 p. 10.1155/2022/3656932

Almeida AZ, Eyng C, Garcia RG, Nunes RV, Sangalli GG, Nunes KC (2020a) Dried cassava residue in laying quail feeding. Brazilian Journal of Poultry Science. v.22 / n.1 / 001-008. 10.1590/1806-9061-2019-1189

Almeida AZ, Eyng C, Nunes RV, Broch J, Souza C, Sangalli GG, Tenório KI (2020b) Carcass characteristics and meat quality of slow-growing broilers fed diets containing dry residue of cassava, with or without the addition of carbohydrates. Tropical Animal Health and Production. v. 52, pages 2677–2685. 10.1007/s11250-020-02308-4

Amorim AF, Siqueira JC de, Rodrigues KF, Vaz RGMV, Barbosa SM, Santos HD, Soares JAR (2015) Inclusion levels of cassava bagasse in the diet of slow-growing broilers: physicochemical characteristics of the meat. Semina: Agricultural Sciences, 36(3), 1685–1700. 10.5433/1679-0359.2015v36n3p1685. [in Portuguese]

Araújo LF, Aguiar EM, Coelho RRP, Luciano RC, Filho RB, Navarro LAO (2017) Nutritional enrichment of cassava peel (Manihot esculenta, Crantz) by a biotechnological process for animal feed. Tropical Roots and Starches Journal, v. 13, nº 1, p. 18-30. 10.17766/1808-981X.2017v13n1p18-30 [in Portuguese]

Babiker E E, Juhaimi FAL, Ghafoor K, Abdoun KA (2017) Comparative study on feeding value of Moringa leaves as a partial replacement for alfalfa hay in ewes and goats, Livestock Science, v. 195, p. 21-26. 10.1016/j.livsci.2016.11.010

Bakare AG, Zindove TJ, Iji PA, Stamatotopoulos K, Cowieson AJ (2021) A review of the limitations of using cassava flour in poultry diets and the potential role of exogenous microbial enzymes. Tropical Animal Health and Production, v. 53, p. 426. 10.1007/s11250-021-02853-6

Batalha OS, Alfaia SS, Cruz FGG, Jesus RS, Rufino JPF, Costa VR (2017) Digestibility and physicochemical characteristics of acid silage meal from pirarucu byproduct in diets for commercial laying hens. Acta Scientiarum. Animal Sciences, v. 3, p. 251-257. 10.4025/actascianimsci.v39i3.35112

Batalha OS, Alfaia SS, Cruz FGG, Jesus RS, Rufino JPF, Silva AF (2018) Acid silage meal from pirarucu byproduct in diets for commercial laying hens. Brazilian Journal of Poultry Science, v. 2, p. 371-376.https://doi.org/10.1590/1806-9061-2017-0518

Batalha OS, Alfaia SS, Cruz FGG, Jesus RS, Rufino JPF, Guimarães CC (2019) Economic analysis of flour from acid silage of pirarucu residues in diets for light commercial laying hens. Journal of Agribusiness and Environment, v. 12, n. 2, p. 363-375. 10.17765/2176-9168.2019v12n2p363-375 [in Portuguese]

Benivente AC, Moraes JAT, Da Silva LP, Ferrarezi Junior E (2022) Breeding and management of quail coturnix japonica. Interface Tecnológica Journal, [S. Tardocchi, v. 19, n. 2, p. 691–701. 10.31510/infa.v19i2.1483. [in Portuguese]

Berwanger E, Nunes RV, Pozza PC, Oliveira TMM, Scherer C, Frank R, Bayerle DF, Henz JR (2014) Nutritional and energy values of sunflower cake for broilers. Semina: Ciências Agrárias, Londrina, v. 35, n.6, p. 3429-3438. 10.5433/1679-0359.2014v35n6p3429 [in Portuguese]

Berwanger E, Nunes RV, Oliveira TMM, Bayerle DF, Giusti Bruno LDA (2017a.)Performance and carcass yield of broilers fed increasing levels of sunflower cake. Rev. Caatinga, v. 30, n. 1, p. 201- 212. 10.1590/1983-21252017v30n122rc [in Portuguese]

Brandão JS, de Souza BB, Brandão PA, Ferreira DH, Nascimento CE de O, Benício TMA, Carvalho A de B, da Silva MR (2023) Alternative feeds for quail (Coturnix coturnix) for meat production. Observatory of the Latin American economy, 21(12), 25857–25877. 10.55905/oelv21n12-130SA [in Portuguese]

Brelaz KCBTRI, Brasil RJMI, Rufino JPFI, Costa VRIII, Viana Filho GBI (2019) Fish waste oil in laying hens diets. Brazilian Journal of Poultry Science. Oct - Dec/ v.21 / n.4 / 001-010. 10.1590/1806-9061-2019-1069

Brelaz KCBTR., Cruz FGG, Rufino JPF, Brasil RJM, Silva AF, Santos ANA (2021) Serum biochemistry profile of laying hens fed diets with fish waste oil. Arq. Bras. Med. Vet. Zootec., v.73, n.1, p.223-230. 10.1590/1678-4162-11704

Brelaz KCBTR, Cruz FGG, Rufino JPF, Brasil RJM, Silva AF, Costa VR, Santos ANA (2024) Apparent digestibility of fish waste oil in diets for laying hens. Acta Scientiarum. Animal Sciences, v.46, e66788. 10.4025/actascianimsci.v46i1.66788

Brunelli SR, Pinheiro JW, Fonseca NAN, & Silva CA da. (2012). Effect of different inclusion levels of defatted corn germ meal in diets supplemented with phytase for laying hens. Semina: Agricultural Sciences, 33 (5), 1991–2000. doi.org/10.5433/1679-0359.2012v33n5p1991 [in Portuguese]

Bueno CFD, Veloso ALC, Faria Filho DE, Dias NA, Fernandes V, do Couto FMP, Matos Júnior JB, Carneiro WA (2014). Detoxifi ed castor cake feed for laying hens. Rural Science, Santa Maria, v.44, n.3, p.538-543. doi.org/10.1590/S0103-84782014000300024 [in Portuguese]

Cândido RS, Watanabe PH, Oliveira PJD, Angelim AL, Siqueira AF, Ximenes JCM, Normando LRO, Melo JM, Freitas ER. (2017) Meat quality and performance of pigs fed diets with fish silage meal. Pesq. agropec. bras., Brasília, v.52, n.10, p.905-913. 10.1590/S0100-204X2017001000010

Capeletto C, Conterato G, Scapinello J, Rodrigues FS, Copini MS, Kuhn F, Tres MV, Magro JD, Oliveira JV (2016) Chemical composition, antioxidant and antimicrobial activity of guavirova (Campomanesia xanthocarpa Berg) seed extracts obtained by supercritical CO2 and compressed n-butane. The Journal of Supercritical Fluids. 110, 32-38. 10.1016/j.supflu.2015.12.009

Carrijo AS, Madeira LA, Sartori JR, Pezzato AC, Gonçalves JC, da Cruz VC, Kuibida KV, Pinheiro DF (2005) Powdered garlic in the alternative feeding of broiler chickens. Brazilian agricultural research, Brasília, v.40, n.7, p.673-679. doi.org/10.1590/S0100-204X2005000700008

Chaves FAL, Guimarães LL, Guimarães CC, Souza LSS, Rufino JPF, Pereira AM (2024) Tucumã bran as an alternative food to diets for slow-growing broilers. Revista em Agronegócio e Meio Ambiente 17(3), e11782. doi.org/10.17765/2176-9168.2024v17n3e11782 [in Portuguese]

Chukwukaelo AK, Aladi NO, Okeudo NJ, Obikaonu HO, Ogbuewu IP, Okoli IC (2018) Performance and meat quality characteristics of broilers fed fermented mixture of grated cassava roots and palm kernel cake as replacement for maize. Tropical Animal Health and Production, 50: 485-493. 10.1007/s11250-017-1457-7.

Corioletti NSD, Backes C, Taveira JH da S, Roswalka LC, Cardoso RL, Corioletti S, Luz VSV (2022). Processes, types and uses of biodigesters, in the treatment of waste of animal origin. Brazilian Journal of Development, 8(7), 53775–53805. 10.34117/bjdv8n7-312

Cohen-Zinder M, Leibovichb H, Vakninc Y, Sagi G, Shabtaya A, Ben-Meir Y, Nikbachat M, Portnike Y, Yishaya M, Miron J (2016) Effect of feeding lactating cows with ensiled mixture of Moringa oleifera, wheat hay and molasses, on digestibility and efficiency of milk production.Animal Feed Science and Technology, v. 211, p. 75-83. 10.1016/j.anifeedsci.2015.11.002

Costa APGC, Cruz FGG, Rufino JPF, Feijó JC, Melo RD, Melo LD, Damasceno JL (2018) Tucumã meal in diets for broilers on performance, carcass traits and serum biochemical profile. Archivos de Zootecnia 67, 137–142. doi.org/10.21071/az.v67i257.3501

CQBAL 4.0 (2020). Table of chemical and bromatological composition of foods. 2017-2018. Available online: http://www.cqbal.com.br. (Accessed on 01January 2025) [in Portuguese]

Correddu F, Lunesu MF, Buffa G, Atzori AS, Nudda A, Battacone G, Pulina G (2020) Can Agro-Industrial By-Products Rich in Polyphenols be Advantageously Used in the Feeding and Nutrition of Dairy Small Ruminants? Animals (Basel). v. 10, n. 1. 10.3390/ani10010131.

Cruz CEB, Freitas ER, Xavier RPS, Fernandes DR, Nascimento GAG, Watanabe PH (2015) Cashew nut meal in the feeding of brown laying hens. Ciênc. Agrotec., Lavras, v.39, n.1, p.68-74, jan./fev. 10.1590/S1413-70542015000100008

Cruz FGG, Rufino JPF, Melo RD, Feijó JC, Damasceno JL, Costa APGC (2016) Socioeconomic profile of poultry farming in the primary sector of the state of Amazonas, Brazil. Rev. in Agribusiness and Environment, v. 9, n. 2, p. 371-391, 2016. 10.17765/2176-9168.2016v9n2p371-391. [in Portuguese]

Diaz-Vargas M, Murakami AE, Pintro PTM, Ospina-Rojas IC, Souza CHP, Eyng C (2019) Dehydrated citrus pulp in broiler diets. Can. J. Anim. Sci. 99: 33–40. 10.1139/cjas-2017-0087

Duarte CRA, Murakami AE, De Mello KS, Picoli KP, Garcia AFQM, Ferreira MFZ (2013) Soybean hulls in quail diets. Semina: Ciências Agrárias. 34(6):3057-3068. 10.5433/1679-0359.2013v34n6p3057 [in Portuguese]

Eddin AS, Ibrahim SA, Tahergorabi R (2019) Egg quality and safety with an overview of edible coating application for egg preservation. Food Chemistry;296:29-39. 10.1016/j.foodchem.2019.05.182

Frasao B, Costa M, Silva F, Rodrigues B, Baltar J, Araujo J, Moreira D, Torrezan R, Conte-Junior C (2018) Effect of pequi (Caryocar brasiliense) and juçara (Euterpe edulis) waste extract on oxidation process stability in broiler meat treated by UV-C. PLoS ONE 13(12): e0208306. 10.1371/journal.pone.0208306

Falcone DB, Klinger ACK. Toledo GP, Silva L P (2020) Performance, meat characteristics and economic viability of rabbits fed diets containing banana peel. Tropical Animal Health and Production, v. 52, p. 681–685. 10.1007/s11250-019-02057-z

Ferreira MW, Dias GC, Silva TR, Kiefer C, Silveira US, Marques RR (2019) Macaúba meal levels in the diet of naked neck broilers. Cienc. anim. bras., Goiânia, v.20, 1-12, e-52626. 10.1590/1809-6891v20e-52626

Freitas MAG, Siqueira GB, Siqueira FLT (2014) Evaluation of use of waste meal babassu (Orbignya sp) in ruminant diets. INTERAÇÕES, Campo Grande, v 15, n 1, p. 59-70, doi.org/10.1590/S1518-70122014000100006 [in Portuguese]

Gaur VK, Sharma P, Sirohi R, Awasthi MK, Dussap CG, Pandey A (2020) Assessing the impact of industrial waste on environment and mitigation strategies: A comprehensive review. Journal of Hazardous Materials. v. 398, p.123019. 10.1016/j.jhazmat.2020.123019.

Georganas A, Giamouri E, Pappas AC, Zoidis E, Goliomytis M, Simitzis P (2023) Utilization of Agro-Industrial By-products for Sustainable Poultry Production. Sustainability, 15, 3679. 10.3390/su15043679

Goulart FR, Adoriam TJ, Mombach PI, da Silva LP (2016) Importance of dietary fiber in the nutrition of non-ruminant animals. Journal of Science and Innovation, v. 1, pp. 141-154, May 23. 10.26669/2448-4091104 [in Portuguese]

Gouveia ABVS, Paulo LM, Silva JM S, Sousa FE, Santos FR, Minafra CS (2020) Soybean byproducts in bird feeding: Review. Research, Society and Development, [S. l.], v. 9, n. 7, p. e471974187. 10.33448/rsd-v9i7.4187.

Guimarães CC, Nóbrega TC, Santos ANA, Barai1 AA, Mourão LS, Gomes MFS, Ferreira WS, Chaves FAL, Junior JLS, Mendonça MAF, Silva1 AJI, Rufino JPF, Oliveira AT (2025) Biological silage from tambaqui (Colossoma macropomum) byproducts on the productive performance, hematological parameters and egg quality of older commercial hens. Trop Anim Health Prod 57, 20. https://doi.org/10.1007/s11250-024-04273-8

Guimarães CC, Silva AJI, Cruz FGG, Rufino JPF, Silva AF, Costa VR (2019) Digestibility and physicochemical characteristics of tambaqui waste biological silage meal included in commercial layer diets. Brazilian Journal of Poultry Science,v. 21, n. 3, p. 1-6. 10.1590/1806-9061-2018-0869

Gutiérrez Castro LL, & Corredor Matus JR. (2019) Blood chemistry in broilers fed with golden button meal (Thitonia diversifolia) in the final phase. CES Medicina Veterinaria Y Zootecnia, 14(3), 42–52. doi.org/10.21615/cesmvz.14.3.4

Guzmán-Maldonado SH, López-Manzano MJ, Madera-Santana TJ, Núñez-Colín CA, Grijalva-

Verdugo CP, Villa-Lerma AG, Rodríguez-Núñez JR (2020) Nutritional characterization of Moringa oleÌfera leaves, seeds, husks and flowers from two regions of Mexico. AgronomÌa Colombiana, v. 38, n. 2, p. 287–297. 10.15446/agron.colomb.v38n2.82644

Halmemies-Beauchet-Filleau A, Rinne M, Lamminen1 M, Mapato C, Ampapon T, Wanapat M, Vanhatalo A (2018) Review: Alternative and novel feeds for ruminants: nutritive value, product quality and environmental aspects. Animal. v. 12, n. s2, p. s295-10.1017/s1751731118002252.

Hassan HMA, El-Moniary MM, Hamouda Y, El-Daly EF, Youssef AW, El-Azeem NAA (2016) Effect of different levels of moringa oleifera leaves meal on productive performance, characteristics and carcass some blood parameters of broiler chicks reared under heat stress conditions. Asian Journal of Animal and Veterinary Advances, 11(1): 60-66. 10.3923/ajava.2016.60.66

He LW, Meng QX, Li DY, Zhang YW, Ren LP (2015) Influence of feeding alternative fiber sources on the gastrointestinal fermentation, digestive enzyme activities and mucosa morphology of growing Greylag geese. Poult. Sci., 94, pp. 2464-2471. 10.3382/ps/pev237

Holanda MAC, Holanda MCR, Vigoderes RB, Dutra Junior WM, Albino LFT (2015) Performance of broilers redneck fed cassava meal. Revista Brasileira de Saúde e Produção Animal 16(1), 106-117. doi.org/10.1590/S1519-99402015000100012

Hu X, Li X, Xiao C, Kong L, Zhu Q, Song Z (2021) Effects of dietary energy level on performance, plasma parameters, and central AMPK levels in stressed broilers. Frontiers in Veterinary Science 8, 681858. 10.3389/fvets.2021.681858

Jiang J, Xiong Y L (2016) Natural antioxidants as food and feed additives to promote health benefits and quality of meat products: a review. Meat Sci. 120, 107-117. 10.1016/j.meatsci.2016.04.005

Junior, AP, Alves OH, Alves AF (2023) Projection of laying poultry production in Brazil from 2022 to 2030. In: Proceedings of the 61st Congress of the Brazilian Society of Economics, Administration and Rural Sociology (SOBER). Proceedings. Piracicaba (SP) ESALQ/USP.10.29327/sober2023.627200 [in Portuguese]

Kamboh AA, Arain MA, Mughal MJ, Zaman A, Arain ZM, Soomro AH (2015) Flavonoids: Health promoting phytochemicals for animal production – A review. J. Anim. Health Prod. 3(1), 6-13. 10.14737/journal.jahp/2015/3.1.6.13

Klinger ACK, Toledo GSP, Falcone DB, Knob AN (2020) Elephant grass (Pennisetum purpureum) as a supplement in diets for meat rabbits. Brazilian Journal of Development, v.6, n.9, p.70275-70281. 10.34117/bjdv6n9-470

Kusum M, Verma RC, Renu M, Jain Hk and Deepak S (2018) A review: chemical composition and utilization of egg. International Journal of Chemical Studies. 6(3): 3186-3189.

Lazzari A, Barbosa HD, Silva IC da, Silva LHM da, Dada AP, Oliveira Cestário AC de, Machado Filho ER (2021) Antioxidant potential of agro-industrial waste from tropical fruits: review. Research, Society and Development, [S. l.], v. 10, n. 3, p. e29710313357.10.33448/rsd-v10i3.13357.

Limeneh DY, Tesfaye T, Ayele M, Husien NM, Ferede E, Haile A, Mengie W, Abuhay A, Gelebo GG, Gibril M, Kong F (2022) A Comprehensive Review on Utilization of Slaughterhouse Byproduct: Current Status and Prospect. Sustainability 2022, 14, 6469. 10.3390/su14116469

Lohmann ML, Eyng C, Nunes RV, Argandona EJS, Correia CAC, Köhler TL, Costa APGC (2021) Effects of guavira fruit (Campomanesia adamantium) peel extract on performance and meat quality of broilers. South African Society for Animal Science. vol. 50.10.4314/sajas.v51i1.2

Lopes IRV, Zapata JFF, Freitas ER, Souza DV, Viana Neto JL, Lima JR (2013) Meat quality and color of abdominal fat of broilers fed diets containing cashew nut meal treated with antioxidant. Acta Scientiarum. Technology. Maringá, v. 35, n. 1, p. 169-174, Jan.-Mar. 10.4025/actascitechnol.v35i1.9564

Lynch SA., Mullen AM, O'Neill EE, García, CÁ (2017) Harnessing the potential of blood proteins as functional ingredients: A Review of the State of the Art in Blood Processing. Compr. Rev. Food Sci. Food Saf. 2017, 16, 330–344. 10.1111/1541-4337.12254

Macambira GM, Rabello CBV, Navarro MIV, Ludke MCMM, Silva JCR, Lopes EC, Nascimento GR, Lopes CC, Bandeira JM, Silva DA (2018) Chemical and nutritional characterization of Moringa oleifera leaves for broilers. Brazilian Journal of Veterinary and Animal Science, 70(2): 570-578. 10.1590/1678-4162-9522 [in Portuguese]

Maia KM., Pozza PC, Dalcin LC, Vasconcellos RS, Marcato SM (2024) Influence of dietary electrolyte balance on amino acid absorption and metabolism in non-ruminant animals. Arch. Zootec. 73 (282): 94-100. 10.21071/az.v73i282.5846 [in Portuguese]

Malhado ALN, Alves JR, D'Avilla Lima HJ, Rosa M S (2021) Barley residue levels in the diet of Label Rouge broilers. Academic Journal of Animal Science, [S. l.], v. 20, p. 1–6. dx.doi.org/10.7213/acad.2022.20002 [in Portuguese]

Mateos GG, Jiménez-Moreno E, Serrano MP, Lázaro RP (2012) Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of

Applied Poultry Research 21, 156–174. https://doi.org/10.3382/japr.2011-00477

Maquiné L, Guimarães C, Santos A, Oliveira A, Rufino J, Silva Junior J, Chaves F, Mendonça M, Costa Neto P, Pereira J (2024) Use of autochthonous lactic acid bacteria as probiotic additives for Muscovy Ducks in Housing. Braz J Poult Sci 26, eRBCA-2024-1944. 10.1590/1806-9061-2024-1944.

Marinho JBM, Arruda AMV, Melo AS, Souza RF, Santos LOG, Figueirêdo LC, Fernandes RTV, Mesquita ACN (2016) Use of Moringa in animal and human nutrition: Review. PUBVET, v. 10, p. 580-635. 10.22256/pubvet.v10n8.619-627 [in Portuguese]

Melo RD, Cruz FGG, Feijó JC, Rufino JPF, Melo LD, Damasceno JL (2016) 'Black pepper (Piper nigrum) in diets for laying hens on performance, egg quality and blood biochemical parameters', Acta Scientiarum. Animal Science, vol. 38, no. 4, pp. 405-410. 10.4025/actascianimsci.v38i4.31498

Melo RD, Cruz FGG, Feijo JC, Rufino JPF, Damasceno JL, Dias ECS, Brandao ABT (2015) Digestibility of Diets Containing Cara Flour (Dioscorea trifida L.) For Laying Hens. International Journal of Poultry Science, 14: 156-160. 10.3923/ijps.2015.156.160

Morais AMVB, Melo AMB, Martins AS, Camargo JGA, Morais LVB, Gomes DMS, Minafra CS (2023) "Biochemical profile of blood of broilers fed oregano, cinnamon and annatto. International Seven Journal of Multidisciplinary, 2(1), 95–103. doi.org/10.56238/isevmjv2n1-005

Nascimento Filho WB, Franco CR (2015) Assessment of the Potential of Residues Produced Through Agro-industrial Processing in Brazil. Rev. Virtual Quim ,7 (6), 1968-1987. 10.5935/1984-6835.20150116 [in Portuguese]

Nogueira M de A, Cruz FGG, Tanaka E de S, Rufino JPF, Santana TM (2014) Palm oil (Elaeais guineensis Jaquim) in the diet of light laying hens in a tropical climate. Rev. Acad. Anim. Sci. [Internet]. Apr 15 [cited 2025 Jan 7];12(2):103-11.10.7213/academica.12.02.AO03 [in Portuguese]

Oliveira PVC de, Oliveira PVC de, Rodrigues SC, Melo AMP de, Lima R N da S, Neto CO de A, Nogueira HC (2020) Utilization of oil moringa oleiferous in animal feed. Brazilian Journal of Development, 6(7), 53881–53893. 10.34117/bjdv6n7-872 [in Portuguese]

Oliveira TMM, Nunes RV, Eyng C, Berwanger E, Bayerle DF (2016) Sunflower meal and exogenous enzymes in initial diets for broilers. Rev. Caatinga, Mossoró, v. 29, n. 4, p. 996 – 1005, out. – dez. 10.1590/1983-21252016v29n425rc

Oliveira AN, Freitas ER, Cruz CEB, Filgueira TMB, Nascimento GAJ, Lima RC (2014) Inclusion of leucaena leaf hay in the diet of laying hens during the growing phase. Acta

Scientiarum. Animal Sciences. Maringá, v. 36, n. 3, p. 297-301, July-Sept. 10.4025/actascianimsci.v36i3.21834

Oliveira DD, Baião NC, Cançado SV, Figueiredo TC, Lara LJC, Lana AMQ (2010) Lipids sources on layer hen diet: performance and egg quality. Arch. Bras. Med. Vet. Zootec., v.62, n.3, p.718-724. doi.org/10.1590/S0102-09352010000300029 [in Portuguese]

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Aki EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hrobjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonalds, McGuinness LA, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. For more information, visit: BMJ 372, n71. 10.1136/bmj.n71.

Parente IP, Albino LFT, Rodrigues KF, Vaz RGMV, Sousa LF, Fonseca FLR, Silva MC (2018) Cassava bagasse and annatto colorific (Bixa orellana L.) in diets for slow-growing broilers from 30 to 90 days of age. Brazilian Journal of Animal Health and Production, 19: 58-68. 10.1590/S1519-99402018000100006

Picoli KP, Murakami AE, Nunes RV, Amaral-Duarte CR, Eyng C, Ospina-Rojas IC (2014) Cassava starch factory residues in the diet of slow-growing broilers. Tropical Animal Health and Production, 46: 1371–1381. 10.1007/s11250-014-0649-7

Piccolo E, Duval HC, Ferraz JMG, Gallo Z (2024). Sustainability in brazilian poultry farming: protagonism in mercosur and main exporting blocks . Journal of Interdisciplinary Studies , 6(1), 01–25. 10.56579/rei.v6i1.864 [in Portuguese]

Pinheiro JW, Fonseca NAN, Bridi AM, Silva CA, Oba A & Medeiros LG (2012) Performance and egg quality of light commercial laying hens fed diets containing forage radish cake (Raphanus sativus). Semina: Agricultural Sciences. 33(4), 1555-1564. 10.5433/1679-0359.2012v33n4p1555 [in Portuguese]

Rostagno HS, Albino LFT, Hannas M. I, Donzele JL, Sakomura NK, Perazzo FG, Saraiva A, Teixeira ML, Rodrigues PB, Oliveira RF, Barreto SLT, Brito CO (2017) Brazilian tables for poultry and swine: feed composition and nutritional requirements. 4th ed. Viçosa, MG: Federal University of Viçosa. [in Portuguese]

Rufino JPF, Cruz FGG, Miller WP, Melo RD, Feijó JC, Chagas EO (2015) Economic analysis of the inclusion of tucumã (Astrocaryum vulgareMart) residue flour in the diet of commercial laying hens. Rev. Bras. Health Prod. Anim., v. 16, p. 1-9.10.1590/S1519-99402015000100001 [in Portuguese]

Rufino JPF, Cruz FGG, Oliveira Filho PA, Melo RD, Feijó JC, Melo LD (2017) Dietary fiber in poultry diets - A review. Rev. Cient. Avic. Suin., v. 3, n. 2, p. 033-042. [in Portuguese]

Rufino JPF, Cruz FGG, Dias FJ, Brasil RJM, Silva ARP, Melo PLG (2020) Açaí meal on diet digestibility for commercial laying hens. Acta Scientiarum. Animal Sciences, v. 42, e46926. 10.4025/actascianimsci.v42i1.46926

Rufino JPF, Cruz FGG, Brasil RJM, Oliveira Filho PA, Melo RD, Feijo JC (2021) Relationship between the level and the action period of fiber in diets to laying hens. Acta Sci. - Anim. Sci., v. 43, p. e49033.10.4025/actascianimsci.v43i1.49033

Sakomura NK, Vilar-Silva JH, Perazzo-Costa FG, Fernandes JBK, Hauschild L (2014) Nutrition of Non-Ruminants. (FUNEP: Jaboticabal, SP) 678p. ISBN: 978-857805132-7 [in Portuguese]

Salami SA, Luciano G , O'Grady MN, Biondi L, Newbold CJ, Kerry JP, Priolo A (2019) Sustainability of feeding plant byproducts: A review of the implications for ruminant meat production. Animal Feed Science and Technology. v. 251, n. 37-55. 10.1016/j.anifeedsci.2019.02.006.

Sanches DS, Moraes G, Elis R de, Kiefer C (2023) Alternative diets for poultry and swine: a brief review. Multidisciplinary Electronic Journal of Scientific Research | Vol. 2 | No. S1.10.56166/remici.2023.2.v2n1.2.3 [in Portuguese]

Santos ANA, Rufino JPF , Viana AL, Guimarães CC, Gomes MFS, Barai AA, N'obrega TC, Ribeiro MWS, Silva AJI, Chaves FAL, Mendonça MAF, Silva Junior JL, Costa Neto PQ, Oliveira AT (2024) Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science 64, AN24137. 10.1071/AN24137

Santos Bourdon VDD, Vieirar DVG, Costa FGPP, Kaneko IN, Lima AV, Santana LP, Santos Neto EL, Lima MR, Sousa MS, Silva GF, Cavalcante D (2023) Model for predicting metabolizable energy requirements for laying Japanese quails. Peer Review, v. 5, n. 26, p. 667-685. 10.53660/1640.prw3231 [in Portuguese]

Sasu Y, Cederberg C, Wirsenius S (2014) Localising livestock protein feed production and the impact on land use and greenhouse gas emissions. Animal. v. 8, n. 8, p. 1339-48. 10.1017/S1751731114001293.

Scherr C, Gagliardi ACM, Miname MH, Santos RD (2014) Fatty acid and cholesterol concentrations in usually consumed fish in Brazil. Arquivos Brasileiros de Cardiologia;104(2):152-158. 10.5935/abc.20140176

Schmidt NS, Silva CL (2018) Research and Development in the Broiler Production Chain in Brazil. RESR, Piracicaba-SP, Vol. 56, No. 03, p. 467-482, Jul./Sept. 10.1590/1234-56781806-94790560307 [in Portuguese]

Sebola NA, Mlambo V, Mokoboki HK (2017) Chemical characterisation of Moringa oleifera (MO) leaves and the apparent digestibility of MO leaf meal-based diets offered to three chicken strains. Agroforest Systems. 93:149–160. 10.1007/s10457-017-0074-9

Sharma P, Gaur VK, Kim SH, Pandey A (2020) Microbial strategies for bio-transforming food waste into resources. Bioresource Technology. v. 299, p. 122580. 10.1016/j.biortech.2019.122580.

Silva MC, Siqueira JC, Vaz RGMV, Rodrigues KFR, Neiva ACGR, Silva GFS, Fonseca FLR, Sousa JPL, Alves CFA, Cunha LPN (2015) Replacement of soybean meal by babassu cake in diets for broiler chickens from 22 to 42 days of age. Semina: Agricultural Sciences, Londrina, v. 36, p. 1099-1110. 10.5433/1679-0359.2015v36n2p1099 [in Portuguese]

Silva AF, Cruz FGG, Rufino JPF, Miller WMP, Flor NS, Assante RT (2017) Fish by-product meal in diets for commercial laying hens. Acta Scientiarum. Animal Sciences. Maringá, 39 (3): 273- 279. 10.4025/actascianimsci.v39i3.34102 [in Portuguese]

Silva HMD, Silva VCD (2021) Supply of cassava scrapings as an alternative feed for pigs. Multidebates, v. 5, nº 3, p. 222-230. [in Portuguese]

Siqueira MU, Contin B, Fernandes PRB, Ruschel-Soares R, Siqueira PU, Baruque-Ramos J (2022) Brazilian Agro-industrial Wastes as Potential Textile and Other Raw Materials: a Sustainable Approach. Mater Circ Econ 4, 9. 10.1007/s42824-021-00050-2

Soares MB, Fuentes MFF, Freitas ER, Lopes IRV, Moreira RF, Sucupira FS, Braz NM, Lima RC (2007) Cashew nut meal in the diet of Japanese quails in the laying phase. Brazilian Journal of Animal Science. 36(4):1076-1082. 10.1590/S1516-35982007000500013 [in Portuguese]

Souza DH, Freitas ER, Alencar AVO, Costa MKO, Santos AS, Freire JF, Rocha AKS, Coelho RD, Nepomuceno RC (2020) Sunflower cake in brown-egg laying pullet diets: Effects on the growing phase and on the beginning of production cycle . Animal Feed Science and Technology 269- 114663. 10.1016/j.anifeedsci.2020.114663

Souza BB de, Silva RC, Rodrigues LR, Rodrigues VP & Arruda A de S (2015) Analysis of the effect of heat stress on production, physiology and diet of poultry. Scientific Agriculture in the Semiarid Region, v. 11, n. 2, p. 22-26. 10.30969/acsa.v11i2.644

Stefanello FS, Fruet APB, Trombetta F, Fonseca PAF, Silva MS, Stefanello S, Nörnberg JL (2019) Stability of vacuum-packed meat from finishing steers fed different inclusion levels of brewer's spent grain. Meat Science. v. 147, p.155-61. 10.1016/j.meatsci.2018.09.004.

Tremea, FT & Silva AC da. (2020) The poultry sector in Brazil and its regional distribution. Economy and Region, 8(1), 183–200. 10.5433/2317-627X.2020v8n1p183 [in Portuguese]

Tripathi N, Hills CD, Singh RS, Atkinson CJ (2019) Biomass waste utilization in low-carbon products: harnessing a major potential resource. Nature NPJ / Climate and Atmospheric Science, n. 35.10.1038/s41612-019-0093-5

Toldrá F, Mora L, Reig M (2016) New insights into meat by-product utilization. Meat Sci. Oct;120:54-59. 10.1016/j.meatsci.2016.04.021.

Valentim JK, D'Ávila LHJ, Marques BT, Matos SNE, de Castro BMF, Garófallo GR, de Carvalho PJ, Barbosa DK (2021) Dried Distiller's Grains in Broiler Feeding. Essays and Science: Biological, Agricultural and Health Sciences, [S. l.], v. 25, n. 1, p. 44–49.10.17921/1415-6938.2021v25n1p44-49 [in Portuguese]

Vastolo A, Calabro S, Cutrignelli MI (2022) A review on the use of agro-industrial CO-products in animals' diets. Italian Journal of Animal Science, VOL. 21, NO. 1, 577–594.10.1080/1828051X.2022.2039562

Vásquez JVA, Vaz RGMV, Machado SB, Rodrigues KF, Araújo CC, Pinedo WC (2024) Moringa leaf meal in diets of slow-growing chickens on metabolizability, performance, carcass, organ biometry and meat colorimetry. Rev. Bras. Saúde Prod. Anim., Salvador, v.25, 01 - 18, 20230035. 10.1590/S1519-994020230035

Viecili PRN, Borges DO, Kirsten K, Malheiros J, Viecili E, Melo RD, Trevisan G, Silva MA, Bochi GV, Moresco RN, Klafke JZ (2014) Effects of Campomanesia xanthocarpa on inflammatory processes, oxidative stress, endothelial dysfunction and lipid biomarkers in hypercholesterolemic individuals. Atherosclerosis. 234(1), 85-92. 10.1016/j.atherosclerosis.2014.02.010

Vieira SS, Vieira ES, Barbosa FRS, Lima ACS, Marinho AM, Reis CP, Tavares FB, Oliveira LRS, Alves KS, Neta ERS (2022) Cassava residues in the diet of slow-growing broilers. Acta Amazonica 52: 189-198. 10.1590/1809-4392202100843

Wils-Plotz EL, Dilger RN (2013) Combined dietary effects of supplemental threonine and purified fiber on growth performance and intestinal health of young chicks. Poultry Science. 92(3):726-734. 10.3382/ps.2012-02664.

Zhou Y, Chen Z, Lin Q, Yang Y, Hang Y, Zhou X, Wu C, Xie Z (2020) Nuciferine reduced fat deposition by controlling triglyceride and cholesterol concentration in broiler chickens. Poultry Science 99, 7101–7108.10.1016/j.psj.2020.09.013

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CHAPTER 3: Econometric and Market Analysis of the Guarana Production Chain in the Amazon Region – Brazil

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Abstract

The guaraná (*Paullinia cupana*) production chain holds strategic economic and socioenvironmental significance for the Brazilian Amazon, especially in the state of Amazonas. This study investigates the structure and performance of guaraná production across Amazonas microregions from 2010 to 2023, applying descriptive and econometric analyses to identify key drivers and bottlenecks. Data from local institutions were aggregated to assess production volume, yield, number of producers, prices, and income indicators. A log-log panel regression model was developed to evaluate the influence of these variables on total production. The number of producers and productive yield significantly influence output, while average price and per capita income showed limited explanatory power. Regional disparities in productivity and participation were observed, with Middle Amazonas leading production. The study provides a data driven foundation for future public and private interventions aimed at revitalizing the guaraná value chain in Amazonas and ensuring its long term resilience.

Keywords: agricultural economics; guaraná; fixed effects model; Paullinia cupana; productive yield.

INTRODUCTION

The Amazon biome harbors a uniquely complex ecosystem, marked by exceptional biological richness and high potential for economic exploitation of its biodiversity (Andrade et al., 2024; Clement et al., 2005; Clement et al., 2010; Ladislau et al., 2019; Lemos et al., 2015; Oliveira et a., 2021). Among its endemic fruit species, those with bioactive properties, promising phytochemical profiles and economic valuation stand out for their relevance in biotechnology, nutraceuticals, and sustainable development strategies by the firms (Diniz et al., 2019; Rodrigues et al., 2023). One notable example is guaraná (Paullinia cupana), a species cultivated almost exclusively in Brazil and of substantial economic and socioenvironmental relevance to the Amazon (Schimpl et al., 2013; Ferreira et al., 2022). Its visually distinctive fruit featuring a red rind, black seed, and partially exposed white aril is emblematic of the region's natural wealth (Santana et al., 2018).

Guaraná is widely recognized for its medicinal, nutritional, stimulant, and wound healing properties (Marques et al., 2016), with approximately 70% of produc-tion allocated to the soft drink and energy beverage industry, and the remaining 30% directed to the nutraceutical and dermocosmetic sectors or consumed in natura (Schimpl et al., 2013; da Silva et al., 2017). Its seeds, typically commercialized in raw, powdered, capsule, or tablet forms, are rich in caffeine (2.41–5.07%), theophylline (0.06%), theobromine (0.03%), total tannins (5.0–14.1%), proteins (7.0–8.0%), polysac-charides (30–47%), sugars (6.0–8.0%), fibers (3.0%), fatty acids (0.16%), ash (1.06–2.88%), and moisture (4.3–10.5%) (Marques et al., 2019; Schimpl et al., 2013; Machado et al., 2018). In addition, bioactive compounds such as saponins and tannins contribute to its antioxidant and antimicrobial potential (Fernandes et al., 2020).

The rising domestic and international demand for guaraná based products, combined with fiscal incentives from the Manaus Free Trade Zone, has concentrated approximately 90% of soft drink concentrate production plants in Manaus, Amazonas (Meneghetti et al., 2021). This has driven the expansion of guaraná cultivation in Amazonas and Bahia, consolidating its economic role in regional agriculture (Marques et al., 2019; Meneghetti et al., 2021). Recent studies underscore that adopting modern processing techniques for Amazonian fruits could further strengthen sustainable economic growth in the region (Nascimento & Oliveira, 2024).

Guaraná also plays an essential role in traditional Amazonian medicine due to its stimulant and therapeutic effects (Silva et al., 2015). In municipalities like Maués, its value chain involves rural producers, middlemen, and large corporations such as AmBev, establishing complex commercial relations that, while not stripping farmers of autonomy, reinforce economic dependency structures (Silva et al., 2018; Costa & Cruz, 2019). In many rural areas of Amazonas, guaraná cultivation represents a vital source of household income (Souza et al., 2018).

Understanding the economic networks tied to Amazonian biodiversity is essential for designing strategies that improve production efficiency and enhance the market value of local goods (Silva et al., 2018). However, a persistent lack of accurate data on the guaraná value chain in Amazonas hampers sustainable development, undermining public policy formulation and limiting the evaluation of key metrics such as operational yield, competitiveness, market behavior, and critical bottlenecks (Homma, 2012; Cabral et al., 2023; Freitas et al., 2023). Therefore, the systematic organization of economic data is crucial to optimize value chain performance and expand market access (Drummond, 1996; Cabral et al., 2023). In this context, this study aimed to assess the structure of the guaraná value chain in the state of Amazonas, mapping its geographic distribution across microregions and applying econometric tools to analyze its production dynamics.

MATERIALS AND METHODS

The guaraná production chain in the state of Amazonas, Brazil, was initially characterized based on the territorial division into microregions adopted by the Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). The study covers the period from 2010 to 2023, considering cumulative data from January to December for each year. The microregions analyzed were composed of the following municipalities:

- Alto Rio Negro: Barcelos, Santa Isabel do Rio Negro, and São Gabriel da Cachoeira.
- Alto Solimões: Amaturá, Atalaia do Norte, Benjamin Constant, São Paulo de Olivença, Santo Antônio do Içá, Tabatinga, and Tonantins.
- Baixo Amazonas: Barreirinha, Boa Vista do Ramos, Nhamundá, Parintins, São Sebastião do Uatumã, and Urucará.
- Juruá: Carauari, Eirunepé, Envira, Guajará, Ipixuna, and Itamarati.
- Jutaí/Solimões/Juruá: Alvarães, Fonte Boa, Japurá, Juruá, Jutaí, Maraã, Tefé, and Uarini.
- Madeira: Apuí, Borba, Humaitá, Manicoré, Santo Antônio do Matupi, and Novo Aripuanã.
- Médio Amazonas: Itacoatiara, Itapiranga, Maués, Nova Olinda do Norte, Novo Remanso, Presidente Figueiredo, Silves, and Urucurituba.
- Purus: Boca do Acre, Canutama, Lábrea, Vila Extrema, Pauini, and Tapauá.
- Rio Negro/Solimões: Anamã, Anori, Autazes, Beruri, Caapiranga, Careiro, Careiro da Várzea, Coari, Codajás, Iranduba, Manacapuru, Manaquiri, Manaus, Novo Airão, Rio Preto da Eva, and Vila Rica de Caviana.

The data used in this study are secondary and were sourced from IDAM's internal database, which collects information through questionnaires administered to active guaraná producers in all Amazonas municipalities registered with its local units. It is worth noting that IDAM is the official body responsible for collecting primary sector data in Amazonas, with regional offices and technical personnel deployed throughout the state an institutional feature that lends considerable reliability to the database it maintains on primary production chains. The researchers processed and analyzed the data. Initially, the information was grouped by municipality based on questionnaire samples, considering production volume and the number of active producers. Subsequently, the data were consolidated by microregion according to IDAM's territorial classification described above.

Guaraná production data refers exclusively to agricultural cultivation activities. In the descriptive stage, annual guaraná production in each microregion was expressed as a percentage of the state's total output for each year, alongside the number of active producers. Additionally, productivity was calculated by determining the rate of harvested area relative to the total planted area.

Based on production data from IDAM and per capita income data (municipal GDP per capita) provided by the Amazonas State Secretariat for Economic Development, Science, Technology and Innovation (SEDECTI-AM), a log-log econometric model (1) was developed using absolute panel data for guaraná production by microregion in Amazonas from 2010 to 2023, following the algebraic structure:

$$\ln Y_{it}=\beta_1+\beta_2 \ln Prod_{it}+\beta_3 \ln Ren_{it} + \beta_4 \ln RendProd_{it} + \beta_5 \ln Pre_{it} + u_{it} \quad (1)$$

Where:

lnY = natural logarithm of guaraná production;

lnProd = natural logarithm of the number of active producers in the activity;

lnRen = natural logarithm of the average per capita income of the municipalities;

lnRendProd = natural logarithm of the productive yield of the activity;

lnPre = natural logarithm of the average price paid to the producer.

Note: The subscript i represents the i-th observation (municipality) and t refers to time (years). The coefficients β are the parameters estimated by the econometric regression model.

This model was based on a panel data analysis, which allows a given cross-sectional unit (such as a country, state, or firm) to be observed over time. As such, panel data analysis incorporates spatial and temporal dimensions (Wooldridge, 2005; Gujarati & Porter, 2011). The econometric model was initially specified in three primary forms using Gretl software (Gnu Regression, Econometrics and Time-series Library, v.2023): the pooled OLS model, the fixed effects model, and the random effects model.

To determine the most appropriate specification and the one that best fit the data behavior, Chow, Breusch-Pagan, and Hausman tests were applied at a 5% significance level, as recommended by Gujarati and Porter (2011). Multicollinearity was assessed using the Variance Inflation Factor (VIF), where values greater than 10 may indicate collinearity problems (Wooldridge, 2005; Gujarati & Porter, 2011), and through the construction of the correlation matrix among the analyzed variables. Heteroskedasticity was tested using the White test at a 5% significance level. It is essential to highlight that, due to the log-log specification of the model, the coefficients of the independent variables represent the percentage change in productivity for each 1% increase in the corresponding independent variable (Gujarati & Porter, 2011).

To support the analysis, particularly about the market dynamics of the guaraná production chain in Amazonas, additional qualitative and quantitative data were collected from reports and technical staff of the following institutions: the Brazilian Agricultural Research Corporation (EMBRAPA – Western and Eastern Amazon units), the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), the Brazilian Institute of Geography and Statistics (IBGE), and the Federation of Agriculture and Livestock of the State of Amazonas (FAEA). These secondary data sources were used to provide insight into the structure of the guaraná production chain, including production flow, key territories, standard production processes, and target markets (commercial reach).

RESULTS

The table 1, Figure 1, reveals a pronounced and persistent spatial concentration of output. Municipalities within the Middle Amazonas microregion consistently held the largest share of state production, typically accounting for 40% to 60% of the total annual output. This sustained predominance is primarily driven by the municipality of Maués, a historic and culturally emblematic hub of guaraná cultivation that plays a central role in structuring the state's supply chain. Maués contributes a substantial proportion of the region's total volume and anchors the production system through its accumulated technical expertise, established producer base, and long-standing integration into commercial networks, especially with major beverage corporations.

The low Amazonas and Rio Negro/Solimões microregions also made significant, though less stable, contributions to total output across the series. Their performance was marked by considerable interannual variability, likely attributable to agroclimatic events, unequal access to extension services, logistical constraints, and public or private investment fluctuations. Notably, in certain years, the low Amazonas approached parity with the Middle Amazonas regarding output, reflecting its latent productive potential.

Table 1. Percentage of each microregion in total guaraná production in the state of Amazonas, Brazil, from 2010 to 2023.[1]

Microregion[2]	Percentage share of each microregion in the total guaraná production of Amazonas by year													
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ARN	0.00	0.05	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ASL	0.06	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
BAM	19.47	22.72	19.95	19.32	14.72	18.01	12.53	14.77	16.34	15.12	14.87	21.90	29.15	18.58
JUR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JSJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAD	1.32	1.79	2.32	2.17	3.08	4.27	3.83	5.68	3.76	12.39	26.94	8.51	8.05	7.12
MAM	46.75	52.00	55.71	58.75	47.97	68.49	68.30	60.06	62.51	52.34	42.44	58.15	45.59	61.30
PUR	0.13	0.17	0.09	0.09	0.07	0.04	0.06	0.18	0.08	0.07	0.06	0.05	0.09	0.08
RNS	32.27	23.27	21.81	19.55	34.16	9.19	15.28	19.31	17.31	20.08	15.69	11.37	17.10	12.90
Total[3]	1.16	1.02	0.84	0.88	1.08	1.97	1,22	1,15	1.19	1.02	0.78	1.31	1.19	1.15

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Volume presented in thousand tons.

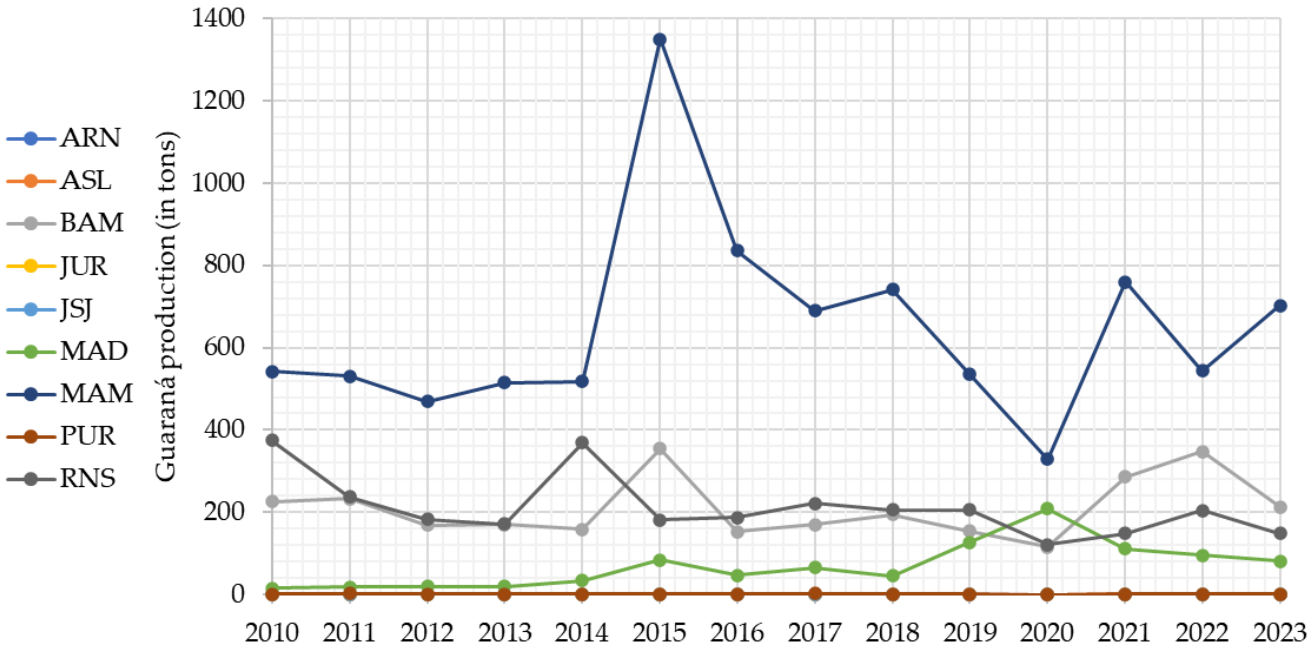

Figure 1. Annual guaraná production (in absolute numbers) in the microregions of Amazonas from 2010 to 2023.

Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

Source: Authors’ elaboration.

This regional concentration also influenced the structure of guaraná producers across the state (Table 2). While production volumes varied by year, a progressive decline in the number of active producers was observed throughout the period, suggesting potential structural changes in the production chain. Interestingly, the microregions with the highest productive yields were not necessarily those with the most significant number of producers. For instance, the Madeira microregion showed a dramatic increase in its relative share of production, from 3.82% in 2010 to 50.17% in 2023. On the other hand, microregions such as Alto Rio Ne-gro, Alto Solimões, Juruá, and Jutaí/Solimões/Juruá showed marginal involvement, both in terms of volume produced and number of producers. Meanwhile, despite low production levels, the Purus microregion experienced a slight increase in the number of active producers over the same period.

Table 2. Percentage of producers in each microregion relative to the total number of active producers in the guaraná supply chain in Amazonas, Brazil, from 2010 to 2023.[1]

Microregion[2]	Percentage share of each microregion in the total number of guaraná producers in Amazonas by year													
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ARN	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
ASL	0.05	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.67	0.99
BAM	21.61	20.66	18.21	16.08	16.40	21.16	19.83	16.55	19.96	21.49	23.02	27.49	3.26	3.56
JUR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.10
JSJ	0.00	0.00	0.00	0.03	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.03	3.00	1.97
MAD	3.82	4.19	4.83	5.08	7.93	9.99	10.30	8.60	9.43	7.21	4.98	5.77	36.01	50.17
MAM	72.71	72.48	73.92	76.41	73.76	65.20	66.19	72.00	68.32	68.93	69.54	64.53	30.44	25.42
PUR	0.03	0.05	0.08	0.10	0.12	0.15	0.27	0.22	0.24	0.22	0.19	0.18	3.54	2.50
RNS	1.78	2.52	2.81	2.15	1.76	3.47	3.41	2.63	2.05	2.16	2.27	1.97	22.74	15.29
Total[3]	3,873	3,892	3,854	3,861	4,097	3,445	3,339	4,140	3,763	3,690	3,618	3,812	1,518	1,502

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Values presented in absolute numbers.

The low Amazonas microregion registered the highest overall performance in the historical series (Table 3), with an average yield of 95.89%. It was followed closely by Rio Negro/Solimões (92.94%), and, at a moderate level, by middle Amazonas (56.83%) and Madeira (52.40%). Although low Amazonas led in terms of productivity, the municipality of

Maués, located in the middle Amazonas microregion, emerges as a central actor in the state's guaraná production chain. Maués combines cultural heritage, economic relevance, and historical tradition in guaraná cultivation, positioning itself as a strategic center for primary production and local value aggregation. Relatively high productivity rates further reinforce its role in the middle Amazon, which still outperforms most other regions despite not reaching the levels of the low Amazon. Meanwhile, regions such as Juruá, Alto Rio Negro, and Jutaí/Solimões/Juruá displayed limited or inconsistent yield values throughout the period, signaling ongoing regional disparities and the need for targeted investment to enhance agronomic performance in less-developed areas.

Table 3. Productive yield of the guaraná supply chain in each microregion of Amazonas, Brazil, from 2010 to 2023.

Micror.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Av.[3]
ARN	0.00	81.15	80.23	83.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.46
ASL	65.00	0.00	69.00	67.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.00	87.00	83.00	32.64
BAM	95.61	96.87	97.82	97.01	97.70	99.22	97.93	96.39	80.78	89.45	98.12	98.19	99.53	97.84	95.89
JUR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	95.12	94.19	13.52
JSJ	0.00	0.00	0.00	59.13	61.33	62.59	0.00	0.00	0.00	0.00	0.00	0.00	91.12	92.23	20.24
MAD	39.43	38.65	41.71	36.45	36.69	46.59	46.10	47.32	53.73	37.11	20.49	94.83	97.12	97.35	52.40
MAM	40.32	39.48	58.62	54.62	55.66	51.46	52.22	50.69	64.61	58.79	52.96	52.68	83.10	80.43	56.83
PUR	93.00	94.00	96.00	96.00	97.00	96.00	77.78	81.82	81.82	81.82	81.82	55.56	9 5.12	96.18	87.42
RNS	95.29	98.14	94.35	97.89	97.50	98.29	92.96	92.92	62.47	80.64	98.81	98.54	98.58	94.71	92.94
Av.[4]	47.63	49.81	59.75	59.12	42.73	54.62	40.78	41.02	38.16	38.65	39.13	53.98	82.97	81.77	52.15

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: Microrregions: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Average productive yield of each microregion over the historical series.

[4] Average productive yield of the state in each year is evaluated.

To better understand the determinants of guaraná production, an econometric model was developed (Table 4). The model proved to be statistically significant, and results from Chow, Breusch-Pagan, Hausman, and White tests ($p < 0.01$) confirmed that the fixed effects model was the most suitable specification, offer-ing the best fit to the data.

Table 4. Econometric model of total guaraná production in Amazonas from 2010 to 2023.

Variable	Coefficient	Standard Error	p-value	VIF
Constant (β_1)	0.81444	0.27414	<0.01	-
Number of producers	0.88309	0.04520	<0.01	2.127
Productive yield	0.34627	0.04604	<0.01	1.919
Per capita GDP / Income	0.03025	0.01606	0.05	1.145
Average price paid to producers	-0.08787	0.09525	0.35	1.337
Model p-value		<0.01		
R^2		0.94		
Chow test p-value[1]		0.48		
Breusch-Pagan test p-value[2]		<0.01		
Hausman test p-value[3]		0.34		
White test p-value[4]		0.32		
Durbin-Watson test p-value – positive autocorrelation[5]		0.37		
Durbin-Watson test p-value – negative autocorrelation[5]		0.77		

[1] H_0: the pooled model is preferable to the fixed effects model.

[2] H_0: the pooled model is preferable to the random effects model.

[3] H_0: the random effects model is preferable to the fixed effects model.

[4] H_0: there is no heteroskedasticity in the model.

[5] H_0: there is no autocorrelation in the model.

Among the independent variables, the number of active producers strongly positively influenced guaraná production ($p<0.01$). A 10% increase in the number of producers was associated with an estimated 8.83% increase in production, ceteris paribus. The second most influential factor was productive yield, which also showed a statistically significant effect ($p < 0.01$). Specifically, a 10% improvement in yield was associated with a 3.46% increase in total production. In contrast, the average price paid to producers exhibited a negative but statistically insignificant effect on production. Likewise, municipal per capita income showed no meaningful relationship with production levels.

The strong positive correlation between the number of producers and guaraná production (Table 5) reinforces the critical role of labor in sustaining output. The moderate correlation between productive yield and production ($r = 0.44$) further supports its relevance as a key efficiency driver.

Table 5. Correlation matrix of the variables included in the econometric model of total guaraná production in Amazonas from 2010 to 2023.

Production	Producers	Production yield	Per capita GDP / Income	Price paid to producers	Variables
1.00	0.93	0.44	0.11	-0.06	Production
	1.00	0.66	0.08	0.32	Producers
		1.00	0.07	0.05	Production yield
			1.00	0.33	Per capita GDP / Income
				1.00	Price paid to producers

Conversely, the weak correlation between per capita income and production (r = 0.11) aligns with the regression results and indicates that improvements in income alone are unlikely to influence guaraná production dynamics. Similarly, the low correlation between producer prices and output (r = -0.06) is consistent with the model's negative coefficient. Together, these results suggest that the guaraná production chain in Amazonas is shaped more by production side factors particularly labor availability and yield efficiency than by market or income-related drivers.

DISCUSSION

Initially, the variations in production and the economic and geographic concentration of guaraná cultivation in Amazonas can be attributed to several interrelated factors. Firstly, as Silva et al. (2022) noted, guaraná cultivation has historically suffered from deficiencies in agronomic practices. Agriculture in the Amazon faces substantial challenges due to the intrinsic properties of the region's soils, which are naturally low in nutrients and highly acidic, conditions that hinder cultivation without proper management (Júnior et al., 2011; Candotti et al., 2023).

Secondly, the expansion of modern agriculture in the middle Amazonas microre-gion can be pointed out, including practices such as soil correction, fertilization, and controlled irrigation (Tavares et al., 2022), has significantly improved productivity per hectare. Municipalities like Maués and Presidente Figueiredo have attracted sustainable agriculture investments (Silva et al., 2018), with cultivation predominantly occurring in integrated systems managed by major industry players such as AmBev and Coca-Cola (Costa, 2010).

Thirdly, the growing domestic and international demand for guarana, driven by its chemical composition and functional properties, combined with fiscal incentives from the Manaus Free Trade Zone, has led approximately 90% of guaraná concentrate industries to establish themselves in the state capital (Meneghetti et al., 2021). The dominance of middle Amazonas may also be attributed to a more structured supply chain, with better organized producer associations and public policies aimed at boosting agriculture in previously neglected areas (Said et al., 2021). In contrast, Baixo Amazonas has lost relevance, likely due to infra-structure shortcomings, logistical bottlenecks, and reduced competitiveness compared to more dynamic regions (Garrett et al., 2017; Said et al., 2021). According to Silva et al. (2018), logistics have always posed a significant obstacle to the economic sustainability of rural and extractive supply chains in Amazonas, a reality particularly evident in Maués due to the municipality's vast territorial area and heavy reliance on river transport and fossil fuels.

Finally, climate change and pest pressure have also affected traditional guaraná growing regions, particularly in the low Amazonas, which has experienced outbreaks of diseases such as anthracnose (Sutton, 1992; Hyde et al., 2009). Until the early 1990s, guaraná production largely depended on natural environmental conditions (Meneghetti et al., 2021). Although the state has access to more than 19 productive and pest-resistant cultivars, adopting available technological packages remains very limited. This has hindered production expansion, as most plantations are not renewed regularly, exacerbating disease susceptibility issues (Tricaud et al., 2016; Meneghetti et al., 2021).

As a native species of the Amazon, guaraná represents a valuable biological resource (Cavalcanti et al., 2020), with a wide range of applications across local, national, and international markets due to its bioactive compounds (Dalonso & Petkowicz, 2012). Its market potential has expanded beyond the food, beverage, and cosmetics industries, gaining increasing relevance in the pharmaceutical sector (Santana & Macedo, 2019; Malík & Tlustoš, 2023). In this context, the guaraná market has experienced significant growth in recent years, driven both by its economic value and by its growing social and functional appeal, particularly as global demand for natural and functional products rises (Marques et al., 2016; Marques et al., 2019).

Despite its Amazonian origins, the guaraná production chain has undergone no table geographic expansion, established in several other Brazilian regions over the past centuries (Lopes & Silva, 1998; Homma, 2012; Dias & Carvalho, 2017). An illustrative case is Bahia, which emerged as the leading guaraná producing state, accounting for 68.5% of national production in 2023. However, the state recorded a 4.8% decrease in output compared to the previous year, resulting from a 1.9% reduction in planted area and a 2.8% decline in yield per hectare. Amazonas ranked second nationally, accounting for 24.2% of total production with 611 tons harvested, a level 10.9% lower than the previous cycle. This decline was primarily due to a 18.1% contraction in cultivated areas, which was not offset by a modest 1.3% gain in productivity (CONAB, 2024).

On the other hand, despite the ongoing expansion of the guaraná market, the decline in the number of active producers in the most recent years of the historical series reveals an alarming scenario for the agricultural sector. This reduction may be linked to financial constraints, changes in the rural producer profile, or even competition from more profitable and less labor-intensive crops, among other factors (Rocha et al., 2025). Paiva (2019) notes that guaraná has been losing its appeal among younger generations, compromising the sector's renewal and threatening its long-term sustainability.

Until the mid-20th century, Amazonas particularly the municipality of Maués held an undisputed leadership in national guaraná production, while Bahia and Mato Grosso were only beginning to cultivate the crop, driven by the growing demand from soft drink manufacturers (Homma, 2014). Considering national production figures, Amazonas exhibits the lowest average yield among all guaraná producing regions in Brazil, with productivity levels well below those of other national players (IBGE, 2019; IBGE, 2023).

According to Homma (2014) and Silva et al. (2018), the expansion of the beverage industry throughout the 20th century culminated in the enactment of the socalled “Juice Law” (Decree-Law No. 5,823/1972, regulated in 1973), which encouraged the systematic cultivation of guaraná. The legislation required that soft drinks contain between 0.2 g and 2 g of guaraná per liter. In comparison, syrups had to include 1 g to 10 g per liter, allowing for a tenfold variation between minimum and maximum thresholds. This regulatory milestone triggered a substantial expansion of the planted area of guarana across all of Brazil's territory, especially in Bahia.

According to CONAB (2024), the crop’s high added value transcends national borders, with significant volumes being exported, particularly to North American and European markets (CONAB, 2024). This growing global demand reinforces guaraná’s strategic importance as a regional product and a high-value commodity in international trade (Marques et al., 2016; Marques et al., 2019; Brasil, 2022).

The product’s value is expressed through its incorporation into various industrial segments, from carbonated beverages and energy supplements to pharmaceutical and nutraceutical formulations (Brasil, 2022). This diversification of applications has elevated guaraná to a new status within global value chains, further intensifying international competition and encouraging the development of more technologically advanced production systems in other Brazilian states (Homma, 2012; Dias & Carvalho, 2017; Silva et al., 2018). In this context, Amazonas continues to face a dual challenge: while it holds a symbolic and ecological centrality in the guaraná narrative, it struggles with structural limitations that have kept its average yields significantly lower than those of other producing states, such as Bahia (IBGE, 2023). These productivity gaps and logistical and technical barriers threaten the state's long-term competitiveness in a market that increasingly demands efficiency, traceability, and product standardization (Silva et al., 2018; Said et al., 2021; Rosa et al., 2024).

The fact that the number of producers is the variable with the most significant influence on guaraná production in Amazonas reveals a characteristic feature of production systems in the Amazon region: the firm reliance on human labor due to the low level of mechaniza-tion in production processes (Drummond, 1996; Gomes, 2018). This dynamic significantly limits operational efficiency, particularly when considering large-scale production models, thereby keeping the activity below its current technological productivity potential (Pindyck & Rubinfeld, 2014; Varian, 2023).

Introducing new agronomic varieties aimed to expand cultivated areas and boost productivity (Nascimento Filho et al., 2016). However, this potential is hindered by farmers' low adoption of technological packages, an outcome reflecting the state sector's structural realities. These include the predominance of small-scale family farming, the incomplete implementation of good agricultural practices, and the lack of standardized protocols for managing seeds and propagation materials, such as clones (Silva et al., 2018). Such advancements have the potential to significantly increase productive yield significantly, making the sector more competitive and attractive to investors and new farmers (Gonçalves et al., 2010). However, the true challenge lies in balancing economic efficiency with ecological responsibility, ensuring that gains in productivity do not come at the expense of natural resource degradation (Dias & Carvalho, 2017; Willerding et al., 2020).

On the other hand, the insignificant influence of the price paid to producers can be explained by the low-price elasticity of supply, even when prices rise, producers are unable to expand production due to structural bottlenecks, such as lack of infrastruc-ture and limited access to essential inputs (Pindyck & Rubinfeld, 2014; Varian, 2023). Interestingly, despite currently having lower productivity, the state of Amazonas sells its guaraná at a higher price than Bahia R$ 83.26/kg in Amazonas compared to R$ 44.57/kg in Bahia (Conab, 2025). This situation is rooted in the regional commercial dynamics: while Amazonas has historically benefited from stable, long term buyers, huge soft drink manufacturers located in the region and taking advantage of fiscal incentives from the Manaus Free Trade Zone, Bahia's production faces logistical and tax related hurdles that limit its access to these same markets (Albertino et al., 2012; Santos et al., 2021). These conditions are marked by deep income inequalities and the economic precariousness of rural areas, where most farmers face insurmountable barriers to acquiring basic inputs and implementing technological solutions that could modernize their cultivation systems (Homma, 2012; Gomes, 2018).

The strong correlation between production volume and the number of producers reinforces a defining characteristic of Amazonian agriculture: its high dependence on family labor (Drummond, 1996; Gomes, 2018). At the same time, the scarcity of technological adoption continues to constrain productivity gains (Pindyck & Rubinfeld, 2014). Another critical dimension is the gradual introduction of technological innovations adapted to local conditions. The successful implementation of these innovations requires synergy among public policies, private sector initiatives, and community-based organizations (Said et al., 2021; Santos Sousa et al., 2022).

The relationship between production and productive yield indicates that the implementation of improved agricultural techniques, such as proper soil management, integrated pest control, and strategic crop renewal, could significantly enhance out-comes (Silva et al., 2018; Hampf et al., 2020; Said et al., 2021). However, despite this potential, productivity remains below expectations, primarily due to two interrelated challenges: the limited adoption of these practices and the lack of standardized protocols for crop management (Tricaud et al., 2016). As emphasized by Silva et al. (2018), this situation directly affects production costs, which are inflated by low agricultural yields, a vicious cycle sustained by the very absence of optimized management tech-niques. The weak correlation between production and per capita income further illustrates that, although higher income levels may improve access to agricultural inputs, their effectiveness is limited by deep structural inequalities and the precarious conditions of rural areas (Homma, 2012; Zhang & Hu, 2020).

Similarly, the relationship between production and the average price paid to producers reflects the low-price elasticity of supply: even when prices rise, producers are often unable to increase output due to bottlenecks such as poor logistics and limited access to inputs (Pindyck & Rubinfeld, 2014; Said et al., 2021; Rosa et al., 2024). This rigidity suggests that strategies to enhance the value of guaraná should prioritize efficiency gains through technological adoption, rather than relying solely on price adjustments.

When considering these relationships together, it becomes evident that the guaraná supply chain in Amazonas requires multifaceted interventions to overcome its structural challenges. One of the main obstacles is the weakness of local productive organizations. In Maués, for instance, associations and cooperatives remain marginal actors within the commercial structure, exerting limited influence over market dynamics (Silva et al., 2018).

To reverse this situation, it is essential to strengthen collective arrangements, such as cooperatives, to reduce excessive dependence on individual labor and scale up productivity gains (Schroth et al., 2001). At the same time, it is crucial to disseminate technologies adapted to family farming, emphasizing sustainable management and crop renewal, ensuring greater productivity without compromising natural resources (Silva et al., 2022). However, these measures will only reach their full potential if accompanied by a robust logistical integration, reducing transportation and distribution costs and connecting producers to larger and more competitive markets (Said et al., 2021).

CONCLUSION

This study provides a comprehensive econometric and structural analysis of the guaraná production chain in Amazonas, Brazil, over the 2010–2023 period. By combining descriptive statistics, spatial temporal trends, and a fixed effects panel regression model, the research sheds light on the main drivers and bottlenecks of guaraná production at the microregional level.

The findings reveal that supply side factors predominantly shape guaraná production in Amazonas. Chief among them is the number of active producers, whose strong positive influence underscores the sector's reliance on manual labor and its low degree of mechanization. Productive yield emerges as a second critical determinant, highlighting the importance of adopting improved agricultural techniques and technological innovation to boost efficiency. However, widespread structural limitations, including limited access to inputs, lack of standardized cultivation protocols, and insufficient institutional support, continue suppressing the region’s productive potential.

Contrary to expectations, economic variables such as the average price paid to producers and municipal per capita income showed weak or insignificant relationships with production levels. These results reflect the rigidity of supply, stemming from logistical challenges and infrastructural deficiencies, and emphasize that price signals alone are insufficient to drive regional production growth.

Moreover, the analysis exposes substantial geographic asymmetries in productivity and participation across microregions. While areas such as Médio Amazonas and Baixo Amazonas maintain a dominant role in the supply chain, others remain margin-al, signaling opportunities for targeted investments and capacity building.

The findings point to the urgent need for a multipronged strategy to ensure the long-term sustainability and competitiveness of the guaraná sector in Amazonas. This includes: (i) strengthening local cooperatives and producer associations; (ii) disseminating context-appropriate technologies, particularly for smallholders; (iii) promoting institutional arrangements that reduce market asymmetries; and (iv) improving infrastructure and logistics to integrate isolated producers into broader commercial networks.

Ultimately, aligning policy interventions with the structural realities of Amazonian agriculture is essential to enhance guaraná production and support broader goals of sustainable regional development. The results of this study may serve as a basis for future public and private strategies aimed at revitalizing and diversifying agro-industrial chains in the Brazilian Amazon.

Declarations Conflict of interest

The authors have no concerns of interest that are relevant to the content of this article.

Human and animal rights

This article contains no studies with human participants or animals performed by any of the authors.

REFERENCES

1. Albertino, S.M.F.; Nascimento Filho, F.J.; Silva, J.F.; Atroch, A.L.; & Lima Galvão, A.K. Rooting of guarana cultivar cuttings with fertilization of matrix plants. Pesquisa Agropecuária Brasileira, 2012; 47, 1449–1454. https://doi.org/10.1590/S0100-204X2012001000006
2. Andrade, J.C.; Oliveira, A.T.; Amazonas, M.G.F.M.; Galvan, D.; Tessaro, L.; Conte Junior, C.A. Fingerprinting based on spectral reflectance and chemometrics - An analytical approach aimed at combating the illegal trade of stingray meat in the Amazon. Food Chemistry, 2024; 436, 137637. https://doi.org/10.1016/j.foodchem.2023.137637
3. Brasil. Ministério da Agricultura, Pecuária e Abastecimento. Exportações de produtos agrícolas: guaraná em destaque. Brasília: MAPA. 2022. Available online: http://www.agricultura.gov.br (accessed on 07 April 2024).
4. Cabral, M.V.A.; Bitencourt, E.B.; Caripuna, L.A.; Costa, R.A.S.; Leal, M.V.S.; Sousa, A.M.; Avelar, M.C.; Dias, M.C.; & Araújo, J.A.C. The development of bioeconomy in the state of Pará: potentialities, challenges and perspectives. REASE, 2023; 9(11), 4211–4224. https://doi.org/10.51891/rease.v9i11.12713
5. Candotti, C.S.; Alfaia, S.S.; Oliveira, F.B.; & Oliveira, C.H.R. Rochagem e sua importância em solos tropicais do Amazonas [Conference presentation]. XXIII Encontro Latino Americano de Pós-Graduação e XIII Encontro de Iniciação à Docência,

Universidade do Vale do Paraíba, Brazil. 2023, November. https://dx.doi.org/10.18066/inic0302.23

6. Cavalcanti, V.; Marques, M.; do Nascimento, W.M.; Rocha, A.W.D.O.; Ferreira, I.D.J.; Leão, D.P.; & de Oliveira, C.M.C. Bioproducts based on guarana (Paullinia cupana) for practitioners of physical activity. European Academic Research, 2020; 8(3), 1746–1759.
7. Clement, C.R.; Lleras, P.E.; & Van Leeuwen, J. The potencial of Brazilian tropical palms: successes and failures of recent decades. Agrociencias, 2005; 9(1/2), 67–71.
8. Clement, C.R.; de Cristo-Araújo, M.; Coppens D'Eeckenbrugge, G.; Alves Pereira, A.; & Picanço-Rodrigues, D. Origin and domestication of native Amazonian crops. Diversity, 2010; 2, 72–106. https://doi.org/10.3390/d2010072
9. Companhia Nacional de Abastecimento (CONAB), 2024. Relatório de acompanhamento da safra brasileira: Guaraná – Análise mensal agosto de 2024. Brasília: Companhia Nacional de Abastecimento. Available online: https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuario-e-extrativista/analises-do-mercado/historico-mensal-deguarana/item/24418-guarana-analise-mensal-agosto-2024 (accessed on 07 April 2024).
10. Companhia Nacional de Abastecimento (CONAB), 2025. Guaraná – Análise mensal fevereiro de 2025. Brasília: Com-panhia Nacional de Abastecimento. Available online: file:///C:/Users/phped/Downloads/GUARANZZ-ZAnaliseZmensalZZ-ZfevereiroZ2025.pdf (accessed on 31 March 2025).
11. Costa, L.F.B.; & Cruz, M.J.M. The commercial network of guaraná and the monopolization of the territory by the capital in the municipality of Maués-AM. Revista GEONORTE, 2019; 10(35), 1133–1151. https: DOI: 10.21170/geonorte.2019.V.10.N.35.132.151
12. Costa, W.M. Communities arrangements, productive systems, scientific and technological inputs for land use and forest resources in Amazon. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas, 2010; 5(1). https://doi.org/10.1590/S1981-81222010000100005
13. Dalonso, N.; & Petkowicz, C.L.O. Guarana powder polysaccharides: Characterisation and evaluation of the antioxidant activity of a pectic fraction. Food Chemistry, 2012; 134(4), 1804–1812. https://doi.org/10.1016/j.foodchem.2012.03.088
14. Da Silva, G.S.; Canuto, K.M.; Ribeiro, P.R.V.; de Brito, E.S.; Nascimento, M.M.; Zocolo, G.J.; Coutinho, J.P.; & de Jesus, R.M. Chemical profiling of guarana seeds (Paullinia cupana) from different geographical origins using UPLC-QTOF-MS combined with

chemometrics. Food Research International, 2017; 102, 700–709. https://doi.org/10.1016/j.foodres.2017.09.055

15. Dias, R.F.; & de Carvalho, C.A.A. Bioeconomy in Brazil and in the World: Current Situation and Prospects. Revista Virtual de Química, 2017; 9(1), 410–430. http://DOI: 10.21577/1984-6835.20170023
16. Diniz, M.B.; Diniz, M.J.T.; Silva, A.L.F.; Barrios, M.L.C.; & Lima, E.B.F. Região amazônica: biodiversidade e possibilidades de transformação industrial. Cadernos CEPEC, 2019; 6(1–6). https://doi.org/10.18542/cepec.v6i1-6.7037
17. Drummond, J.A. A extração sustentável de produtos florestais na Amazônia brasileira: vantagens, obstáculos e perspec-tivas. Estudos Sociedade e Agricultura, 1996; 6, 115–137.
18. Ferreira, F.A.M.; Ferreira, B.B.; Bragança, V.A.N.; Lima, C.L.S.; & Brasil, D.S.B. Guarana (Paullinia cupana Kunth), ma-rapuama (Ptychopetalum olacoides Benth.), gentian (Gentiana lutea L.), quassia (Quassia amara L.) and their properties: A brief review. Research, Society and Development, 2022; 11(2). http://dx.doi.org/10.33448/rsd-v11i2.24592
19. Fernandes, A.M.; Costa Siqueira, S.M.; Furtado, M.L.; Ribeiro Campos, A.E.Q.; Portela Pinheiro, N.A.; & de Amorim, A.F.V. Evaluation of antioxidant and photoprotective activities of the species syzygium cumini (L.) Skeels. BrazilianJournal of Development, 2020; 6(9), 64719–64725. https://doi.org/10.34117/bjdv6n9-055
20. Freitas, A.M.P.; Corcioli, G.; & Cruz, F.T. Retrato das agroindústrias e dos programas governamentais de apoio à agroindústria familiar no Brasil. Revista de Economia e Agronegócio – REA, 2023; 20(2), 1–21. https://doi.org/10.25070/rea.v20i2.14055
21. Garrett, R.D.; Gardner, T.A., Fonseca, T.; Marchand, S.; Barlow, J.; Ezzine de Blas, D.; Ferreira, J.; Lees, A.C.; & Parry, L. Explaining the persistence of low income and environmentally degrading land uses in the Brazilian Amazon. Ecology and Society, 2017; 22(3), 27. https://doi.org/10.5751/ES-09364-220327
22. Gomes, C.V.A. Economic cycles of extractivism in the Amazon from the perspective of traveling naturalists. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas, 2018; 13(1), 129–146. https://doi.org/10.1590/1981.81222018000100007
23. Gonçalves, M.F.; Carneiro, W.M.A.; & Sena, J.V.C. A cadeia produtiva do cacau na Bahia: uma análise à luz da nova economia institucional. Revista Fortaleza, 2010; 2(2), 55–68.
24. Gujarati, D.N.; & Porter, D.C. Econometria básica (5th ed.). Porto Alegre: AMGH Editora

Ldta, 2011.

25. Hampf, A.; Stella, T.; Berg-Mohnicke, M.; Kawohl, T.; Kilian, M.; & Nendel, C. Future yields of double-cropping systems in the Southern Amazon, Brazil, under climate change and technological development. Agricultural Systems, 2020; 177, 102707. https://doi.org/10.1016/j.agsy.2019.102707
26. Homma, A.K.O. Extrativismo vegetal ou plantio: qual a opção para a Amazônia? Estudos Avançados, 2012; 26(74), 167–186. https://doi.org/10.1590/S0103-40142012000100012
27. Homma, A.K.O. Extrativismo vegetal na Amazônia: história, ecologia, economia e domesticação. Brasília, DF: Embrapa, 2014.
28. Hyde, K.D.; Cai, L.; Cannon, P.F.; Crouch, J.A.; Crous, P.W.; Damm, U.; Goodwin, P.H.; Chen, H.; Johnston, P.R.; et al. Colletotrichum – names in current use. Fungal Diversity, 2009; 39, 147–182.
29. IBGE – Instituto Brasileiro de Geografia e Estatística, 2019. Censo Agropecuário 2017: resultados definitivos. Rio de Janeiro: IBGE. https://biblioteca.ibge.gov.br/visualizacao/periodicos/3096/agro_2017_resultados_definitivos.pdf (accessed on 06 April 2025).
30. IBGE – Instituto Brasileiro de Geografia e Estatística, 2023. Produção de guaraná, 2023. Available online: https://www.ibge.gov.br/explica/producao-agropecuaria/guarana/am (accessed on 06 April 2025).
31. Júnior, J.F.V.; Souza, M.I.L.; Nascimento, P.P.R.R.; & Cruz, D.L.S. Soils of the Amazon: etnopedology and sustainable development. Revista Agro@mbiente On-line, 2011; 5(2), 158–165. https://doi.org/10.18227/1982-8470ragro.v5i2.562
32. Ladislau, D.S.; Ribeiro, M.W.S.; CASTRO, P.D.S.; Aride, P.H.R.; Paiva, A.J.V.; Polese, M.F.; Souza, A.B.; Bassul, L.A.; Lavander, H. D.; Oliveira, A.T. Ornamental fishing in the region of Barcelos, Amazonas: socioeconomic description and scenario of activity in the view of -piabeiros-. Brazilian Journal of Biology, 2019; 80, 544-556. https://doi.org/10.1590/1519-6984.215806
33. Lemos, J.R.G.; Oliveira, A.T.; Santos, M.Q.C.; Pereira, C.N.; Nascimento, R.B.; Tavares-Dias, M. Influência do Transporte na Relação Peso-Comprimento e Fator de Condição de Paracheirodon axelrodi (Characidae). Biota Amazônia, 2015; 5, 22-26.
34. Lopes, C.M.D.; & Silva, N.M. Economic Impact of the Cupuaçu Fruit Borer, Conotrachelus humeropictus Field (Coleop-tera: Curculionidae) in Amazonas and Rondonia States, Brazil. Anais da Sociedade Entomológica do Brasil, 1998; 27(3), 481–483. https://doi.org/10.1590/S0301-80591998000300019

35. Machado, K.N.; de Freitas, A.A.; Cunha, L.H.; Faraco, A.A.G.; de Pádua, R.M.; Braga, F.C.; Vianna-Soares, C.D.; & Castilho, R.O. A rapid simultaneous determination of methylxanthines and proanthocyanidins in Brazilian guaraná (Paullinia cupana Kunth.). Food Chemistry, 2018; 239, 180–188. https://doi.org/10.1016/j.foodchem.2017.06.089
36. Malík, M.; & Tlustos, P. Nootropic herbs, shrubs, and trees as potential cognitive enhancers. Plants (Basel), 2023; 12(6), 1364. https://doi.org/10.3390/plants12061364
37. Marques, L.L.M.; Panizzon, G.P.; Aguiar, B.A.A.; Simionato, A.S.; Cardozo-Filho, L.; Andrade, G.; & de Mello, J.C.P. Guaraná (Paullinia cupana) seeds: Selective supercritical extraction of phenolic compounds. Food Chemistry, 2016; 212, 703–711. https://doi.org/10.1016/j.foodchem.2016.06.028
38. Marques, L.L.M.; Ferreira, E.D.F.; de Paula, M.N.; Klein, T.; & de Mello, J.C.P. Paullinia cupana: a multipurpose plant – a review. Revista Brasileira de Farmacognosia, 2019; 29(1), 77–110. https://doi.org/10.1016/j.bjp.2018.08.007
39. Meneghetti, G.A.; Silva, L. de J. de S.; Ferreira, M.A.C.; & dos Santos, A.C. Elements for reflection and analysis of condi-tionsof guaraná production in Amazonas. Brazilian Journal of Animal and Environmental Research, 2021; 4(1), 427–442. https://doi.org/10.34188/bjaerv4n1-037
40. Nascimento, T.P.S. do.; & Oliveira, L.A. de. Economic potential, innovation and cooperativism of some cooperatives in Amazonas. Contribuciones a las Ciencias Sociales, 2024; 17(10), e11241. https://doi.org/10.55905/revconv.17n.10-051
41. Nascimento Filho, F.J.; et al. Cultivo do guaranazeiro no Amazonas: técnicas para a melhoria da produtividade. In Circular Técnica (No. 22, pp. 1–12). Manaus: Embrapa Amazônia Ocidental, 2016.
42. Oliveira, A.T.; Lemos, J.R.G.; Santos, M.Q.C.; Sales, R.S.A.; Pantoja-Lima, J.; Aride, P.H.R.; Araujo, M.L.G.; Tavares-Dias, M. Morphological, cytochemical and ultrastructural aspects of blood cells in freshwater stingray species in the middle Rio Negro basin of Amazonian Brazil. Scientific Reports, 2021; 11, 1-11. https://doi.org/10.1038/s41598-021-95183-4
43. Paiva, M. R. F. Narrativas orais: relatos históricos da cidade de Maués-AM sob a perspectiva de alguns idosos do município. Manaus: Universidade do Estado do Amazonas, 2019.
44. Pindyck, R. S.; & Rubinfeld, D. L. Microeconomia (8ª ed.). São Paulo, SP: Pearson Education do Brasil, 2014.
45. Rocha, L.P.; Sá, S.K.G.; Pereira, E.G.; Ramos, S.M.; Souza, V.M.S.; Souza, L.S.S.; &

Pereira, A.M. O mercado do guaraná da Amazônia (Paullinia cupana): aplicações e potencial bioeconômico. In A contribuição das Ciências Sociais Aplicadas na competência do desenvolvimento humano (Cap. 4), 2025. https://doi.org/10.22533/at.ed.784162519024

46. Rodrigues, L.A.P.; Nunes, D.D.G.; Hodel, K.V.S.; Viana, J.D.; Silva, E.P.; & Soares, M.B.P. Exotic fruits patents trends: An overview based on technological prospection with a focus on Amazonian. Heliyon, 2023; 9(12), e22060. https://doi.org/10.1016/j.heliyon.2023.e22060
47. Rosa, J.S.; Oliveira Moreira, P.I.; Carvalho, A.V.; & Freitas-Silva, O. Cupuaçu fruit, a non-timber forest product in sus-tainable bioeconomy of the Amazon—a mini review. Processes, 2024; 12, 1353. https://doi.org/10.3390/pr12071353
48. Said, M.; Rivas, A.; & Oliveira, L. Cupuaçu plant management and the market situation of Itacoatiara, Manacapuru and Presidente Figueiredo counties, Amazonas State, Brazil. Research, Society and Development, 2021; 10(3), e15110313109. https://doi.org/10.33448/RSD-V10I3.13109
49. Santana, Á.L.; & Macedo, G.A. Health and technological aspects of methylxanthines and polyphenols from guarana: A review. Journal of Functional Foods, 2018; 47, 457–468. https://doi.org/10.1016/j.jff.2018.05.048
50. Santana, Á.L.; & Macedo, G.A. Effects of hydroalcoholic and enzyme-assisted extraction processes on the recovery of catechins and methylxanthines from crude and waste seeds of guarana (Paullinia cupana). Food Chemistry, 2019; 281, 222–230. https://doi.org/10.1016/j.foodchem.2018.12.091
51. Santos, A.C.; Brito, A.P.S.B.; & Neves, S.F. The importance of the biocosmetics industry for the economic performance of amazonas state, Brazil. Revista Terceira Margem Amazônia, 2021; 6(16). https://doi.org/10.36882/2525-4812.2021v6i16.ed.esp.p105-125
52. Santos Sousa, M.; Pluta, R.A.; Almeida, K.F.; Sackser, G.A.B.; Kiahara, L.H.; Adam, F.A.; Carvalho, J.A.R.; & Sousa, R.L. Cupuaçu (Theobroma grandiflorum) culture: main pests of economic damage. Journal of Experimental Agriculture Interna-tional, 2022; 44(5), 33–39. https://doi.org/10.9734/jeai/2022/v44i530820
53. Schimpl, F.C.; da Silva, J.F.; Gonçalves, J.F.; & Mazzafera, P. Guarana: Revisiting a highly caffeinated plant from the Amazon. Journal of Ethnopharmacology, 2013; 150(1), 14–31. https://doi.org/10.1016/j.jep.2013.08.023
54. Schroth, G.; Elias, M.; Macêdo, J.; D'Angelo, S.; & Lieberei, R. Growth, yields and mineral nutrition of cupuaçu (Theobroma grandiflorum) in two multi-strata agroforestry

systems on a ferralitic Amazonian upland soil at four fertilization levels. Journal of Applied Botany, 2001; 75, 67–74.

55. Silva, A.K.P.; & Moura, J.W.M.; & Neto, M.P.L. Evaluation toxicity, cytotoxic, genotoxic and mutagenic of Turnera ul-mifolia L. (chanana) in eukaryotic cells. Revista Saúde em Foco, 2015; 2(1), 25–48.
56. Silva, A.C.B.; Brosler, E.M.; Almeida, L.B.; Reia, M.Y.; & Morato, R.W. A cadeia de valor do guaraná de Maués. Manaus: IDESAM, 2018.
57. Silva, L. de J. de S.; Meneghetti, G.A.; & Pinheiro, J.O.C. Cultivating Guarana BRS Maués: Contribution of Agricultural Technology to Development and Sustainability. Conjecturas, 2022; 22. https://doi.org/10.53660/CONJ-1742-2H20A
58. Souza, S.F.; Carvalho, A.C.N.; & Cruz, M.J.M. The commercialization of guaraná by the camponeses in the Divine Spirit Santo Community From Castanhal (Barreirinha/AM). Revista GEONORTE, 2018; 9(31), 137–153. https://doi.org/10.21170/geonorte.2018.V.9.N.31.137.153
59. Sutton, B.C. The genus Glomerella and its anamorph Colletotrichum. In J.A. Bailey & M.J. Jeger (Eds.), Colletotrichum: Biology, Pathology and Control (pp. 1–26). Wallingford: CAB International, 1992.
60. Tavares, V.S.; dos Santos, G.A.N.; da Silva, A.F.; & Pinheiro, E.C.N.M. Comparative analysis of fertilization in pasture in the municipality of Presidente Figueiredo -AM. Brazilian Journal of Development, 2022; 8(11), 70783–70801. https://doi.org/10.34117/bjdv8n11-003p
61. Tricaud, S.; Pinton, F.; & Pereira, H.D.S. Local knowledge and practices of guarana producers (Paullinia cupana Kunth var. sorbilis) on the middle Amazon: two grassroots organizations confronting innovation. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas, 2016. https://doi.org/10.1590/1981.81222016000100004
62. Varian, H.R. Microeconomia: Uma abordagem moderna (9ª ed.). São Paulo: Atlas, 2023.
63. Willerding, A.L.; Silva, L.R.D.; Silva, R.P.D.; Assis, G.M.O.D.; & Paula, E.V.C.M.D. Estratégias para o desenvolvimento da bioeconomia no estado do Amazonas. Estudos Avançados, 2020; 34(98), 145–166. https://doi.org/10.1590/s0103-4014.2020.3498.010
64. Wooldridge, J.M. Introdução à econometria: Uma abordagem moderna. São Paulo: Thomson Learning, 2005.
65. Zhang, C.; & Hu, R. Does fertilizer use intensity respond to the urban–rural income gap? Evidence from a dynamic pan-el-data analysis in China. Sustainability, 2020; 12, 430. https://doi.org/10.3390/su12010430

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CHAPTER 4: Analysis of total phenols and cellular cytotoxicity of Paullinia cupana by-products as potential alternative feeds for animal nutrition

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Short-title: Bioactive potential of *Paullinia cupana*

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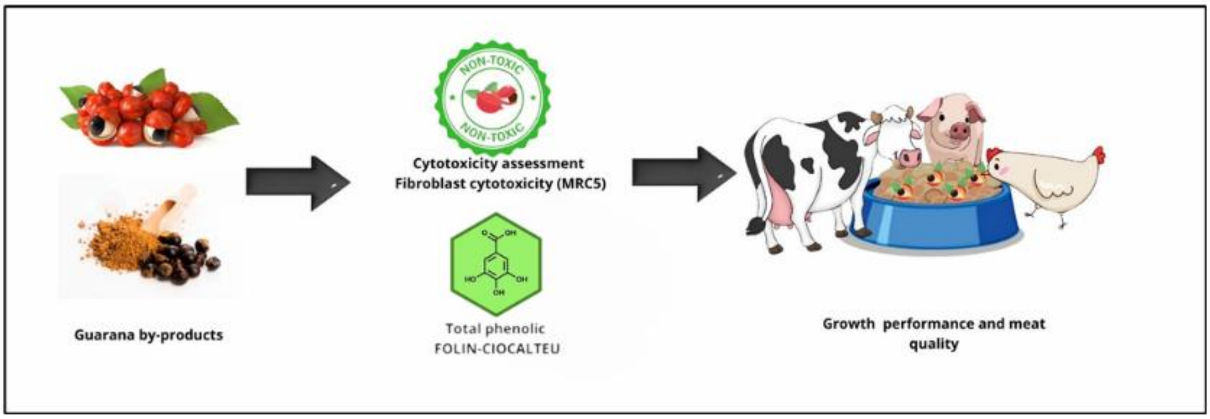
Graphical Abstract



Abstract

The processing of *Paullinia cupana* (guarana) generates significant by-products with potential nutritional and functional properties; however, comprehensive safety and bioactivity assessments are essential before its widespread adoption. To evaluate the total phenolic content, and cytotoxicity of different *P. cupana* derivatives (powder, peel, pulp, and shell) to assess their safety and potential functional applications in poultry nutrition. Cytotoxicity was evaluated using fibroblast cells (MRC5) treated with guarana derivatives at concentrations from 3.9 to 500 μg/mL, with cell viability determined via Alamar Blue assay. Cytotoxicity assessment revealed CC_{50} values ranging from 178.5 ± 17 μg/mL (guarana peel) to 214.1 ± 30.5 μg/mL (guarana powder), indicating low toxicity at moderate concentrations. Guarana powder exhibited the most significant antioxidant activity ($p= 0.0069$; $p< 0.0001$; $p= 0.0034$) compared to other derivatives. Total phenolic content analysis showed that guarana powder and guarana shell contained the highest levels of phenolic compounds at the 500 μg/mL concentration. The correlation between low cytotoxicity and high phenolic content provides scientific evidence supporting the safety and functional benefits of guarana derivatives, particularly guarana powder and peel meal, for application in poultry nutrition. These findings corroborate previous research, demonstrating that the inclusion of guarana peel meal in slow-growing broiler diets has a positive effect on growth performance and meat quality, without adverse health effects, thereby supporting its use as a sustainable alternative feed ingredient in production systems.

Keywords: alternative feed; guarana by-products; phenolic compounds; nutrition.

INTRODUCTION

The search for sustainable and functional feed ingredients has become increasingly important in modern animal production systems (Santos et al., 2025), particularly as the industry faces challenges related to feed costs, environmental concerns, and consumer demands for natural products. Agricultural by-products with bioactive compounds offer promising alternatives that can simultaneously address nutritional requirements, enhance animal health, and contribute to sustainable production practices (Lemes et al., 2022). In this context, *Paullinia cupana* (guarana) by-products have emerged as potential functional feed ingredients due to their rich phytochemical composition and biological activities (Fonseca Júnior et al., 2020; Pinho et al., 2021).

Guarana, a plant native to the Amazon basin, is primarily cultivated in Brazil (Schimpl et al., 2013). The seeds are commercially exploited for their stimulant properties in beverages and dietary supplements, generating significant quantities of by-products including peels, shells, and pulp that are often discarded despite their potential value (Madison Patrick et al., 2019). The antioxidant properties of plant-derived compounds are increasingly recognized for their importance in animal nutrition, where oxidative stress can negatively impact growth performance, immune function, and meat quality (Surai, 2016).

However, before incorporating novel feed ingredients into animal diets, comprehensive safety assessments are essential to ensure they do not pose risks to animal health or product quality. Cytotoxicity evaluations provide valuable information about the potential cellular toxicity of compounds, helping to establish safe inclusion levels in feed formulations. For plant-derived materials rich in bioactive compounds, such as guarana, cytotoxicity assessments are critical, as some phytochemicals may exhibit dose-dependent effects, being beneficial at specific concentrations but potentially harmful at higher levels.

However, the mechanisms underlying these effects and the relationship between the chemical composition of guarana by-products and their functional properties in animal nutrition remain incompletely understood. The present study aims to evaluate the cytotoxicity, antioxidant activity, and total phenolic content of different guarana derivatives (powder, peel, pulp, and shell) to assess their safety and potential functional properties for application in animal nutrition.

Furthermore, the growing interest in circular economy principles within agricultural systems has intensified research efforts toward valorizing agro-industrial waste streams (Nesterov et al., 2024). Guarana processing generates substantial amounts of by-products that represent both an environmental challenge and an economic opportunity. The transformation of these residues contributes to the development of more sustainable and cost-effective animal production systems. This approach aligns with global initiatives aimed at reducing the environmental footprint of livestock production while maintaining or improving animal performance and product quality (Khairi, Maharani, Clarisa & Aditya, 2025). The comprehensive characterization of guarana by-products' bioactive properties and safety profiles is therefore essential to support evidence-based decisions regarding their incorporation into commercial feed formulations and to establish appropriate regulatory frameworks for their use in animal nutrition.

MATERIAL AND METHODS

Sample Preparation and Processing

Paullinia cupana derivatives were acquired from the municipality of Maués, Amazonas, Brazil, located 259 km from Manaus (Figure 1). Four different derivatives were evaluated: guarana powder, guarana peel, guarana pulp, and guarana shell.

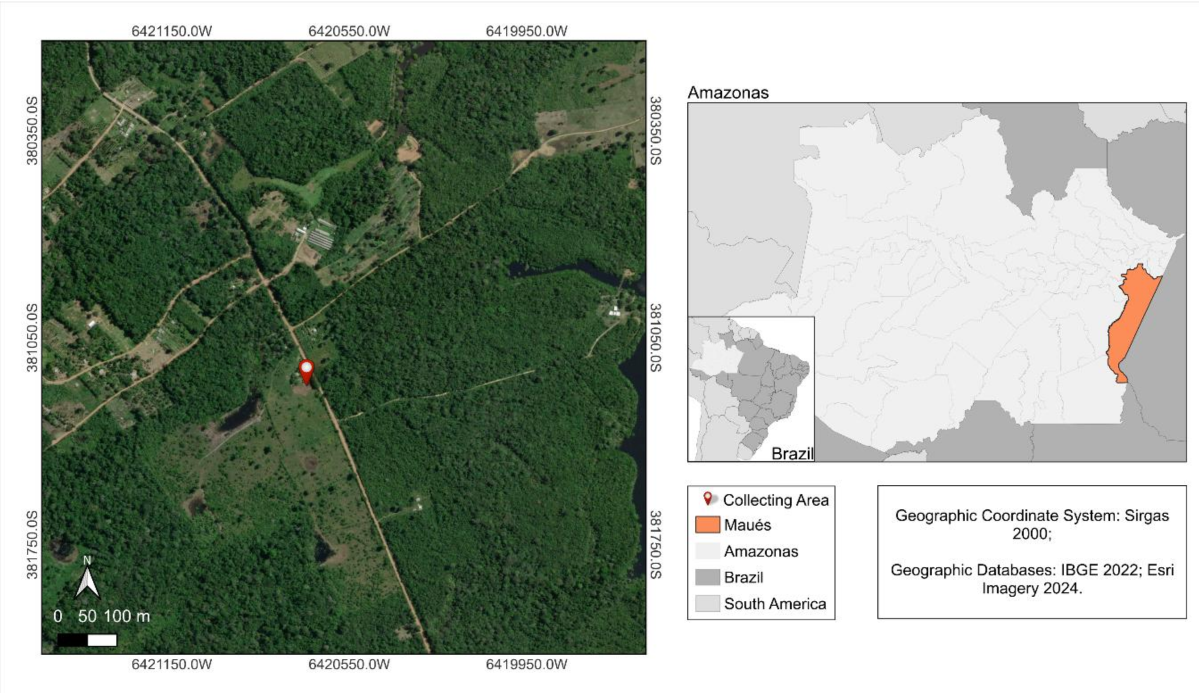


Figure 1. Place of acquisition of *Paullinia cupana* derivatives.

The processing of guarana fruits followed the following established protocols (Figure 2): 1) Manual harvesting of ripe guarana fruits; 2) Storage of the harvested fruits in baskets for approximately three days, undergoing a fermentation process; 3) Guarana seeds; 4) Guarana peels isolated as waste; 5) Drying of the guarana peels in a closed circulation oven at 105°C for 24 hours; 6) The seeds underwent a roasting process; 7) Removal of the film covering the seeds (guarana shell); 8) Grinding of the roasted seeds without the film; 9) Guarana powder; 10) Processing of the roasted seeds to extract the guarana extract, used in the production of industrialized carbonated beverages; 11) Waste from the guarana extract extraction process, known as guarana pulp; 12) Drying of the guarana pulp in a closed circulation oven at 105°C for 24 hours.

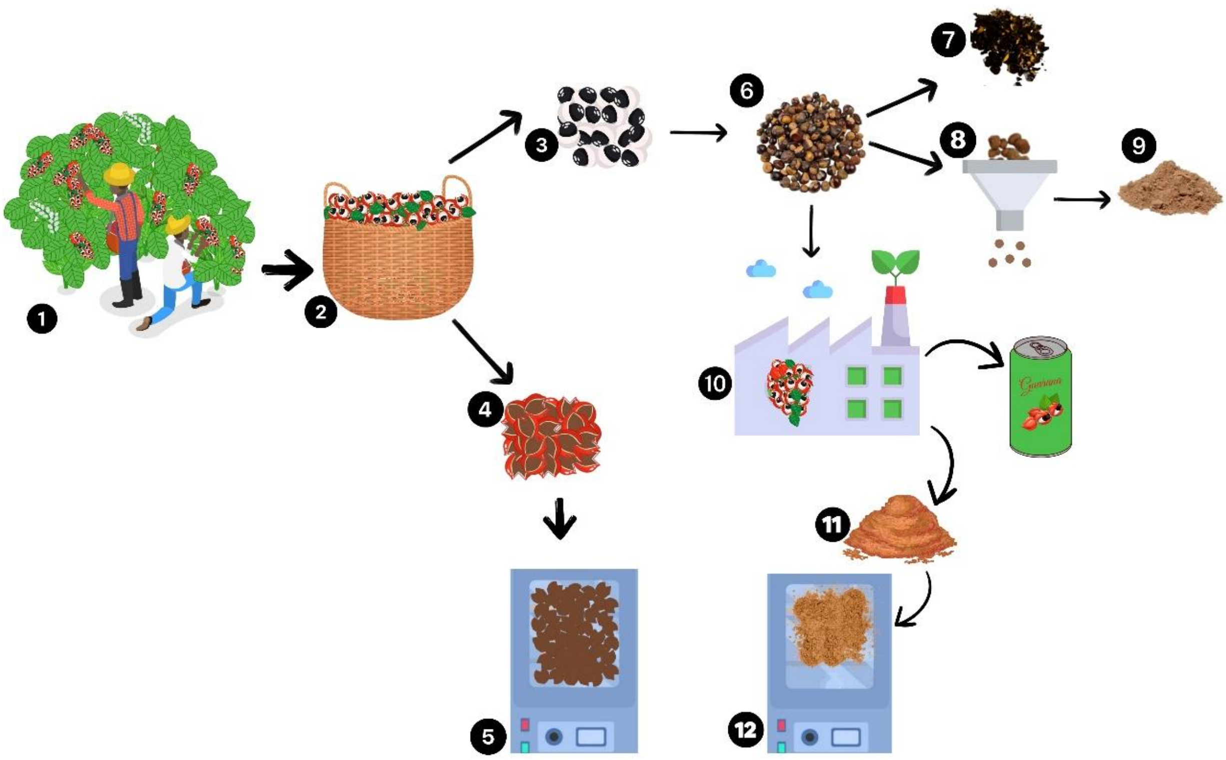


Figure 2. Stages of processing of guarana fruit and its by-products.

Cytotoxicity Assessment

Fibroblast cells (MRC5) were obtained from cryopreservation at -80°C and cultured in high-glucose DMEM medium supplemented with 10% inactivated fetal bovine serum (FBSi) and incubated at 37°C with 5% CO_2. After 24 hours, the fibroblasts were treated in triplicate with guarana derivatives (powder, peel, pulp, and shell) at concentrations ranging from 3.9 to 500 µg/mL. DMSO (0.5%) was used as a negative control. After 72 hours of incubation, the cells were exposed to a dose-response reaction using Alamar Blue® following the protocol described by Nakayama et al. (1997).

Cell viability was assessed using the Alamar Blue assay, which measures the metabolic activity of viable cells. The cytotoxic concentration that reduces cell viability by 50% (CC_{50}) was calculated for each guarana derivative based on the dose-response curves.

Total Phenolic Content Determination

The total phenolic content of guarana derivatives was determined using the Folin-Ciocalteu method. The assay involved incubating 10 µL of each guarana derivative (powder, peel, pulp, and shell) at a concentration of 500 µg/mL with 50 µL of 50% Folin-Ciocalteu reagent for 8 minutes at room temperature. After this incubation period, 240 µL of sodium carbonate solution was added, followed by a further 3-minute incubation. The absorbance of the samples was measured at 740 nm using a microplate reader (Multimode Detector DTX 800, Beckman) according to the protocol described by Horszwald and Andlauer (2011). All analyses were conducted in triplicate, and the results were expressed as percentages.

Statistical analyses

The Cytotoxicity Assessment statistical analysis was performed using Two-way ANOVA and Tukey's test with a significance level of $p < 0.05$, comparing all treatments to the negative control. The total phenolic content data were analyzed using Two-way ANOVA followed by Tukey's test with a significance level of $p < 0.05$, comparing all treatments to the positive control. The half-maximal inhibitory concentration (IC_{50}) was determined for each sample through linear regression analysis.

RESULTS

Cytotoxicity Assessment

Figure 3 describes the dose–response curves of human lung fibroblasts (MRC-5) following 72 h exposure to guarana powder, guarana peel, guarana pulp and guarana shell (0.5 % DMSO as negative control), using the Alamar Blue® assay.

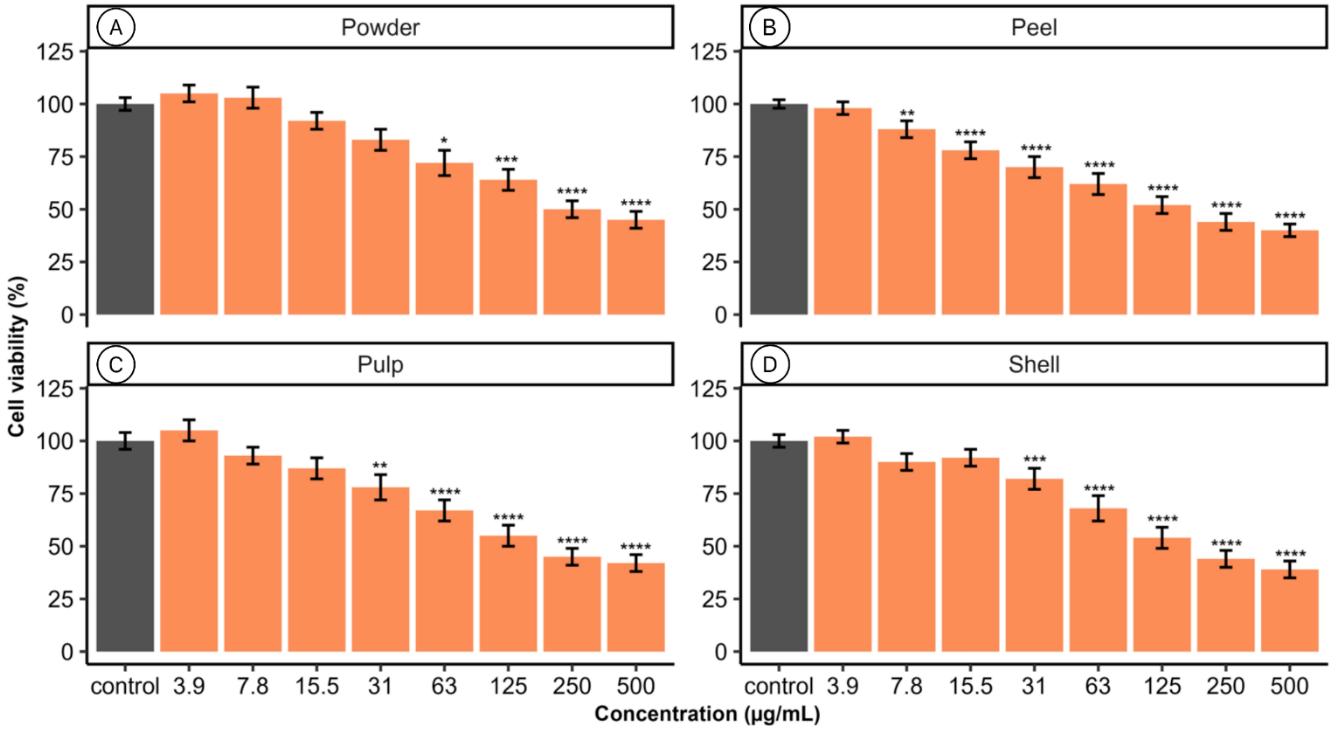


Figure 3. Cytotoxicity of fibroblasts (MRC5) exposed to guarana derivatives: guarana powder, guarana peel, guarana pulp, and guarana shell at concentrations ranging from 3.9 to 500 µg/mL – negative control, 0.5% DMSO for 72 hours. The dose-response reaction was performed using Alamar Blue®. Statistical analysis was conducted using Two-way ANOVA and Tukey's test – $p < 0.05$. Asterisks denote significant differences (**$p<0.05$; ***$p<0.01$; ****$p<0.001$) when compared with negative control.

In Figure 3A, it can be seen that guarana powder showed a significant reduction in viability at concentrations of 125 to 500 µg/mL, resulting in a CC_{50} of 214.1 ± 30.5 µg/mL. However, Figure 3B shows that guarana peel induced cytotoxicity at most concentrations tested (≥ 7.8 µg/mL), with a CC_{50} of 178.5 ± 17.0 µg/mL. In Figure 3C, it can be seen that guarana pulp reduced cell viability from 63 to 500 µg/mL, resulting in a CC_{50} of 187.3 ± 15.7 µg/mL. On the other hand, guarana peel presented a toxicity profile comparable to the other fractions, with CC_{50} of 202.0 ± 24.7 µg/mL (Figure 3D).

Total Phenolic Content

The total phenolic content of guarana derivatives at a concentration of 500 µg/mL is presented in Figure 4.

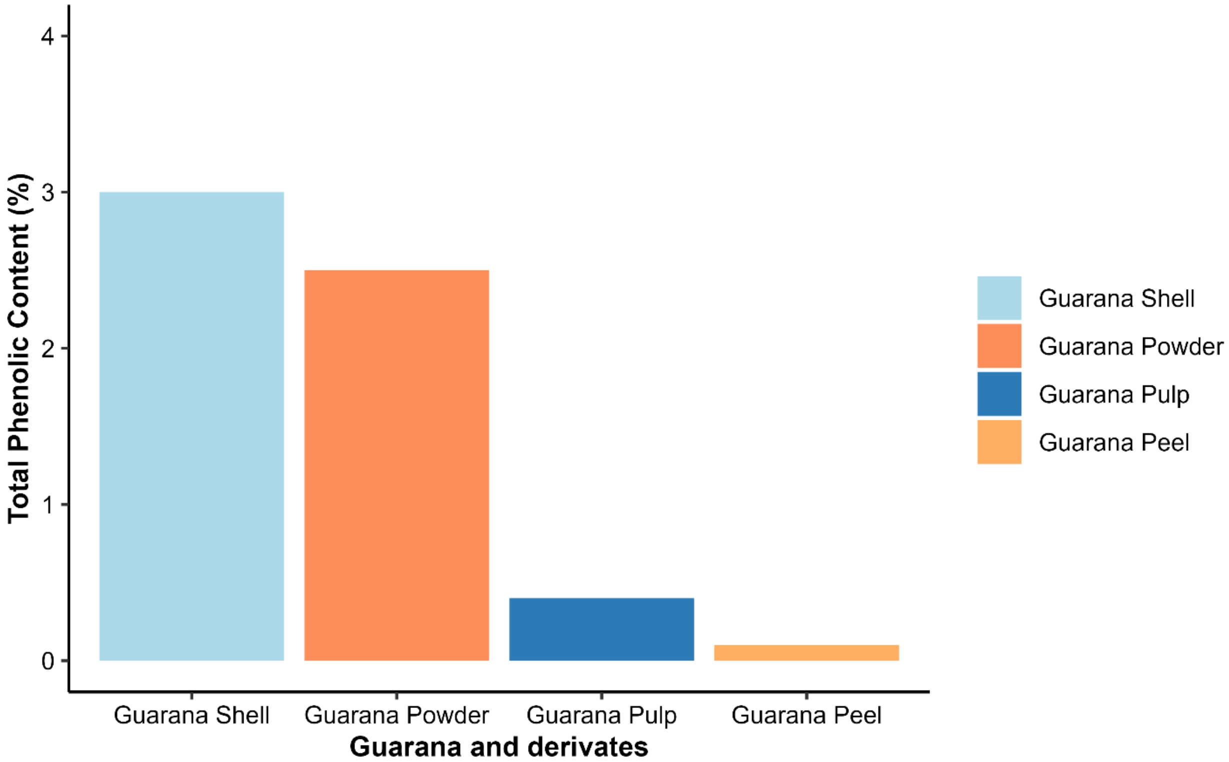


Figure 4. Total phenolic content of guarana derivatives—powder, pulp, peel, and shell—at 500 µg/mL. Data are presented as mean ± SEM (n = 3).

At 500 µg/mL, guarana shell exhibited the highest phenolic content (3.0 ± 0.2 % GAE), followed by guarana powder (2.5 ± 0.1 % GAE). Both were significantly greater than guarana pulp (0.4 ± 0.05 % GAE) and guarana peel (0.1 ± 0.02 % GAE) ($p < 0.05$). No significant difference was observed between shell and powder ($p > 0.05$). These data suggest that the processing methods yielding the powder and shell fractions preserve phenolic compounds more effectively than those producing the pulp and peel by-products.

DISCUSSION

Safety Profile Based on Cytotoxicity Assessment

The cytotoxicity results revealed that all guarana derivatives exhibited relatively low toxicity at moderate concentrations, with CC_{50} values ranging from 178.5 to 214.1 µg/mL. These values are considerably higher than those typically associated with highly toxic substances, suggesting that guarana derivatives can be safely incorporated into animal feeds at appropriate inclusion levels.

The observed cytotoxicity profile aligns with previous research by Santos et al. (2024), which demonstrated that inclusion of *P. cupana* peel meal (PCPM) at levels up to 10% in slow-growing broiler diets did not adversely affect health parameters, in that study, broilers fed diets containing PCPM showed normal hematological and serum biochemical parameters, with some beneficial effects observed, such as decreased blood triglyceride levels. Similarly, Behera et al. (2019) found that supplementation with citrus residues up to 5% of cholesterol and triglycerides improved the antioxidant status in broiler chickens.

The relatively higher CC_{50} value of guarana powder (214.1 ± 30.5 µg/mL) compared to other derivatives suggests that it may have the most favorable safety profile. However, all derivatives showed acceptable safety levels, indicating that various guarana by-products could potentially be utilized in animal nutrition with minimal risk of toxicity when used at appropriate inclusion rates. Studies show that guarana powder is safe when used correctly (Roggia et al., 2020; Patrick et al., 2019). Furthermore, laboratory tests indicate that its possible toxic effect depends on the quantity: in moderate doses, there is no risk (Santa Maria et al., 1998).

Furthermore, research on the infusion of Plectranthus barbatus leaves revealed toxic, cytotoxic and genotoxic effects on Allium cepa root meristems, including inhibition of root growth, decreased mitotic index and chromosomal aberrations (Bezerra & Oliveira, 2016). The antimicrobial peptide P34, isolated from an Amazonian fish, showed different levels of toxicity in several cell lines, with RK13, MDBK and MDCK cells tolerating higher concentrations (Fernandes et al., 2016). Cytotoxicity assessments are crucial for initial biocompatibility assessments, but have limitations in clinical correlations (Heggendorn et al., 2020).

Total Phenolic Content and Its Implications

The analysis of total phenolic content revealed that guarana powder and shell contained the highest levels of phenolic compounds among the derivatives tested. Phenolic compounds are known for their potent antioxidant properties and potential health benefits (Shahidi and Ambigaipalan, 2015; Arnoso et al., 2019; González-Barraza et al., 2017), making them valuable components in functional feed animal ingredients (Jiang et al., 2024).

The high phenolic content observed in guarana powder correlates with its superior antioxidant activity, suggesting that phenolic compounds are major contributors to the antioxidant properties of guarana derivatives. This finding is consistent with previous research on guarana, which has identified various phenolic compounds, including catechins, epicatechins, and proanthocyanidins, as key bioactive constituents (Santos et al., 2024; Rocha et al., 2024)

The presence of these bioactive compounds in guarana derivatives may confer additional functional benefits beyond their antioxidant properties. Phenolic compounds have been associated with various biological activities, including anti-inflammatory, antimicrobial, and immunomodulatory effects (Shahidi and Ambigaipalan, 2015; Silva et al., 2019), which could contribute to improved animal health and performance when incorporated into feeds.

Studies demonstrate their potential in the prevention and treatment of diseases such as diabetes, obesity, and cancer. The bioavailability of these compounds is crucial for their effectiveness and depends on factors related to food and physiology in humans (Arnoso et al., 2019). Some phenolic compounds, such as flavonoids and tannins, can act as agents that modify bacterial resistance, enhancing the action of antibiotics against resistant Staphylococcus aureus (Miklasińska-Majdanik et al., 2018). Although promising, it is important to consider that high concentrations of phenolic compounds can pose risks to the body, highlighting the need for further studies on their therapeutic use (Vargas & Bellaver, 2022).

Implications for Sustainable Animal Production

The utilization of guarana by-products as alternative feed ingredients not only provides a solution for agricultural waste management but also offers potential functional benefits for animal health and performance. The incorporation of guarana derivatives into animal feeds aligns with the principles of circular economy and sustainable resource use (Santos et al., 2024), as it transforms what would otherwise be waste materials into valuable feed ingredients (Georganas et al., 2023). This approach can contribute to reducing the environmental footprint of animal production by decreasing reliance on conventional feed ingredients that compete with human food production (Pérez-Palencia and Bolívar-Sierra, 2023; Souza et al., 2024).

Moreover, the functional properties of guarana derivatives, particularly their antioxidant activity and high phenolic content, suggest that they may confer additional health benefits beyond basic nutrition. This aspect is increasingly important in modern animal production systems, which aim to reduce the use of antibiotics and other synthetic additives by incorporating natural functional ingredients that promote animal health and welfare (Casillo-López et al., 2017; Almeida et al., 2022).

CONCLUSION

The cytotoxicity assessment demonstrated that guarana derivatives exhibit relatively low toxicity at moderate concentrations, with CC_{50} values ranging from 178.5 to 214.1 µg/mL. At the same time, the total phenolic content analysis showed that guarana powder and shell contain the highest levels of phenolic compounds.

The correlation between low cytotoxicity and high phenolic content provides a mechanistic explanation for the beneficial effects observed in vivo, strengthening the scientific basis for using guarana by-products as alternative feed ingredients. This strategy aligns with the growing demand for sustainable and functional animal feeds that contribute to enhanced production efficiency, improved product quality, and responsible environmental stewardship. Future research should focus on optimizing inclusion levels of different guarana derivatives in animal diets, investigating their effects on specific aspects of animal health and performance, and exploring potential synergistic effects with other feed ingredients.

Data availability

The data of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors have no conflicts of interest to declare.

Declaration of funding

None.

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REFERENCES

1. Almeida, A.A.; Valentim, J.K.; Oliveira, H.F.; Zanella, J.; Mendes, J.P.; Oliveira, G.C.; Geraldo, A.; Silva, A.F. Sustainable performance improveers in the quail diet. Vet. e Zootec. 2022; v29: 001-011. https://doi.org/10.35172/rvz.2022.v29.701

2. Arnoso, B.J.M.; Costa, G.F.; Schmidt,B. Bioavailabilityandclassificationofphenoliccompounds. Nutrição Brasil;18(1);39-48, 2019. https://doi.org/10.33233/nb.v18i1.1432

3. Ajila, C.M.; Aalami, M.; Leelavathi, K.; Rao, U.P. Mango peel powder: A potential source of antioxidant and dietary fiber in macaroni preparations. *Innov. Food Sci. Emerg. Technol.* 2010, *11*, 219-224. https://doi.org/10.1016/j.ifset.2009.10.004

4. Arnoso, B.J.M.; da Costa, G.F.; Schmidt, B. Bioavailability and classification of phenolic compounds. *Nutr Bras*, 2019;18(1);39-48. https://doi.org/10.33233/NB.V18I1.1432

5. Behera, D.P.; Sethi, A.P.S.; Singh, C.; Singh, U.; Wadhwa, M. Effect of citrus waste on blood parameters of broiler birds with and without cocktail of enzymes, Veterinary World. 2019; 12(4):483-488.

6. Bezerra, C. M.; Silva Oliveira, M. A. Avaliação da toxicidade, citotoxicidade e genotoxicidade do infuso de malva-santa (*Plectranthus barbatus* - LAMIACEAE) sobre o ciclo celular de Allium cepa. Revista Eletrônica de Farmácia, Goiânia, v. 13, n. 4, p. 220–228, 2016. https://doi.org/10.5216/ref.v13i4.36887

7. Castillo-López, R. I.; Gutiérrez-Grijalva, E. P.; Leyva-López, N.; López-Martínez, L. X. and Heredia, J. B. Natural alternatives to growth-promoting antibiotics (GPA) in animal production. The Journal of Animal & Plant Sciences, 27(2): 2017, 349-359.

8. Fernandes, M. H. V.; Silva, D. S. e.; Castro, C. C. de.; Corrêa, R. A.; Vargas, G.D.; Fischer, G.; Motta, A. de S. da.; & Hübner, S. de O. (2016). Avaliação da citotoxicidade do peptídeo antimicrobiano P34. *Science and Animal Health*, *1*(1), 02-10. https://doi.org/10.15210/sah.v1i1.368

9. Fonseca Júnior, E.Q.; Façanha da Silva, G.; Maquiné, L.V.; Monteiro, Y.M.; Gurgel, R.S.; Aranha, E.S.P.; Vasconcellos, M.C.; Albuquerque, P.M. Photoprotective, antioxidant, antimicrobial and cytotoxic activities of guarana (Paullinia cupana) seed extracts. *Int. J. Pharm. Nutr. Ind.* 2020, *7*, 10. https://doi.org/10.15171/IJPNI.2020.10

10. Georganas, A.; Giamouri, E.; Pappas, A.C.; Zoidis, E.; Goliomytis, M.; Simitzis, P. Utilization of Agro-Industrial By-Products for Sustainable Poultry Production. Sustainability 2023, 15, 3679. https://doi.org/10.3390/su1504367

11. González-Barraza, L.; Díaz-Godínez, R.; Castillo-Guevara, C.; Nieto-Camacho, A.; Méndez-Iturbide, D. Phenolic compounds: presence, identification and antioxidant activity in plants and fruits. *Mexican Journal of Biotechnology.* 2017: January-June v. 2, n. 1. https://doi.org/10.29267/mxjb.2017.2.1.46

12. Heggendorn, F. L.; Gonçalves, L. de S.; Cardoso, E. A.; Lutterbach, M. T. S.; & Lione, V. de O. F. Testes de biocompatibilidade: cultivo de células animais e suas aplicações em estudos de toxicidade. *Conexão Ciência (Online)*, *15*(1), 67–77, 2020. https://doi.org/10.24862/cco.v15i1.1001

13. Horszwald, A.; Andlauer, W. Characterisation of bioactive compounds in berry juices by traditional photometric and modern microplate methods. *J. Berry Res.* 2011, *1*, 189-199.

14. Jiang, Z.; Jiang, S.; Yang, H.; Lin, Y.; Zheng, C. Effects of Complex Antioxidants Added to Chicken Diet on Growth Performance, Meat Quality, Antioxidant Capacity, and Intestinal Microbiota. *Animals* 2024, *14*, 360. https://doi.org/10.3390/ani14030360

15. Lemes, A.C.; Egea, M.B.; Oliveira Filho, J.G.; Gautério, G.V.; Ribeiro, B.D.; Coelho, M.A.Z. Biological Approaches for Extraction of Bioactive Compounds From Agro-industrial By-products: A Review. *Front. Bioeng. Biotechnol.* 2022, *9*, 802543. https://doi.org/10.3389/fbioe.2021.802543

16. Madison, P.; Kim, H.A.; Oketch-Rabah, H.; Marles, R.J.; Roe, A.L.; Calderón, A.I. Safety of Guarana Seed as a Dietary Ingredient: A Review. *J. Agric. Food Chem.* 2019, *67*, 11281-11287. https://doi.org/10.1021/acs.jafc.9b03781

17. Mensor, L.L.; Menezes, F.S.; Leitão, G.G.; Reis, A.S.; dos Santos, T.C.; Coube, C.S.; Leitão, S.G. Screening of Brazilian plant extracts for antioxidant activity by the use of DPPH free radical method. *Phytother. Res.* 2001, *15*, 127-130.

18. Miklasinska-Majdanik, M.; Kepa, M.; Wojtyczka, R.D.; Idzik, D.; Wasik, T.J. Phenolic Compounds Diminish Antibiotic Resistance of Staphylococcus Aureus Clinical Strains. Int. J. Environ. Res. Public Health, 15, 2321; 2018. https://doi.org/10.3390/ijerph15102321

19. Nakayama, G.R.; Caton, M.C.; Nova, M.P.; Parandoosh, Z. Assessment of the Alamar blue assay for cellular growth and viability in vitro. *J. Immunol. Methods* 1997, *204*, 205-208.

20. Nesterov, I.; Barrera-Martínez, C.; Martínez-Sánchez, A.; Sandoval-González, E.; Bustos. Approaching the circular economy: Biological, physicochemical, and electrochemical methods to valorize agro-industrial residues, wastewater, and industrial wastes.Journal of Environmental Chemical Engineering, Volume 12, Issue 5, 2024. https://doi.org/10.1016/j.jece.2024.113335.

21. Patrick, M.; Kim, HA.; Oketch-Rabah, H.; Marles, R.J.; Roe, A.L.; Calderón, A.I. Safety of Guarana Seed as a Dietary Ingredient: A Review. J Agric Food Chem. 2019, Oct 16;67(41):11281-11287. https://doi: 10.1021/acs.jafc.9b03781. Epub 2019 Oct 3. PMID: 31539257.

22. Pérez-Palencia, J. Y.; y Bolívar-Sierra, A. F. Alternative feedstuffs in combination with enzyme supplementation to improve efficiency and sustainability of swine and poultry production. Orinoquia. 2023, 27(1), e–787. https://doi.org/10.22579/20112629.787

23. Pinho, L.S.; da Silva, M.P.; Thomazini, M.; Cooperstone, J.L.; Campanella, O.H.; da Costa Rodrigues, C.E.; Favaro-Trindade, C.S. Guaraná (Paullinia cupana) by-product as a source of bioactive compounds and as a natural antioxidant for food applications. *J. Food Process. Preserv.* 2021, *45*, e15854. https://doi.org/10.1111/jfpp.15854

24. Rocha, C.A.M.; Santana, G.M.; Santos, H.M.; de Jesus, R.M.; Lôbo, I.P. Comprehensive evaluation of methylxanthines and phenolic compounds in Bahia's guarana (Paullinia cupana), Brazil: implications for variety selection and by-product utilization. *Food Sci. Technol.* 2024, *44*. https://doi.org/10.5327/fst.00064

25. Roggia, I.; Dalcin, A.J.F.; de Souza, D.; Machado, A.K.; de Souza, D.V.; da Cruz, I.B.M.; Ribeiro, E.E.; Ourique, A.F.; Gomes, P. Guarana: Stability-Indicating RP-HPLC method and safety profile using microglial cells. *Journal of Food Composition and Analysis*, V. 94, 2020, 103629. https://doi.org/10.1016/j.jfca.2020.103629.

26. Santa Maria, A.; Lopez, A.; Diaz, M.M.; Muñoz-Mingarro, D.; Pozuelo, J.M. Evaluation of the toxicity of guarana with in vitro bioassays. Ecotoxicol Environ Saf. 1998, Mar;39(3):164-7. https://doi: 10.1006/eesa.1997.1576. PMID: 9570905.

27. Santos, F.A.L.; Alves, F.S.; Do Rego, J.A.R. Aplicação de sementes de açaí (euterpe oleracea) na produção de rações – um conceito de sustentabilidade na cadeia nutricional animal. **ARACÊ** , *[S. l.]* , v. 3, pág. 11143–11163, 2025. https://doi.org/10.56238/arev7n3-061

28. Santos, A.N.A.; Rufino, J.P.F.; Viana, A.L.; Guimarães, C.C.; Gomes, M.F.S.; Barai, A.A.; Nóbrega, T.C.; Ribeiro, M.W.S.; Silva, A.J.I.; Chaves, F.A.L.; et al. Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. *Anim. Prod. Sci.* 2024, *64*, AN24137. https://doi.org/10.1071/AN24137

29. Santos, G.A.N.; Schimpl, F.C.; Ribeiro, M.D.; Filho, C.S.; Valente, M.; Silva, J.F. Methylxanthine and polyphenol distribution in guarana cultivars. *Sci. Plena* 2024, *20*, 061503. https://doi.org/10.14808/sci.plena.2024.061503

30. Schimpl, F.C.; da Silva, J.F.; Gonçalves, J.F.; Mazzafera, P. Guarana: revisiting a highly caffeinated plant from the Amazon. J Ethnopharmacol. 2013 Oct 28;150(1):14-31. https://doi.org/10.1016/j.jep.2013.08.023

31. Silva, C.P.; Soares-Freitas, R.A.M.; Sampaio, G.R.; et al. Guarana as a source of bioactive compounds. *Journal of Food Bioactives*. 2019, 6: 1-5. https://doi.org/10.31665/JFB.2019.6182

32. Souza, T. de.; Rufino, J. P. F.; Dias, P. G.; Souza, L. F. de; Araújo, K. F. de.; & Machado, N. de J. B. Use of regional alternative feeds in poultry diets in the Amazon rainforest. OBSERVATÓRIO DE LA ECONOMÍA LATINOAMERICANA. 2024, 22(12), e8447. https://doi.org/10.55905/oelv22n12-287

33. Shahidi, F.; Ambigaipalan, P. Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects – A review. *J. Funct. Foods.* 2015, *18*, 820-897. https://doi.org/10.1016/j.jff.2015.06.018

34. Surai, P.F. Antioxidant Systems in Poultry Biology: Superoxide Dismutase. *J. Anim. Res. Nutr.* 2016, *1*, 8. https://doi.org/10.21767/2572-5459.100008

35. Vargas, G.C.; Bellaver, E.H. Study of the antioxidant activity of phenolic compounds in preventive medicine: Literature Review. Visão Acadêmica, Curitiba, v.23 n.1, Jan. - Mar. 2022.

36. Khairi, F.; Maharani, Cl.; & Aditya, F.A. Sustainable Livestock Management: Strategies for Enhancing Productivity While Reducing Environmental Impact. The Journal of Academic Science. 2025, 2. 382-391. https://doi.org/10.59613/efybvy75.

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CHAPTER 5: *Paullinia cupana* peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers

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Short-title: *Paullinia cupana* meal on broiler growth & quality

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Abstract

Context: Animal feed production systems have been suffering from a shortage of feedstuffs due to competition for these resources with human food consumption. The use of by-products can increase efficiency and circularity in production chains, reducing this competition. **Aims:** This study investigated the impacts of *Paullinia cupana* peel meal (PCPM) on the growth performance, meat quality, and hematological and serum biochemical parameters of slow-growing broilers. **Methods:** Two hundred and forty slow-growing male Label Rouge broilers were distributed in a completely randomized experimental design. The treatments consisted of inclusion levels of PCPM (0%, 2.5%, 5.0%, 7.5%, and 10%) in the diets, with four replicates of 12 birds each. Growth performance data, and hematological and serum biochemical parameters were monitored. Twelve broilers per treatment were slaughtered to meat quality analysis. **Key results:** In the starter stage, there was a significant increase ($p<0.05$) in feed intake and weight gain with increasing PCPM levels in the diets. However, this effect diminished in the final stage. Even with a reduction ($p<0.05$) in feed intake during the final stage, the broilers showed an increase ($p<0.05$) in weight gain and improvement ($p<0.05$) in feed efficiency in the cumulative performance. Broilers fed higher PCPM levels in the diets had lower ($p<0.05$) concentrations of erythrocytes and blood triglycerides, as well as a decreased hematocrit percentage. However, these broilers exhibited higher ($p<0.05$) results for MCH and MCHC. Broilers fed higher PCPM levels in the diets were heavier ($p<0.05$) at slaughter, with higher ($p<0.05$) carcass yield, greater ($p<0.05$) liver, gizzard, and heart weight, increased breast, drumstick, and thigh yields, and higher moisture and lipid contents in the breast. **Conclusions:** The high inclusion levels of PCPM in diets for slow-growing broilers positively impacts growth performance, meat quality, and yields of valuable cuts, though it increases moisture and decreases protein in breast meat, affecting some blood parameters. **Implications:** This study emphasizes the potential advantages of using PCPM as an alternative food in diets for slow-growing broilers to improve the productivity and health of a sustainable livestock.

Keywords: alternative food, Amazon, feed efficiency, poultry science, sustainability.

INTRODUCTION

he current structure of the global food system presents a suboptimal availability of feedstuffs for animal feed, as many resources are being used for human consumption (Mottet et al., 2017; Sandström et al., 2022). In this context, the use of by-products and crop residues from food production chains as feedstuffs in animal diets has been proposed to meet this demand and improve the efficiency of these production chains (Van Kernebeek et al., 2016; Röös et al., 2017), consequently reducing competition for food (Van Zanten et al., 2018), promoting the concept of a circular economy in these chains (Van Hal et al., 2019; Billen et al., 2021), and causing an economically beneficial due to their potential widespread availability and low cost (Yang et al., 2021).

Rufino et al. (2015), Cruz et al. (2016), Monteiro et al. (2024), Clement et al. (2024), and Rosenfeld et al. (2024) identified the Brazilian Amazon and its production chains as a notable case where this scenario frequently occurs, with a wide variety of native species being exploited for their economic, technological, and nutritional potential, generating residues that can be used in animal feed. Among these, *Paullinia cupana* stands out due to its great nutritional properties, including volatile and fixed constituents, starch, protein, tannins, and caffeine (Sousa et al., 2010; Santana et al., 2018; Hack et al., 2023), in addition to the fact of its processing yields organic residues with biological potential for reuse.

Paullinia cupana, also popularly known as guaraná, guaraná-da-amazônia, guaranaina, guaranauva, uarana, or narana, is an Amazon native plant of the *Sapindaceae* family. It exhibits vigorous growth, with branches reaching up to 10 m in height, produces capsule-format fruits with septicidal dehiscence and a developed peduncle. The fruit starts with a dark green color and matures to shades ranging from yellow-orange to bright red. The seeds are covered by thick white films (Schimpl et al., 2013; Filoche and Pinton, 2014; Pinho et al., 2021). Currently, *Paullinia cupana* plays a significant role in Latin America agribusiness, where Brazil is the world's largest producer, catering to major markets like the US, EU, Japan, and China (Ferreira et al., 2021; Pinho et al., 2021).

From this, it was hypothesized that the use of *Paullinia cupana* peel meal (PCPM) could be employed as an alternative food in diets for slow-growing broilers due to the rich nutritional properties of *Paullinia cupana* and its potential in produce a considerable volume of residues after the processing (Cruz and Rufino, 2017; Oliveira, 2018; Ali et al., 2021). This approach, paired with sustainable animal production practices like using breeds with slightly reduced growth or productivity but with proportional growth and better environmental adaptability, contributes to the emerging green revolution in animal production (Schader et al., 2015; Van Hal et al., 2019; Vastolo et al., 2022). Based on this information, the present study was conducted to investigate the impacts of *Paullinia cupana* peel meal (PCPM) on the growth performance, meat quality, and hematological and serum biochemical parameters of slow-growing broilers.

MATERIAL AND METHODS

Acquisition and composition analysis of PCPM

Paullinia cupana residues were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The entire process of processing *Paullinia cupana*, obtaining its by-products, and processing these by-products to obtain PCPM followed these steps: 1) The ripe *Paullinia cupana* fruits were manually harvested; 2) the collected fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) the fruits were separated into seeds and peels; 4) the peels were set aside as residues; 5) the seeds were processed for the extraction of *Paullinia cupana* extract, which is used in the production of carbonated beverages by the beverage industry; 6) the *Paullinia cupana* peels underwent a drying process in a closed-circulation oven at a temperature of 105°C (221°F) for 24 hours; 7) the dried *Paullinia cupana* peels were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); and 8) the final product, called PCPM, was bagged and stored in a dry and airy place to be used in the preparation of experimental diets. It is important to highlight that the yield of PCPM relative to the raw product (peels before drying) was 84.32%.

To determine the price of the feeds and production costs, only the per-kilogram values of the feedstuffs used and their updated prices in the region during the experiment were considered. These were: corn, $1.66; soybean meal, $3.65; limestone, $0.73; dicalcium phosphate, $4.50; salt, $0.83; DL-Methionine 99%, $51.00; and $28.35/kg (average price) for mineral and vitamin supplements (F1 - initial; F2 - final). For the calculation of PCPM costs, only transportation and handling expenses (labor) were considered, estimating the price per kilogram of the product at $0.30. Fixed costs consisted of depreciation of facilities and equipment (maintenance, water, electricity, among others), with capital interest remaining unchanged in the short term and considered constant across all treatments. Variable costs included only expenses for bird feed and labor.

Before conducting the experiment, the proximate composition of PCPM (Table 1) was determined at the Fish Technology Laboratory of the Federal University of Amazonas (UFAM). The dry matter content was determined in an oven at 105 °C (221 °F) according to AOAC method 925.10 (2019); minerals content was determined by calcination in a muffle furnace at 550 °C (1022 °F) following AOAC method 923.03 (2019); lipid content analyses followed AOCS method Ba 3-38; total proteins were determined using the Kjeldahl method, following AOAC method 920.87 (2019); and the determination of fibers content (crude fiber, neutral detergent fiber (NDF) and acid detergent fiber (ADF)) was performed according to the methods described by Van Soest et al. (1991).

Table 1. *Paullinia cupana* peel meal composition.

Variables	Values
Dry matter, %	89.11
Crude protein, %	18.72
Fats, %	5.36
Minerals, %	5.33
Crude fiber, %	44.04
Neutral detergent fiber, %	61.34
Acid detergent fiber, %	33.33
Soluble carbohydrates, %	26.55

Gross energy, kcal/kg	6,752.61
Metabolizable energy*, kcal/kg	4,227.20[1]

* Determined by the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024)

Facilities, animals, diets and experimental design

The current experiment was conducted in an aviary with ceiling height of 3.25 m, with structural adaptations to improve bird welfare. Ventilation occurred naturally, with the aviary being fully surrounded by trees to ensure a pleasant and comfortable environment for the birds. The temperature and relative humidity were monitored using a small digital weather station, registering averages of 27.6 °C (81.68 °F) and 62.3%, respectively. Throughout the entire experimental period, the broilers were monitored for signs of thermal stress caused by the environment, a situation that was not observed during all this time. It is important to mention that the experiment was conducted during the rainy season in the Amazon, which occurs between November of one year and April of the following year, where temperatures are cooler and provide a pleasant environment for animal management.

Slow-growing male Label Rouge broilers (n = 240) produced by the incubation center of the Research Poultry Farm of UFAM were used. Initially, the 1-day-old broilers (43.57±0.59 g) were housed in a protective circle with wood shavings, tray-type feeders, and cup-type drinkers at a density of 50 birds/m^2, with a central electric heating source, until they reached 7 days old. With 8 days-old, the broilers were distributed in the experimental groups in pens measuring 4 m^2 each, equipped with tubular feeders, hanging drinkers, and wood shavings covering the floor. The experimental stages were divided into starter (8-28 days) and final (29-56 days). The birds had *ad libitum* access to feed and water during all the experimental period. A lighting program suitable for slow-growing broilers was used (Wu et al., 2022).

The experimental design was completely randomized, with treatments comprising a control diet (without PCPM) and four levels of PCPM inclusion (2.5%, 5.0%, 7.5%, and 10%) in the diets, with four replicates of 12 birds each. Experimental diets (Table 2) were formulated based on reference values reported by Rostagno et al. (2024), except for PCPM composition, which used values from prior product composition analyses performed in this study. The metabolizable energy value for PCPM was determined using method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024), where a small digestibility trial was conducted prior to the main experiment, with the collected feed and feces samples being analyzed in the laboratory.

PCPM was a fixed component in the diet calculations, with other ingredient values adjusted based on PCPM inclusion levels. Diets were formulated using SuperCrac software (TD Software©, Viçosa, Brazil). The composition of these diets was analyzed to confirm their proximate composition according to the methods described by the AOAC (2019), where moisture content was determined according to method 925.10; minerals content was determined following method 923.03; lipid content analyzes followed the method Ba 3-38; total proteins content was determined according to the method 920.87; and the determination of fibers content (crude fiber, NDF and ADF) was performed according to the methods described by Van Soest et al. (1991).

Table 2. Experimental diets composition.

Feedstuffs	Pre-starter (1 to 7 days)	Starter (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7.88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Paullinia cupana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Sodium chloride	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
VMS	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Price, $/kg	3.18	3.08	3.11	3.14	3.17	3.20	2.97	2.90	2.90	2.93	2.96
Nutrients	Guarantee levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF, %	12.07	12.07	11.73	11.37	11.01	10.65	11.84	11.52	11.22	10.87	10.51
ADF, %	4.97	4.97	4.88	4.79	4.70	4.60	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine, %	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine, %	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan, %	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[1] Vitamin/mineral supplement – starter – content in 1 kg of diet = Folic Acid 4 mg, Pantothenic Acid 62.500 mg, Antioxidant 0.0025 g, Biotin 0.2 mg, Niacin 168 mg, Selenium 1.5 mg, Vit. A 33.500 UI, Vit. B1 8.75 mg, Vit. B12 48 mcg, Vit. B2 24 mg, Vit. B6 12.5 mg, Vit. D3 8,000 UI, Vit. E 70 mg, Vit. K3 7.2 mg, Manganese 375 mg, Zinc 250 mg, Iron 250 mg, Copper 40 mg, Iodine 3.75 mg.

[2]Vitamin/mineral supplement – final – content in 1 kg of diet = Pantothenic Acid 35.35 mg, Antioxidant 0.0025 g, Niacin 102 mg, Selenium 1 mg, Vit. A 9,800 UI, Vit. B12 23.5 mcg, Vit. B2 12 mg, Vit. D3 2,750 UI, Vit. E 50 mg, Vit. K3 2.75 mg, Manganese 375 mg, Zinc 250 mg, Iron 250 mg, Copper 40 mg, Iodine 3.75 mg.

[3] Analyzed and calculated levels in Dry Matter.

Growth performance and meat quality

The growth performance of broilers was assessed both individually in each stage (initial and final) and in a cumulative way. The growth performance variables evaluated in this study included feed intake (kg/bird), weight gain (kg/bird), and feed efficiency (kg/kg). Feed intake for each stage was calculated by dividing the total feed consumed by the number of birds in each pen. Weight gain was determined by dividing the total pen weight by the number of birds, relative to the previous weighing. Feed efficiency was computed as the ratio of total feed consumed to weight gain. Combining data from all stages allowed for a comprehensive assessment of these parameters.

At 56 days of age, following a 12-hour fast, 12 birds from each treatment were randomly chosen for meat quality analysis. These birds were weighed, electrically stunned (40 V; 50 Hz), and slaughtered by cutting the jugular vein. Carcasses were then scalded in hot water (60 °C/140 °F for 62 s), plucked, and eviscerated following recommendations by Mendes and Patricio (2004) to determine carcass yield (%) and the yields of the main economically significant viscera (liver (g/bird), gizzard (g/bird) and heart (g/bird)) and foot (g/bird).

Commercial cuts (neck, breast, wing, back, thigh, and drumstick) were separated and weighed using an analytical balance (0.01 g), calculating their yields as a percentage relative to the clean carcass. Samples of breast meat from these carcasses were collected and immediately sent to the laboratory for determination of their proximate composition (percentages of moisture, minerals, fats, and proteins) determined according to the methods described by AOAC (2019).

Hematological and serum biochemical parameters

Before slaughter, the selected broilers, 12 per treatment, underwent blood collection. One milliliter of blood was collected from the broilers directly from the ulnar vein, using disposable syringes containing heparin anticoagulant (5000 IU per sample). These samples were immediately centrifuged at 7,000 rpm for 10 minutes to separate the red blood cells for evaluation of hematological parameters and the plasma used for analysis of serum biochemical parameters.

These samples were identified and preserved at -4 °C (24.8 °F) throughout the process to be sent to the laboratory. In the analysis of hematological parameters, the collected blood was used for the count of circulating erythrocytes (M/mm^3) using a Neubauer chamber after dilution in formaldehyde-citrate and toluidine blue, and visualized using an optical microscope

(Nikon Eclipse E-50i, DM3000, Tokyo, Japan) with a 40x objective lens.

The hemoglobin concentration (g/dL) was determined by the cyanomethemoglobin method, while the hematocrit (%) by the microhematocrit method (Goldenfarb et al., 1971), with centrifugation of heparinized microcapillary tubes at 12,000 rpm for 5 minutes (Aride et al., 2018). Through these analyses, the mean corpuscular volume (MCV, μm^3), mean corpuscular hemoglobin (MCH, pg/cell), and mean corpuscular hemoglobin concentration (MCHC, g/dL) were calculated according to Wintrobe (1934) and Tavares-Dias and Moraes (2004).

In the analysis of serum biochemical parameters, the remaining plasma samples after centrifugation were subjected to commercial enzymatic-colorimetric assay kits according to the manufacturer's specific recommendations, and the readings were taken on a mass spectrophotometer (model K37-UVVIS, Kasvi©, São José dos Pinhais, Brazil) at a specific wavelength for each assay. The biochemical parameters analyzed were the concentrations of total proteins, triglycerides, glucose, cholesterol, and albumin.

Statistical Analyses

The adopted statistical model was as follows:

$$Y_{ik} = \mu + \alpha_i + \epsilon_{ik}$$

where:

Y_{ik} = Observed value for the variable under study;

μ = Overall mean of the experiment;

α_i = Effect of the PCPM levels;

ϵ_{ik} = Experimental error.

All data were analyzed using the R software (2021), with commands executed according to Logan (2010). Initially, the data were subjected to one-way ANOVA (Analysis of Variance), with Tukey's Honest Significant Difference test applied at a 0.05 significance level. Subsequently, the results of significant variables ($p<0.05$) were also subjected to correlation and polynomial regression analysis to examine the influence of the independent variable (PCPM levels) on the dependent variables (Chatterjee; Hadi; Logan, 2010). The mathematical model, whether linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax^2$), was chosen based on criteria that determined which model best expressed the data behavior (Dormann et al., 2013), with R-squared values considered as one of these criteria (Chatterjee; Hadi, 2006; Dormann et al., 2013).

Ethics approval

The Animal Ethics Committee of Federal University of Amazonas approved the study under protocol number 010/2022. All animal manipulations were performed according to the Brazilian Code for the Care and Use of Animals for Scientific Purposes and reported in proportion to guidelines and regulations of Animal Research: Reporting of In Vivo Experiments (ARRIVE).

RESULTS

Growth performance

The growth performance analysis of slow-growing broilers in the starter stage indicated a significant effect ($p<0.05$) of PCPM inclusion on feed intake and weight gain (Table 3), with the increasing inclusion of PCPM causing a linear increase in these variables, that is, the 10% inclusion level of PCPM providing higher results. However, in the final stage, feed intake and feed conversion showed an opposite behavior, with the increasing inclusion of PCPM reducing ($p<0.05$) the broilers' feed intake, and the 10% inclusion level of PCPM providing better feed efficiency result. In this sense, weight gain in this stage increased ($p<0.05$) linearly as the inclusion of PCPM in the diets increased.

When observing the cumulative growth performance, it was found that the inclusion of PCPM did not significantly affect ($p>0.05$) the cumulative feed intake considering the entire evaluated period. However, the cumulative results of weight gain and feed conversion showed that these variables were significantly influenced ($p<0.05$) by the inclusion of PCPM, with weight gain increasing linearly and feed conversion improving as the levels of PCPM in the diets increased, that is, the 10% inclusion level of PCPM providing better cumulative weight gain and feed conversion results.

Table 3. Growth performance of slow-growing broilers fed diets containing *Paullinia cupana* peel meal[1].

Stage	Variables[2]	*Paullinia cupana* peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Starter	FI	1.43±0.13^{b}	1.48±0.15^{b}	1.69±0.28^{a}	1.71±0.16^{a}	1.74±0.03^{a}	<0.01	7.52	0.47	$Y = 1.44 + 0.034x$	0.87
	WG	0.87±0.09^{b}	0.94±0.06^{b}	0.98±0.02^{ab}	1.01±0.03^{a}	1.06±0.02^{a}	<0.01	2.33	0.42	$Y = 0.882 + 0.018x$	0.97
	FC	1.64±0.44	1.57±0.47	1.72±0.58	1.69±0.13	1.64±0.06	0.10	8.28	-	-	-
Final	FI	2.95±0.36^{a}	3.01±0.32^{a}	2.98±0.46^{a}	3.01±0.36^{a}	2.63±0.19^{b}	0.05	12.64	-0.08	$Y = 2.9269 + 0.0681x - 0.0094x^2$	0.85
	WG	1.03±0.14^{b}	1.04±0.11^{b}	1.01±0.03^{b}	1.03±0.04^{b}	1.16±0.01^{a}	0.05	10.69	0.20	$Y = 1.004 + 0.01x$	0.43
	FC	2.86±0.38^{a}	2.89±0.45^{a}	2.95±0.67^{a}	2.92±0.55^{a}	2.27±0.06^{b}	0.05	4.59	-0.36	$Y = 2.8049 + 0.1197x - 0.0166x^2$	0.86
General	FI	4.38±0.28	4.49±0.45	4.67±0.74	4.72±0.34	4.37±0.03	0.09	5.35	-	-	-
	WG	1.90±0.24^{b}	1.98±0.18^{b}	1.99±0.06^{b}	2.04±0.07^{ab}	2.22±0.02^{a}	<0.01	4.69	0.29	$Y = 1.886 + 0.028x$	0.85
	FC	2.31±0.10^{a}	2.27±0.45^{a}	2.35±0.61^{a}	2.31±0.22^{a}	1.97±0.02^{b}	<0.01	4.58	-0.34	$y = 2.262 + 0.058x - 0.0083x^2$	0.81

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FC = Feed conversion (kg/kg).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variabl

Hematological and serum biochemical parameters

In the results of hematological parameters (Table 4), higher levels of PCPM inclusion in the diets led to a reduction ($p<0.05$) in the concentration of erythrocytes and the percentage of hematocrit in the evaluated slow-growing broilers. In contrast, there was a significant increase ($p<0.05$) in the results of MCH and MCHC in these broilers. In the results of serum biochemical parameters (Table 4), only the concentration of triglycerides was significantly influenced ($p<0.05$) by the inclusion of PCPM in the diets, where the higher levels of PCPM in the diets caused a linear reduction in blood triglycerides concentration.

Meat yield and quality

The slaughter weight and carcass yield (Table 5) of slow-growing broilers were significantly influenced ($p<0.05$) by the inclusion of PCPM in the diets, where higher levels of PCPM in the diets, especially the 7.5% and 10% inclusion levels, resulted in heavier (>2kg) broilers at slaughter and with higher carcass yield (>79%). Similarly, as the levels of PCPM inclusion in the diets increased, occurred a linear increase ($p<0.05$) in the weights of the liver, gizzard, and heart of the evaluated slow-growing broilers, where the 7.5% and 10% inclusion levels provided better results.

Evaluating the commercial cuts (Table 5), as the levels of PCPM inclusion in the diets increased, slow-growing broilers showed higher ($p<0.05$) breast, thigh, and drumstick yields, however, these broilers exhibited proportionally lower ($p<0.05$) yields of back, wings, and neck. In the proximate composition of the breasts (Table 6), it was observed that the moisture and lipid contents increased linearly ($p<0.05$) as the levels of PCPM in the diets of slow-growing broilers increased. Conversely, there was a linear reduction ($p<0.05$) in the mineral and protein contents of these broilers' breasts.

Table 4. Hematological and serum biochemical parameters of slow-growing broilers fed diets containing *Paullinia cupana* peel meal[1].

Analysis	Variables[2]	*Paullinia cupana* peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Hematol.	HEMOG	10.61±1.81	10.87±1.55	9.79±1.51	9.75±1.28	10.48±1.54	0.16	15.33	-	-	-
	ERI	3.00±0.07[a]	3.00±0.09[a]	2.90±0.21[a]	2.97±0.15[a]	2.21±0.16[b]	<0.01	12.05	-0.35	$Y = 2.9451 + 0.0899x - 0.0154x^2$	0.83
	HEMAT	29.75±1.57[a]	30.25±2.23[a]	30.18±2.53[a]	29.81±2.21[a]	28.12±1.75[b]	0.03	7.37	-0.13	$Y = 29.764 + 0.2654x - 0.0348x^2$	0.98
	MCV	99.19±6.70[c]	100.99±8.97[b]	104.24±10.42[b]	100.57±14.41[b]	127.83±6.97[a]	<0.01	13.61	0.29	$Y = 98.772 + 1.9366x - 0.2188x^2$	0.74
	MCH	35.40±6.22[b]	36.25±5.01[b]	33.69±4.27[b]	44.18±5.45[a]	35.41±5.82[b]	<0.01	17.41	0.17	$Y = 36.223 - 1.9408x + 0.3856x^2$	0.79
	MCHC	35.66±5.62	36.11±5.47	32.42±3.51	34.98±5.92	35.36±6.36	0.35	15.72	-	-	-
Biochem.	TP	3.15±0.40	3.54±0.56	3.53±0.38	3.26±0.61	4.72±0.88	0.17	8.78	-	-	-
	TRI	134.63±99.77[a]	100.97±23.11[b]	57.25±11.40[c]	54.13±19.50[c]	40.25±21.20[c]	<0.01	7.93	-0.44	$Y = 129.53 - 11.409x$	0.91
	GLU	230.88±35.95	219.97±52.80	214.34±35.52	227.92±57.52	224.43±26.94	0.94	8.54	-	-	-
	CHO	189.46±52.16	175.28±50.13	195.12±42.22	192.66±48.65	189.03±64.25	0.38	2.89	-	-	-
	ALB	3.12±0.70	2.64±0.60	3.40±0.80	3.20±0.44	3.36±0.71	0.20	2.23	-	-	-

[1] All data represent the average of 12 replicates (broilers) per treatment.

[2] HEMOG = Hemoglobin (g/dL). ERI = RBC erythrocytes (M/mm^3). HEMAT = Hematocrit (%). MCV = Mean Corpuscular Volume (um^3). MCH = Mean Corpuscular Hemoglobin (pg/cel). MCHC = Mean Corpuscular Hemoglobin Concentration (g/dL). TP = Total Proteins (g/dL). TRI = Triglycerides (mg/dL). GLU = Glucose (mg/dL). CHO = Cholesterol (mg/dL). ALB = Albumin (mg/dL).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.
[6] MM = Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variable.

Table 5. Meat quality of slow-growing broilers fed diets containing *Paullinia cupana* peel meal[1].

Variables[2]	*Paullinia cupana* peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
SW	1.91±0.29[b]	1.98±0.14[b]	1.99±0.07[b]	2.05±0.09[ab]	2.23±0.12[a]	<0.01	4.69	0.34	$Y = 1.89 + 0.0284x$	0.85
CY	76.10±4.02[b]	73.93±1.27[b]	77.99±2.57[b]	80.31±1.22[a]	79.19±1.21[a]	0.01	4.02	-0.18	$Y = 74.992 + 0.5024x$	0.61
FO	4.34±0.44	4.56±0.33	4.98±0.27	4.82±0.42	4.34±0.28	0.08	8.97	-	-	-
LI	18.33±0.94[b]	18.00±1.63[b]	19.33±3.37[b]	22.00±1.80[a]	25.00±2.58[a]	0.02	1.63	0.31	$Y = 17.064 + 0.6936x$	0.86
GI	42.50±2.79[b]	44.83±4.26[b]	47.50±1.37[ab]	44.83±5.57[b]	51.66±3.37[a]	0.03	10.13	0.56	$Y = 42.6 + 0.7328x$	0.68
HE	6.22±1.92[c]	7.50±0.63[b]	7.16±1.43[b]	8.00±1.91[b]	9.50±1.37[a]	0.05	2.86	0.51	$Y = 6.264 + 0.2824x$	0.85
BR	23.83±5.79[b]	25.86±4.68[b]	28.01±2.27[ab]	30.40±3.35[a]	31.20±4.38[a]	<0.01	9.20	0.08	$Y = 24.004 + 0.7712x$	0.98
DR	15.31±3.68[b]	16.46±1.92[b]	17.13±0.64[b]	19.05±1.55[b]	21.07±2.19[a]	<0.01	12.01	0.07	$Y = 14.982 + 0.5644x$	0.96
TH	15.66±4.82[b]	16.13±1.53[b]	18.03±1.34[a]	19.07±1.41[a]	20.77±2.87[a]	<0.01	12.80	0.20	$Y = 15.3 + 0.5264x$	0.97
BA	22.23±5.09[a]	22.21±4.85[a]	18.10±3.96[b]	14.02±2.21[c]	12.50±3.53[c]	0.03	12.24	0.09	$Y = 23.342 - 1.106x$	0.93
WI	14.44±2.67[a]	10.82±2.01[b]	9.79±0.87[b]	9.31±2.34[b]	6.99±1.30[c]	<0.01	6.82	0.19	$Y = 13.552 - 0.6564x$	0.90
NE	8.53±1.70[a]	8.52±0.83[a]	8.94±0.37[a]	8.15±0.46[a]	7.47±0.87[b]	<0.01	9.23	-0.01	$Y = 8.4557 + 0.1918x - 0.0291x^2$	0.88

[1] All data represent the average of 12 replicates (broilers) per treatment.

[2] SW = Slaughter weight (kg/bird). CY = Carcass yield (%). FO = Foot (g/bird). LI = Liver (g/bird). GI = Gizzard (g/bird). HE = Heart (g/bird). BR = Breast (%). DR = Drumsticks (%). TH = Thighs (%). BA = Back (%). WI = Wings (%). NE = Neck (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variable.

Table 6. Proximate composition of breast fillets from slow-growing broilers fed diets containing *Paullinia cupana* peel meal[1].

Variables[2]	*Paullinia cupana* peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MO	70.48±0.69[c]	71.20±0.23[b]	71.15±0.35[b]	73.04±0.76[a]	73.65±0.47[a]	<0.01	1.83	0.63	$Y = 70.268 + 0.3272x$	0.90
MI	1.21±0.02[a]	1.14±0.06[b]	1.12±0.17[b]	1.04±0.23[c]	1.02±0.15[c]	<0.01	6.63	-0.79	$Y = 1.202 - 0.0192x$	0.96
FA	1.69±0.11[b]	1.39±0.15[c]	1.53±0.18[b]	1.58±0.13[b]	1.81±0.23[a]	<0.01	10.12	0.38	$Y = 1.6526 - 0.0937x + 0.0111x^2$	0.84
PR	26.62±0.59[a]	26.27±0.15[a]	26.20±0.18[a]	24.34±0.28[b]	23.52±0.36[c]	<0.01	5.05	-0.65	$Y = 27.016 - 0.3252x$	0.87

[1] All data represent the average of 12 replicates (broilers) per treatment.

[2] MO = Moisture (%). MI = Minerals (%). FA = Fats (%). PT = Proteins (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variable.

DISCUSSION

Firstly, we observed that the inclusion of PCPM in diets for slow-growing broilers caused a positive impact in most of growth performance variables, especially providing heavier broilers presenting better feed efficiency. It is a great result when it was considering that PCPM present a considerable amount of fiber in its composition and, consequently, influenced the fiber level of the diets, ranging from 4 to 7%. However, it appears that this increase in fiber level did not negatively affect the broilers' response to the increasing inclusion of PCPM.

The presence of fiber in poultry diets has always been a major challenge for both researchers and the industry because the gastrointestinal tract of birds tends to have low enzymatic activity suitable for digesting fibers, especially the broilers, which can result in restrictions in nutrients' use (Azizi et al., 2021). However, González-Alvarado et al. (2010), Mateos et al. (2012) and Rufino et al. (2021) reported that recent studies have indicated that moderate levels of fiber in poultry diets are very important components for improving results regarding their physiology and nutrient utilization, enhancing the growth performance and other important productive indexes. According to Jiménez-Moreno et al. (2009a,b) and Svihus (2011), the positive effects caused by moderate levels of fiber are direct associated with an improvement on digestibility through continuous stimulation of the gizzard, stimulation of the small intestine activity, and a positive effect on intestinal microbiota due to their prebiotic action.

For instance, in a study conducted by Pushpakumara et al. (2017), the inclusion of palm kernel meal in broiler diets proved beneficial, with improvements in feed efficiency and increased weight gain, leading the authors to recommend using up to 15% of this food in the broiler diet. Conversely, Malhado et al. (2022) studied different levels of barley residues in the feeding of slow-growing Label Rouge broilers and found no significant differences ($p>0.05$) in weight gain, final weight, and feed efficiency. However, they observed a significant difference ($p<0.05$) in feed intake, with a linear increase as the inclusion of barley in the diet increased. Similarly, Costa et al. (2017) found that gradually increasing the inclusion of babassu flour in broiler diets resulted in birds with higher weight and better production efficiency. However, when the inclusion reached 25%, there was a decrease in these indices.

These relations between fiber levels and their action on poultry physiology present an important challenge to the use of alternative foods in poultry diets, as many alternative foods are residues from the food processing industry, mainly consisting of peels and seeds, which naturally have a high fiber content (Rufino et al., 2015; Cruz and Rufino, 2017; Rufino et al., 2021). Depending on the alternative food being used, its fiber content can be considerably high, affecting the metabolism of other nutrients, especially proteins and soluble carbohydrates, and harming growth performance (Liu et al., 2018; Rufino et al., 2021; Cho et al., 2024).

When considering these positive effects of PCPM in the diets for slow-growing broilers on both growth performance and meat quality, it should also be emphasized that residues from the processing of *Paullinia cupana* may also contain substances that confer stimulating, energetic, antioxidant, antimicrobial, and chemoprophylactic properties (Marques et al., 2016; Yonekura et al., 2016). As with other alternative foods, these additional properties may improve nutrient utilization and the physiological response of the birds (Cruz and Rufino, 2017).

The results obtained from hematological parameters help reinforce these observations, as the increased levels of PCPM inclusion in the broiler diets led to a reduction in the concentration of erythrocytes and the hematocrit percentage evaluated, however, alongside an increase in the results of MCH and MCHC. Literature reports, for example, that reference values for hematocrit in birds typically range from 25% to 50%; values below this limit may indicate anemia, while values above may suggest dehydration or polycythemia (Muneer et al., 2021; Al-Khalaifah et al., 2022). For the other variables, we also observed that in all evaluated treatments, the broilers fell within in an acceptable stable range, albeit close to the limit (Seo et al., 2015; Muneer et al., 2021).

In the results of serum biochemical parameters, even though only the concentration of triglycerides was significantly influenced by the inclusion of PCPM in the diets of the broilers, this is an important result once the concentration of triglycerides can be an important indicator of metabolic disorders caused by feeding. In broilers, triglycerides are available in the intestinal mucosa and liver from the digestion and absorption of fatty acids, where high concentrations of these can lead to a significant reduction in growth performance (Zhou et al., 2020; Hu et al., 2021). Once the results of this study showed a linear reduction in triglyceride concentration with the inclusion of PCPM, this can be considered a positive aspect, as even slow-growing broilers, due to their natural accelerated growth compared to other poultry categories, may present scenarios with elevated metabolic rates, which can be detrimental to their health and growth performance.

Moreover, it was also possible to observe the positive influence of the great growth performance results on meat quality, with broilers feeding higher levels of PCPM, 7.5% and 10% of PCPM inclusion, showing better carcass yield, higher values of liver, gizzard, and heart, as well as more breast, thigh, and drumstick yield, in addition to good content of fats. According to Malhado et al. (2022), good growth performance results from the use of alternative foods generally end up being reflected in meat quality, as observed in this study, with the authors commenting that this applies to both fast-growing and slow-growing broilers. Geron et al. (2015), Rossa et al. (2015), Shi et al. (2019) and Rufino et al. (2021) also support this statement in their results, complementing this scenario with the observation that this is directly related to the nutritional composition of the food being tested, how its inclusion can interfere with the composition of the diets, and consequently, their utilization by the broilers.

When comparing the results obtained in this study with those reported in the literature using other alternative feeds in broiler diets, we observe that slow-growing broilers fed diets with lower levels of PCPM (2.5 to 5%) show slightly lower growth performance and meat quality results compared to other slow-growing broilers (Dixon, 2020; Rayner, 2020; Güz et al., 2021; Santos et al., 2021) and significantly lower results than fast-growing broilers (Dixon, 2020; Güz et al., 2021; Santos et al., 2021). On the other hand, slow-growing broilers fed diets with higher levels of PCPM (7.5 to 10%) show growth performance and meat quality results close to or equal to those reported in the literature for other slow-growing broilers (Dixon, 2020; Rayner, 2020; Güz et al., 2021; Santos et al., 2021) and somewhat close to fast-growing broilers (Dixon, 2020; Güz et al., 2021; Santos et al., 2021).

Based on these results, it is possible to assume that PCPM may have maintained to some extent the nutritional profile (rich in carbohydrates and lipids) and bioactive compounds (caffeine) originally contained in the *Paullinia cupana* fruit, and that these were beneficial for the growth of the broilers. Additionally, the antioxidant and fibrous compounds naturally found in the *Paullinia cupana* husk, as observed with the inclusion of other foods, may help in the intestinal health of the birds during this critical phase, further reducing the proliferation of various intestinal bacteria, pathogenic or not, through the reduction of pH and production of volatile fatty acids (Oleforuh-Okoleh et al., 2015).

Here, it is important to mention the peculiarities of the productive and physiological responses of the slow-growing broilers used in this study compared to fast-growing broilers, which are typically used in most studies testing alternative foods in poultry diets. The use of slow-growing broiler breeds has been suggested to decrease welfare issues, especially in tropical climate regions, which are warmer (Montoro-Dasi et al., 2020; van der Eijk et al., 2023), such as observed in this study. Previous studies also reported that slow-growing breeds are more active, have lower levels of lameness and fewer hock and foot pad lesions than fast-growing breeds, in addition to they have lower mortality rates and fewer lameness issues resulting in fewer culls (Dixon, 2020; Güz et al., 2021; Rayner et al., 2021).

This is especially relevant in terms of behavior, welfare, and growth performance in a sustainable approach. De Jong et al. (2022) defines slower-growing broilers as growing ≤ 50 g/d, while fast-growing broilers grow ≥ 60 g/d. In general, slower-growing broilers are more active and exhibit improved welfare measures (Dixon, 2020; Rayner et al., 2020; Güz et al., 2021; van der Eijk et al., 2022), although differences are not always found (De Jong et al., 2021). Regarding growth performance, slow-growing broilers generally have lower daily body weight gain, daily feed intake, and mortality rates, and can maintain greater feed efficiency compared to fast-growing broilers (Güz et al., 2021; Torrey et al., 2021; Van der Eijk et al., 2022; Van der Eijk et al., 2023). Furthermore, slow-growing broilers had lower carcass yield and breast yield, and higher thigh, drumstick, and wing yield relative to carcass weight (Santos et al., 2021).

CONCLUSION

The inclusion of PCPM in diets for slow-growing broilers positively impacts growth performance, enhancing meat quality and yields of valuable cuts such as breast, drumstick, and thigh, where 10% inclusion level presented better results. Despite the increased moisture content and decreased protein levels in breast meat, the overall benefits to meat quality and bird health were significant. The study's findings suggest that PCPM can be a viable alternative feed ingredient, promoting sustainable livestock management by utilizing residues from the food processing industry.

Data availability

The data of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors have no conflicts of interest to declare.

Declaration of funding

None.

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REFERENCES

Al-Khalaifah H, Al-Nasser A, Al-Surrayai T, Sultan H, Al-Attal D, Al-Kandari R, Al-Saleem H, Al-Holi A, Dashti F (2022) Effect of ginger powder on production performance, antioxidant status, hematological parameters, digestibility, and plasma cholesterol content in broiler chickens. *Animals*, **12**, 901. doi: https://doi.org/10.3390/ani12070901

Ali A, Ponnampalam EN, Pushpakumara G, Cottrell JJ, Suleria HAR, Dunshea FR (2021) Cinnamon: a natural feed additive for poultry health and production - a review. *Animals (Basel)* **11**, 2026. doi: http://dx.doi.org/10.3390/ani11072026

Aride PHR, Oliveira AM, Batista RB, Ferreira MS, Pantoja-Lima J, Ladislau DS, Castro PDS, Oliveira AT (2018) Changes on physiological parameters of tambaqui (*Colossoma macropomum*) fed with diets supplemented with Amazonian fruit Camu camu (*Myrciaria dubia*). *Brazilian Journal of Biology* **78**, 360-367. doi: http://dx.doi.org/10.1590/1519-6984.169442

AOAC-Association of Official Agricultural Chemists (2019) "Official Methods of Analysis of AOAC International (21th ed.)". (AOAC: Rockville, USA).

Azizi MN, Loh TC, Foo HL, Chung ELT (2021) Is palm kernel cake a suitable alternative feed ingredient for poultry?. *Animals (Basel)* **11**, 338. doi: https://doi.org/10.3390/ani11020338

Billen G, Aguilera E, Einarsson R, Garnier J, Gingrich S, Grizzetti B, Lassaletta L, Le Nöe J, Sanz-Cobena A (2021) Reshaping the European agro-food system and closing its nitrogen cycle: the potential of combining dietary change, agroecology, and circularity. *One Earth* **4**, 839-850. doi: https://doi.org/10.1016/j.oneear.2021.05.008

Chatterjee S, Hadi AS (2006) "Regression Analysis by Example (4th ed.)". (John Wiley & Sons Ltd: New Jersey, US).

Cho S, Shi H, Sureshkumar S, Kim I (2024) The Effects of the Dietary Inclusion of By-Products Obtained after the Extraction of Vitamin B_2 from Fermented Soybean on the Performance and Meat Quality of Growing–Finishing Pigs. *Applied Sciences*, **14**, 803. doi: https://doi.org/10.3390/app14020803

Clement CR, Pereira HS, Vieira ICG, Homma AKO (2024) Challenges for a Brazilian Amazonian bioeconomy based on forest foods. *Trees, Forests and People* **16**. doi: https://doi.org/100583. 10.1016/j.tfp.2024.100583

Costa APGC, Cruz FGG, Rufino JPF, Feijó JC, Melo RD, Melo LD, Damasceno JL (2017) Tucumã meal in diets for broilers on performance, carcass traits and serum biochemical profile. *Archivos de Zootecnia* **67**, 137-142. doi:

https://doi.org/10.21071/az.v67i257.3501

Cruz FGG, Rufino JPF, Melo RD, Feijó JC, Damasceno JL, Costa APGC (2016) Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. *Revista em Agronegócio e Meio Ambiente* **9**, 371-391. doi: https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Cruz FGG, Rufino JPF (2017) "Formulation and manufacture of feed (poultry, pigs and fish) [in Portuguese]" (EDUA: Manaus, Brazil).

de Jong IC, Bos B, van Harn J, Mostert P, te Beest D (2022) Differences and variation in welfare performance of broiler flocks in three production systems. *Poultry Science* **101**, 101933. doi: https://doi.org/10.1016/j.psj.2022.101933

Dixon LM (2020) Slow and steady wins the race: The behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed. *PlosONE* **15**, e0231006. doi: https://doi.org/10.1371/journal.pone.0231006

Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JRG, Gruber B, Lafourcade B, Leitão PJ, Münkemüller T, Mcclean C, Osborne PE, Reineking B, Schröder B, Skidmore AK, Zurell D, Lautenbach S (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **36**, 27-46. doi: https://doi.org/10.1111/j.1600-0587.2012.07348.x

Ferreira IJ, Leão DP, Nascimento OV, Cavalcanti V, Vasconcellos MC (2022) Amazon Guarana (Paullinia Cupana Var. Sorbilis): Effect of Consumption on Physical Performance – A Narrative Review. *European Academic Research* **X**(6), 2110-2122.

Filoche G, Pinton F (2014). Who owns guaraná? Legal strategies, development policies and agricultural practices in Brazilian Amazonia. *Journal of Agrarian Change* **14**, 380-399. doi: http://dx.doi.org/10.1111/joac.12035

Geron LJV, Costa FGC, Moraes KJS, Oliveira EM, Gomes R, Pereira SR, Silva AP, Cruz C, Pelicia K (2015) Consumption, performance and carcass yield of broiler chickens fed diets containing dehydrated residual cassava scrap. *Boletim da Indústria Animal* **72**, 304-310. doi: https://doi.org/10.17523/bia.v72n4p304

Goldenfarb PB, Bowyer FP, Hall E, Brosius E (1971) Reproducibility in the hematology laboratory: the microhematocrit determination. *American Journal of Clinical Pathology* **56**, 35-39. doi: https://doi.org/10.1093/ajcp/56.1.35

Gomide LAM, Alencar N, Macedo IA (2012) "Broiler processing (cutting, trimming and boning) [in Portuguese] (2nd ed.)" (LK Editora: Brasília, Brazil)

González-Alvarado JM, Jimenez-Moreno E, González-Sanchez D, Lazaro R, Mateos GG

(2010) Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. *Animal Feed Science and Technology* **162**, 37-46. doi: https://dx.doi.org/10.1016/j.anifeedsci.2010.08.010

Güz BC, de Jong IC, Da Silva CS, Veldkamp F, Kemp B, Molenaar R, van den Brand H (2021) Effects of pen enrichment on leg health of fast and slower-growing broiler chickens. *PLoSONE* **16**, e0254462. doi: https://doi.org/10.1371/journal.pone.0254462

Hu X, Li X, Xiao C, Kong L, Zhu Q, Song Z (2021) Effects of dietary energy level on performance, plasma parameters, and central AMPK levels in stressed broilers. *Frontiers in Veterinary Science* **28**, 681858. doi: https://doi.org/10.3389/fvets.2021.681858

Jiménez-Moreno E, González-Alvarado JM, Coca-Sinova A, Lázaro R, Mateos GG, (2009a) Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. *Animal Feed Science and Technology* **154**, 93-101. doi: https://dx.doi.org/10.1016/j.anifeedsci.2009.06.020

Jiménez-Moreno E, González-Alvarado JM, Lázaro R, Mateos GG (2009b) Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. *Poultry Science* **88**, 1925-1933. doi: https://dx.doi.org/10.3382/ps.2009-00193

Liu CW, Zhou HS, Kim MY, Lee IS, Pang YH, Kim HI (2018) Impacts of rapeseed meal, canola meal and their mixture substitute for soybean meal on performance of lactating sows and their offspring. *Indian Journal of Animal Research* **53**, 124-128. doi: https://dx.doi.org/10.18805/ijar.B-837

Logan M (2010) “Biostatistical design and analysis using R: a practical guide” (John Wiley & Sons Ltd: New Jersey, USA)

Malhado ALN, Alves JR, Lima HJD, Rosa MS (2022) Barley residue levels in the diet of Label Rouge broilers. *Revista Acadêmica: Ciência Animal* **20**, e20002. doi: https://doi.org/10.7213/acad.2022.20002

Marques LLM, Panizzon GP, Aguiar BAA, Simionato AS, Cardozo-Filho L, Andrade G, Oliveira AG, Guedes TA, Mello JCP (2016) Guaraná (*Paullinia cupana*) seeds: Selective supercritical extraction of phenolic compounds. *Food Chemistry* **212**, 703-711. doi: https://doi.org/10.1016/j.foodchem.2016.06.028

Mateos GG, Jiménez-Moreno E, Serrano MP, Lázaro RP (2012) Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. *Journal of Applied Poultry Research* **21**, 156-174. doi: https://doi.org/10.3382/japr.2011-00477

Mendes AA, Patrício IS (2004) Controls, records and performance evaluation of broilers [in

Portuguese]. In "Broiler production [in Portuguese]". (Eds AA Mendes, IA Nääs, M Macari) (FACTA: Campinas, Brazil)

Monteiro A, Barreto-Mendes L, Fanchone A, Morgavi DP, Pedreira BC, Magalhães CAS, Abdalla AL, Eugène M (2024) Crop-livestock-forestry systems as a strategy for mitigating greenhouse gas emissions and enhancing the sustainability of forage-based livestock systems in the Amazon biome. *Science of The Total Environment* **906**, 167396. doi: https://doi.org/10.1016/j.scitotenv.2023.167396

Montoro-Dasi L, Villagra A, de Toro M, Pérez-Gracia MT, Vega S, Marin C (2020) Fast and slow-growing management systems: characterisation of broiler caecal microbiota development throughout the growing period. *Animals* **10**, 1401. doi: https://doi.org/10.3390/ani10081401

Mottet A, De Haan C, Falcucci A, Tempio G, Opio C, Gerber P (2017) Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security* **14**, 1-8. doi: http://dx.doi.org/10.1016/j.gfs.2017.01.001

Muneer M, Bilal M, Ditta A (2021) A comparative study of some hematological parameters of broiler and indigenous breeds of poultry. *SVU-International Journal of Agricultural Sciences* **3**, 203-213. doi: https://dx.doi.org/10.21608/svuijas.2021.99388.1146

Oleforuh-Okoleh VU, Ndofor-Foleng H, Olorunleke S, Uguru J (2015) Evaluation of growth performance, haematological and serum biochemical response of broiler chickens to aqueous extract of ginger and garlic. *The Journal of Agricultural Science* **7**, 167-173. https://doi.org/10.5539/jas.v7n4p167

Oliveira DHR (2018) Alternative food for broiler chickens: an overview. *Scientific Electronic Archives* **11**, 112-117. doi: https://doi.org/10.36560/1152018691

Pinho LS, da Silva MP, Thomazini M, Cooperstone JL, Campanella OH, da Costa Rodrigues CE, Favaro-Trindade CS (2021). Guaraná (*Paullinia cupana*) by-product as a source of bioactive compounds and as a natural antioxidant for food applications. *Journal of Food Processing and Preservation*, **45**, e15854. doi: https://doi.org/10.1111/jfpp.15854

Pushpakumara DMS, Priyankarage N, Nayananjalie WAD, Ranathunge DL, Dissanayake DMDP (2017) Effect of inclusion of palm (*Elaeis guineenses*) kernel cake in broiler Chicken rations. *International Journal of Livestock Research* **7**, 103-109. doi: http://dx.doi.org/10.5455/ijlr.20170201053413

R Core Team (2021) "R: A language and environment for statistical computing" (R Foundation for Statistical Computing: Vienna, Austria)

Rayner AC, Newberry RC, Vas J, Mullan S (2020) Slow-growing broilers are healthier and express more behavioural indicators of positive welfare. *Scientific Reports* **10**, 15151. doi: https://doi.org/10.1038/s41598-020-72198-x

Röös E, Bajželj B, Smith P, Patel M, Little D, Garnett T (2017) Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change* **47**, 1-12. doi: http://dx.doi.org/10.1016/j.gloenvcha.2017.09.001

Rosenfeld T, Pokorny B, Marcovitch J, Poschen P (2024) Local development based on non-timber forest products: evidence from a mapping of initiatives in the Brazilian Amazon since Rio 1992. *Sustainability* **16**, 6005. doi: https://doi.org/10.3390/su16146005

Rossa LS, Stahlke EVR, Malaquias MAS, Diez DC, Stertz SC, Macedo REF (2015) Physical chemical and nutritional profile of organic retail chicken meat. *Boletim do Centro de Pesquisa de Processamento de Alimentos* **33**, 67-78. doi: http://dx.doi.org/10.5380/cep.v33i2.47294

Rostagno HS, Albino LFT, Calderano AA, Hannas MI, Sakomura NK, Costa FGP, Rocha GC, Saraiva A, Abreu MLT, Genova JL, Tavernari FC (2024) "Brazilian tables for poultry and swine: food composition and nutritional requirements [in Portuguese] (5th Ed.)" (Federal University of Viçosa Press: Viçosa, Brazil)

Rufino JPF, Cruz FGG, Miller WP, Melo RD, Feijó JC, Chagas EO (2015) Economical analysis of the inclusion of flour residue of tucumã (*Astrocaryum vulgare*, Mart) in the feeding of laying hens. *Revista Brasileira de Saúde e Produção Animal* **16**, 1-9. doi: https://doi.org/10.1590/S1519-99402015000100001

Rufino JPF, Cruz FGG, Brasil RJM, Oliveira Filho PA, Melo RD, Feijo JC (2021) Relationship between the level and the action period of fiber in diets to laying hens. *Acta Scientiarum. Animal Sciences* **43**, e49033. doi: http://dx.doi.org/10.4025/actascianimsci.v43i1.49033

Sakomura NK, Rostagno HS (2016) "Research methods in monogastric nutrition [in Portuguese]" (Funep: Jaboticabal, SP)

Sandström V, Chrysafi A, Lamminen M, Troell M, Jalava M, Piipponen J, Siebert S, Van Hal O, Virkki V, Kummu M (2022) Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nature Food* **3**, 729-740. doi: https://doi.org/10.1038/s43016-022-00589-6

Santana ÁL, Macedo GA (2018) Health and technological aspects of methylxanthines and polyphenols from guarana: A review. *Journal of Functional Foods* **47**, 457-468. doi: https://doi.org/10.1016/j.jff.2018.05.048

Santos MN, Rothschild D, Widowski TM, Barbut S, Kiarie EG, Mandell I, Guerin MT, Edwards AM, Torrey S (2021) In pursuit of a better broiler: carcass traits and muscle myopathies in conventional and slower-growing strains of broiler chickens. *Poultry Science* **100**, 101309. doi: https://doi.org/10.1016/j.psj.2021.101309

Schader C, Muller A, Scialabba NE-H, Hecht J, Isensee A, Erb K-H, Smith P, Makkar HPS, Klocke P, Leiber F, Schwegler P, Stolze M, Niggli U (2015) Impacts of feeding less food-competing feedstufs to livestock on global food system sustainability. *Journal of The Royal Society Interface* **12**, 20150891. doi: https://doi.org/10.1098/rsif.2015.0891

Schimpl FC, da Silva JF, Gonçalves JF, Mazzafera P (2013) Guarana: revisiting a highly caffeinated plant from the Amazon. *Journal of Ethnopharmacology* **150**, 14-31. doi: https://doi.org/10.1016/j.jep.2013.08.023

Seo J, Kim W, Kim J, Kim JK, Kim SC, Jang Y, Jang K, Kim K, Kim B, Park S, Park I, Kim MK, Seo KS, Kim HB, Kim IH, Seo S, Song M (2015) Performance, Nutrient Digestibility, and Blood Profiles of Weaned Pigs. *Animal Bioscience* **28**, 987-992. doi: https://doi.org/10.5713/ajas.14.0842

Shi, H., Kim, S.H. and Kim, I.H. (2019), Effect of dietary inclusion of fermented sea mustard by-product on growth performance, blood profiles, and meat quality in broilers. J. Sci. Food Agric., 99: 4304-4308. https://doi.org/10.1002/jsfa.9663

Svihus B (2011) The gizzard: function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal* **67**, 207-224. doi: https://doi.org/10.1017/S0043933911000249

Sousa SA, Alves SF, Paula JAM, Fiuza TS, Paula JR, Bara MTF (2010) Determination of tannins and methylxanthines in powdered guarana (*Paullinia cupana Kunth*, Sapindaceae) by high performance liquid chromatography. *Revista Brasileira de Farmacognosia* **20**, 866-870. doi: https://doi.org/10.1590/S0102-695X2011005000001

Supercrac (2021) "Software SuperCrac 6.1 Premium: Formulation of Feed and Nutritional Diets" (TD Software: Viçosa, Brazil)

Tavares-Dias M, Moraes FR (2004) "Hematology of teleost fish [in Portuguese]" (Villimpress: Ribeirão Preto)

Torrey S, Mohammadigheisar M, Santos MN, Rothschild D, Dawson LC, Liu Z, Kiarie EG, Edwards AM, Mandell I, Karrow N, Tulpan D, Widowski TM (2021) In pursuit of a better broiler: growth, efficiency, and mortality of 16 strains of broiler chickens. *Poultry Science* **100**, 100955. doi: https://doi.org/10.1016/j.psj.2020.12.052

van der Eijk JAJ, Bakker J, Güz BC, van Krimpen MM, Molenaar R, van den Brand H, de Jong IC (2022) Providing organic macro minerals and an elevated platform improved tibia characteristics, and increased locomotion and performance of fast- and slower-growing broilers. *Poultry Science* **101**, 101973. doi: https://doi.org/10.1016/j.psj.2022.101973

Van der Eijk JAJ, van Harn J, Gunnink H, Melis S, van Riel JW, de Jong IC (2023) Fast- and slower-growing broilers respond similarly to a reduction in stocking density with regard to gait, hock burn, skin lesions, cleanliness, and performance. *Poultry Science* **102**, 102603. doi: https://doi.org/10.1016/j.psj.2023.102603

Van Hal O, De Boer IJM, Muller A, De Vries S, Erb K-H, Schader C, Gerrits WJJ, Van Zanten HHE (2019) Upcycling food lefovers and grass resources through livestock: impact of livestock system and productivity. *Journal of Cleaner Production* **219**, 485-496. doi: https://doi.org/10.1016/j.jclepro.2019.01.329

Van Kernebeek HR, Oosting SJ, Van Ittersum MK, Bikker P, De Boer IJ (2016) Saving land to feed a growing population: consequences for consumption of crop and livestock products. *The International Journal of Life Cycle Assessment* **21**, 677-687. doi: http://dx.doi.org/10.1007/s11367-015-0923-6

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**, 3583-3597. doi: https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Van Zanten HHE, Herrero M, Van Hal O, Röös E, Muller A, Garnett T, Gerber PJ, Schader C, De Boer IJM (2018) Defining a land boundary for sustainable livestock consumption. *Global Change Biology* **24**, 4185-4194. doi: http://dx.doi.org/10.1111/gcb.14321

Vastolo A, Calabrò S, Cutrignelli MI (2022). A review on the use of agro-industrial CO-products in animals' diets. *Italian Journal of Animal Science*, **21**, 577-594. doi: https://doi.org/10.1080/1828051X.2022.2039562

Waititu SM, Sanjayan N, Hossain MM, Leterme P, Nyachoti CM (2018) Improvement of the nutritional value of high-protein sunflower meal for broiler chickens using multi-enzyme mixtures. *Poultry Science* **97**, 1245-1252. doi: https://doi.org/10.3382/ps/pex418

Wu Y, Huang J, Quan S, Yang Y (2022) Light regimen on health and growth of broilers: an update review. *Poultry Science* **101**, 101545. doi: https://doi.org/10.1016/j.psj.2021.101545

Yang K, Qing Y, Yu Q, Tang X, Chen G, Fang R, Liu H (2021) By-product feeds: current understanding and future perspectives. *Agriculture* **11**, 207. doi: https://doi.org/10.3390/agriculture11030207

Yonekura L, Martins CA, Sampaio GR, Monteiro MP, César LA, Mioto BM, Mori CS, Mendes TM, Ribeiro ML, Arçari DP, Torres EA (2016) Bioavailability of catechins from guaraná (*Paullinia cupana*) and its effect on antioxidant enzymes and other oxidative stress markers in healthy human subjects. *Food & Function* **7**, 2970-2978. doi: https://doi.org/10.1039/c6fo00513f

Zhou Y, Chen Z, Lin Q, Yang Y, Hang Y, Zhou X, Wu C, Xie Z (2020) Nuciferine reduced fat deposition by controlling triglyceride and cholesterol concentration in broiler chickens. *Poultry Science* **99**, 7101-7108. doi: https://doi.org/10.1016/j.psj.2020.09.013

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CHAPTER 6: Effects of *Paullinia cupana* pulp meal inclusion in diets for slow-growing broilers on growth performance, physiological parameters, and meat quality

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Short-title: Tambaqui by-product silage on hen diets

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Abstract

Context: The poultry industry seeks sustainable feed alternatives to reduce costs and dependence on conventional ingredients, especially in regions like the Amazon. *Paullinia cupana* pulp, a by-product of *Paullinia cupana* processment, has nutritional and bioactive potential for use in poultry diets. **Aims:** To evaluate the effects of including different levels of *Paullinia cupana* pulp meal (PCPUM) on the productive performance, physiological parameters, and meat quality of slow-growing broilers. **Methods:** A total of 240 male Label Rouge broilers were used in a completely randomized design with five treatments (0%, 2.5%, 5%, 7.5%, and 10% PCPUM), with four replicates of 12 birds. Performance during the starter (8–28 days) and grower (29–56 days) phases, hematological and biochemical parameters, yield of commercial cuts, and meat proximate composition were evaluated. **Key results:** The

inclusion of 7.5% PCPUM improved weight gain and the yield of cuts such as breast, thigh, and drumstick without negatively affecting the meat's nutritional composition. A significant increase in hemoglobin and hematocrit levels, along with reductions in plasma triglycerides and glucose, indicated beneficial metabolic effects. However, the 10% inclusion level impaired some physiological and performance variables. **Conclusions:** Including up to 7.5% PCPUM in slow-growing broiler diets is viable, promoting productive gains and physiological benefits without compromising meat quality. **Implications:** The use of agro-industrial by-products such as guarana pulp in poultry feed contributes to the sustainability of production, particularly in regional contexts with logistical challenges like the Amazon.
Keywords: alternative food, Amazon, broilers, *Paullinia cupana*, poultry science.

INTRODUCTION

The use of by-products in animal feed can positively impact the global food supply (Sandström et al., 2022), as this approach reduces competition between food used for animal diets and food intended for human consumption (Shurson, 2020; De Souza et al., 2024). Additionally, replacing traditional feedstuffs such as corn and soy with alternative raw materials has gained global attention as a cost-reduction strategy in livestock production while minimizing nutrient waste from the agricultural and food sectors (Dou et al., 2018; Shurson, 2020; Pinotti et al., 2023).

Animal feed costs represent a significant portion of total livestock production expenses, ranging from 60% to 70% (Pacheco et al., 2018; Dos Reis et al., 2024). In more remote regions, such as the Amazon, this impact tends to be even greater due to logistical challenges, as diet production depends on feedstuffs from other regions, further increasing final costs (Cruz et al., 2016; Cruz and Rufino, 2017). Therefore, seeking alternatives that reduce dependence on conventional inputs while simultaneously mitigating environmental impacts is crucial for economic viability and sustainability (Van Hal et al., 2019; Sanches et al., 2023; De Souza et al., 2024).

Considering the rich Amazonian biodiversity, among the economically and nutritionally relevant local species, *Paullinia cupana*, commonly known as guarana, stands out for its high content of bioactive compounds, including caffeine, theobromine, polyphenols, and tannins, which offer remarkable health benefits and significant industrial applications (Carvalho et al., 2016; Souza et al., 2017). Brazil is the world's largest producer of *Paullinia cupana*, mainly in the states of Amazonas and Bahia (Schimpl et al., 2013; Da Silva et al., 2024). The dried seeds of *Paullinia cupana*, primarily valued for their high caffeine content, are predominantly used in the soft drink and energy drink industries (70%), while the remaining portion is directed toward pharmaceutical and cosmetic products (Schimpl et al., 2013; Machado et al., 2018). Additionally, during the industrial processing of *Paullinia cupana*, a considerable volume of organic residues is generated, which exhibit biological potential for reuse, representing a significant opportunity for the adoption of sustainable practices (De Oliveira et al., 2024; Santos et al., 2024).

References on the use of *Paullinia cupana* or its by-products in poultry diets remain scarce in the literature (Santos et al., 2024). However, considering its rich nutritional properties, the volume of production generating by-products and residues, and its importance to Brazilian agribusiness, *Paullinia cupana* by-products may offer good biological and productive potential, as well as economic feasibility for inclusion in poultry diets, while also promoting a circular economy within these production chains (Cruz and Rufino, 2017; De Oliveira et al., 2024; Santos et al., 2024). Based on this information, the present study was conducted to investigate the effects of *Paullinia cupana* pulp meal (PCPUM) on the performance, physiological parameters, and meat quality of slow-growing broilers.

MATERIAL AND METHODS

Acquisition and composition analysis of Paullinia cupana pulp meal

Paullinia cupana residues were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The entire process of guarana processing, by-product extraction, and subsequent processing to obtain PCPUM followed these steps: (1) ripe *Paullinia cupana* fruits were manually harvested; (2) the collected fruits were stored in baskets for approximately three days, undergoing a fermentation process; (3) the fruit extract, used in the production of carbonated beverages by the beverage industry, was obtained; (4) the residue from the extraction process was collected; (5) this residue underwent a drying process in a closed-circulation oven at 105°C (221°F) for 24 hours; (6) the dried residue was ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); and (7) the final product, called PCPUM, was bagged and stored in a dry, ventilated place for use in the preparation of experimental diets.

Before conducting the experiment, the proximate composition of PCPUM (Table 1) was determined. The dry matter content was analyzed in an oven at 105°C (221°F) following AOAC Method 925.10 (AOAC, 2019). Mineral content was determined by calcination in a muffle furnace at 550°C (1022°F), according to AOAC Method 923.03 (AOAC, 2019). Lipid content analysis followed AOCS Method Ba 3-38. Total protein content was determined using the

Kjeldahl method, following AOAC Method 920.87 (AOAC, 2019). The determination of fiber content (crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF)) was performed according to the methods described by Van Soest et al. (1991).

Table 1. Guarana pulp meal composition.

Variables	Guarana pulp meal
Dry matter, %	83.93
Crude protein, %	12.27
Fats, %	2.41
Minerals, %	1.01
Crude Fiber, %	29.17
Neutral detergent fiber, %	40.84
Acid detergent fiber, %	26.25
Soluble carbohydrates, %	55.14
Gross energy, kcal/kg	5,745.42
Metabolizable energy*, kcal/kg	2,828.56

* Determined using the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024)

Facilities, animals, diets and experimental design

The present study was conducted in an aviary with a ceiling height of 3.25 meters, incorporating structural modifications aimed at enhancing the birds' well-being. Natural ventilation was utilized, with the aviary located in a densely wooded area, ensuring a tranquil and comfortable environment for the birds. Temperature and relative humidity were continuously monitored using a compact digital weather device, which recorded average values of 28.8°C (83.84°F) and 60.9%, respectively. Throughout the experimental stage, the broilers were closely observed for any signs of thermal stress due to environmental conditions, none of which were detected. Notably, the experiment took place during the Amazonian rainy season, which extends from November to April of the following year and is characterized by milder temperatures that provide favorable conditions for animal management.

Male slow-growing Label Rouge broilers (n = 240), sourced from the incubation center of the Research Poultry Farm at UFAM, were utilized in this study. Upon arrival, one-day-old chicks (44.05±0.61 g) were placed in a protective brooding circle furnished with wood shavings, tray-style feeders, and cup-style drinkers, maintaining a stocking density of 50 birds per square meter. A central electric heating system was provided to ensure optimal conditions until the broilers reached seven days of age. At eight days old, the birds were systematically allocated into experimental groups and transferred to pens measuring 4 square meters each.

These pens were equipped with tubular feeders, suspended drinkers, and a floor covered with wood shavings. The experiment was divided into two distinct stages: the starter stage (8-28 days) and the final stage (29-56 days). The birds had ad libitum access to feed and water during all the experimental periods. A lighting protocol for slow-growing broilers was used as described by (Wu et al. 2022).

The experimental design was completely randomized, with treatments comprising a control diet (without PCPUM) and four levels of PCPUM inclusion (2.5%, 5.0%, 7.5%, and 10%) in the diets, with four replicates of 12 birds each. Experimental diets (Table 2) were formulated on the basis of reference values reported by Rostagno et al. (2024), except for PCPUM composition, which used values from prior product-composition analyses performed in this study. The metabolizable energy value for PCPUM was determined using method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024), where a small digestibility trial was conducted prior to the main experiment, with the collected feed and fecal samples being analysed in the laboratory.

PCPUM was a fixed component in the diet calculations, with other ingredient values adjusted on the basis of PCPUM inclusion levels. Diets were formulated using SuperCrac software (TD Software©, Viçosa, Brazil). The composition of these diets was analysed to confirm their proximate composition according to the methods described by the AOAC (2019), where moisture content was determined according to Method 925.10, minerals content was determined following Method 923.03, lipid content analyses followed Method Ba 3-38, total protein content was determined according to Method 920.87, and the determination of fibre contents (crude fibre, NDF and ADF) was performed according to the methods described by Van Soest et al.(1991).

Table 2. Composition and guaranteed nutrient concentration (analysed and calculated concentrations in dry matter) of experimental diets with different levels of Guarana pulp meal inclusion (0%, 2.5%, 5%, 7.5% and 10%).

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	56.27	53.17	50.10	47.00	63.34	61,57	58,49	55,4	52,31
Soybean meal 46%	38.32	38.35	35.77	35.66	35.55	35.43	32.53	30,5	30,39	30,28	30,17
Guarana pulp meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2,50	5,00	7,50	10,00
Limestone	0.93	0.82	0.83	0.82	0.81	0.81	1.02	0,76	0,75	0,75	0,74
Dicalcium phosphate	1.79	1.79	1.82	1.84	1.85	1.87	1.55	1,58	1,60	1,61	1,63
Common salt	0.30	0.10	0.27	0.28	0.28	0.28	0.53	0,28	0,28	0,28	0,29
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.14	0.15	0.16	0,18	0.03	0,05	0,06	0,07	0,08
Soybean oil	0.00	0.27	1.90	2.58	3.25	3.93	0.50	2,26	2,93	3,61	4,28
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrients	Guarantee levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.86	87.67	87.58	87.50	87.89	87.76	87.59	87.42	87.35
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.15	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	3.94	4.61	5.27	5.93	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	5.52	6.45	7.38	8.30	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.55	4.15	4.74	5.34	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.14	1.12	1.11	1.10	1.06	1,00	0,99	0,98	0,97
Total methionine, %	0.45	0.45	0.47	0.47	0.48	0.49	0.35	0,35	0,35	0,36	0,37
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0,66	0,66	0,66	0,66
Total threonine, %	0.87	0.87	0.82	0.81	0.80	0.79	0.79	0,75	0,73	0,72	0,71

Total tryptophan, %	0.28	0.28	0.27	0.26	0.26	0.26	0.25	0,24	0,23	0,23	0,23

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[3]Levels analyzed and calculated on a dry matter basis.

Growth performance and meat quality

The growth performance of the broilers was evaluated both for each stage individually (starter and final) and cumulatively across the entire experimental period. The parameters assessed included feed intake (kg/bird), weight gain (kg/bird), and feed conversion (kg/kg). Feed intake for each stage was calculated by dividing the total feed consumed by the number of birds in each pen. Weight gain was determined by comparing the total weight of the birds in each pen to their previous recorded weight, divided by the number of birds. Feed conversion was calculated as the ratio of total feed consumption to the corresponding weight gain. A comprehensive analysis of these performance metrics was conducted by aggregating data from all stages.

At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for meat quality evaluation. The selected birds were weighed, electrically stunned (40 V, 50 Hz), and slaughtered via jugular vein incision. The carcasses were then immersed in hot water (60°C/140°F for 62 seconds) for scalding, mechanically plucked, and eviscerated following the guidelines of Mendes and Patrício (2004). This process facilitated the determination of carcass yield (%) and the yields of key economically relevant viscera, including the liver (g/bird), gizzard (g/bird), heart (g/bird), and feet (g/bird).

Commercial cuts, including the neck, breast, wing, back, thigh, and drumstick, were separated and weighed using a precision analytical balance (0.01 g). Their yields were calculated as a percentage of the clean carcass weight. Additionally, breast meat samples were collected and promptly transported to the laboratory for proximate composition analysis, which determined the percentages of moisture, minerals, fats, and proteins following the standardized methodologies of AOAC (2019).

Physiological parameters

Prior to slaughter, blood samples were collected from 12 broilers per treatment group. One milliliter of blood was drawn from the ulnar vein using disposable syringes containing heparin anticoagulant (5000 IU per sample). The samples were promptly centrifuged at 8217g for 10 minutes at 20 °C (68 °F) to isolate red blood cells for hematological assessment. The resulting plasma was subsequently used for plasma biochemical analysis.

The samples were labeled and stored at −4 °C (24.8 °F) until delivery to the laboratory. For hematological analysis, erythrocyte counts (M/mm^3) were determined using a Neubauer chamber. Blood was diluted in formaldehyde-citrate and toluidine blue, and counts were performed under an optical microscope (Nikon Eclipse E-50i, DM3000, Tokyo, Japan) with a

×40 objective lens.

Hemoglobin concentration (g/dL) was measured using the cyanmethemoglobin method, while hematocrit (%) was determined via the microhematocrit technique (Goldenfarb et al., 1971), involving centrifugation of heparinized microcapillary tubes at 24,149g for 5 minutes (Aride et al., 2018). Based on these results, mean corpuscular volume (MCV, μm^3), mean corpuscular hemoglobin (MCH, pg/cell), and mean corpuscular hemoglobin concentration (MCHC, g/dL) were calculated following the methodologies of Wintrobe (1934) and Tavares-Dias and Moraes (2004).

For plasma biochemical analysis, plasma samples obtained after centrifugation were processed using commercial enzymatic-colorimetric assay kits, following the manufacturer's instructions. Absorbance readings were taken on a mass spectrophotometer (Model K37-UVVIS, Kasvi©, São José dos Pinhais, Brazil) at wavelengths specific to each assay. The biochemical parameters analyzed included total protein, triglycerides, glucose, cholesterol, and albumin concentrations.

Statistical Analyses

The adopted statistical model was as follows:

$$Y_{ik} = \mu + \alpha_i + \epsilon_{ik}$$

where:

Y_{ik} = Observed value for the variable under study;

μ = Overall mean of the experiment;

α_i = Effect of the PCPUM inclusion level;

ϵ_{ik} = Experimental error.

The data were analyzed using R software (version 4.1.3; R Core Team 2021), following the methodology described by Logan (2010). Initially, a one-way ANOVA was performed, with Tukey's honest significant difference test applied at a significance level of 0.05. For variables demonstrating significance ($p \leq 0.05$), correlation and polynomial regression analyses were conducted to evaluate the relationship between the independent variable (PCPUM inclusion level) and the dependent variables (Chatterjee and Hadi, 2006; Dormann et al., 2013). The choice between a linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax^2$) model was based on criteria that best captured the data trends (Dormann et al. 2013), with R-squared values serving as a key determinant for model selection (Chatterjee and Hadi, 2006; Dormann et al., 2013).

Ethics approval

The Animal Ethics Committee of Federal University of Amazonas approved the study under protocol number 010/2022. All animal manipulations were performed according to the Brazilian Code for the Care and Use of Animals for Scientific Purposes and reported in proportion to guidelines and regulations of Animal Research: Reporting of In Vivo Experiments (ARRIVE).

RESULTS

Growth performance

The inclusion of increasing levels of PCPUM in the diet significantly influenced ($p \leq 0.05$) the growth performance of slow-growing broilers across different feeding stages (Table 3). During the starter stage (8-28 days), feed intake increased quadratically with the highest value observed at the 7.5% PCPUM inclusion level (1.63 kg/bird). Similarly, weight gain followed a quadratic trend, with maximum weight gain (0.82 kg/bird) recorded at 7.5% PCPUM inclusion. Feed conversion was highest in the control group (2.61 kg/kg) and significantly decreased ($p \leq 0.05$) with the inclusion of PCPUM, reaching the lowest values between 2.5% and 7.5%, indicating an inverse relationship between PCPUM inclusion and feed conversion.

In the final stage (29-56 days), feed intake also followed a quadratic trend, with the highest values observed at the 7.5% (3.16 kg/bird) and 10% (3.04 kg/bird) inclusion levels of PCPUM. However, weight gain did not differ significantly ($p > 0.05$) among treatments. Feed efficiency improved linearly with increasing PCPUM levels, reaching the high value (2.90 kg/kg) at the 10% inclusion level, suggesting a more inefficient feed conversion at higher PCPUM levels during this stage.

When considering general growth performance (8-56 days), feed intake increased quadratically, with the highest value observed at the 7.5% inclusion level (4.80 kg/bird). Weight gain also followed a quadratic trend, peaking at the 7.5% level (2.01 kg/bird). Feed efficiency exhibited a quadratic response, with the best values observed at 2.50% PCPUM level, while intermediate inclusion levels (5% to 7.5%) showed slightly better efficiency values.

Table 3. Growth performance of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Stage	Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Starter	FI	1.30[c]	1.51[b]	1.52[b]	1.63[a]	1.50[b]	0.04	10.72	0.47	$Y = 1.3051 + 0.0871x – 0.0066x^2$	0.89
	WG	0.50[c]	0.75[b]	0.78[ab]	0.82[a]	0.74[b]	<0.01	8.31	0.60	$Y = 0.5151 + 0.0963x – 0.0074x^2$	0.95
	FC	2.61[a]	1.99[b]	1.94[b]	2.00[b]	2.02[b]	<0.01	14.93	-0.53	$Y = 2.5446 – 0.2057x + 0.0159x^2$	0.87
Final	FI	2.83[b]	2.95[b]	3.10[a]	3.16[a]	3.04[ab]	<0.01	5.17	0.59	$Y = 2.8086 + 0.0903x – 0.0065x^2$	0.93
	WG	1.13	1.20	1.19	1.19	1.05	0.10	8.34	-	-	-
	FC	2.49[c]	2.45[c]	2.59[b]	2.65[b]	2.90[a]	0.02	8.62	0.65	$Y = 2.412 + 0.0408x$	0.82
General	FI	4.13[c]	4.46[b]	4.63[b]	4.80[a]	4.55[b]	<0.01	6.44	0.57	$Y = 4.1123 + 0.1798x – 0.0133x^2$	0.95
	WG	1.64[c]	1.96[a]	1.98[a]	2.01[a]	1.80[b]	<0.01	9.42	0.30	$Y = 1.654 + 0.1348x – 0.012x^2$	0.95
	FC	2.52[a]	2.27[c]	2.33[b]	2.38[b]	2.53[a]	<0.01	5.67	0.13	$Y = 2.276 + 0.2908x – 0.0488x^2$	0.82

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed conversion (kg/kg).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Physiological parameters

The hematological and plasma biochemical parameters of slow-growing broilers fed diets containing different levels of PCPUM are presented in Table 4. In hematological parameters, the inclusion of PCPUM resulted in a quadratic increase ($p \leq 0.05$) in hemoglobin, hematocrit, and mean corpuscular hemoglobin (MCH) levels. The highest values were observed at the 7.5% inclusion level, with hemoglobin reaching 11.53 g/dL and hematocrit increasing to 31.75%. Mean corpuscular hemoglobin also exhibited a significant increase, reaching its peak at 7.5% PCPUM inclusion. Conversely, the inclusion of PCPUM did not significantly affect ($p > 0.05$) erythrocytes (RBC) count, mean corpuscular volume (MCV), or mean corpuscular hemoglobin concentration (MCHC).

In plasma biochemical parameters, total protein, triglycerides, glucose, and uric acid levels exhibited significant reductions ($p \leq 0.05$) with increasing PCPUM inclusion. The total protein concentration declined from 5.12 g/dL in the control group to 3.87 g/dL at the highest PCPUM inclusion level (10.0%). Similarly, triglyceride levels showed a marked reduction, decreasing from 134.63 mg/dL in the control group to 40.25 mg/dL at 10.0% PCPUM inclusion; and glucose levels also decreased with PCPUM inclusion, from 231.67 mg/dL in the control group to 200.15 mg/dL at 10.0% PCPUM.

Interestingly, cholesterol levels significantly increased ($p \leq 0.05$) at 5.0%, 7.5%, and 10.0% PCPUM inclusion, reaching a peak at 5.0% (323.63 mg/dL) before slightly decreasing at higher inclusion levels. Albumin concentrations increased significantly at 7.5% PCPUM inclusion (2.34 g/dL). However, at 10.0% inclusion, albumin levels slightly declined.

Table 4. Physiological parameters of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Parameters	Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Hematological	HEM	9.78[c]	10.66[b]	11.14[ab]	11.53[a]	10.43[b]	<0.01	13.11	0.21	$Y = 9.6954 + 0.5497x – 0.0463x^2$	0.91
	RBC	1.21	1.18	1.25	1.14	1.27	0.48	18.21	-	-	-
	HET	28.68[c]	29.12[c]	30.68[b]	31.75[a]	30.06[b]	<0.01	9.51	0.26	$Y = 28.301 + 0.7585x – 0.0543x^2$	0.74
	MCV	240.88	251.28	259.05	281.85	242.01	0.13	19.74	-	-	-
	MCH	82.35[c]	91.18[b]	93.11[b]	102.56[a]	83.45[c]	<0.01	19.62	0.10	$Y = 80.905 + 6.0701x – 0.5527x^2$	0.69
	MCHC	34.18	36.70	36.50	36.47	34.65	0.25	11.53	-	-	-
Plasma biochemical	TOP	5.12[a]	4.58[b]	4.13[b]	3.96[c]	3.87[c]	0.05	3.66	-0.24	$Y = 4.956 – 0.1248x$	0.90
	TRI	134.63[a]	100.97[a]	57.25[b]	54.13[b]	40.25[c]	<0.01	7.93	-0.44	$Y = 124.57 – 9.424x$	0.90
	GLU	231.67[a]	228.13[ab]	225.28[b]	217.65[bc]	200.15[c]	0.04	10.70	-0.01	$Y = 235.28 – 2.9408x$	0.86
	COL	219.43[b]	239.08[b]	323.63[a]	315.99[a]	311.68[a]	0.03	11.07	0.39	$Y = 209.66 + 26.469x – 1.6013x^2$	0.86
	ALB	1.88[c]	2.17[b]	2.18[b]	2.34[a]	2.00[bc]	0.05	4.05	0.06	$Y = 1.8734 + 0.1433x – 0.0127x^2$	0.83
	URA	4.05[a]	2.86[b]	2.19[b]	2.15[b]	1.80[c]	0.04	6.27	-0.39	$Y = 3.652 – 0.2084x$	0.85

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] HEM = Hemoglobin (g/dL). RBC = Erythrocytes (M/mm³). HET = Hematocrit (%). MCV = Mean Corpuscular Volume (um³). MCH = Mean Corpuscular Hemoglobin (pg/cel). MCHC = Mean Corpuscular Hemoglobin Concentration (g/dL). TOP = Total proteins (g/dL). TRI = Triglycerides (mg/dL). GLU = Glucose (mg/dL). COL = Cholesterol (mg/dL). ALB = Albumin (mg/dL). URA = Uric acid (mg/dL).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Meat quality

Slaughter weight and carcass yield (Table 5) of slow-growing broilers were significantly ($p \leq 0.05$) influenced by the inclusion of PCPUM in the diet. The inclusion level of 7.5% of PCPUM resulted in heavier chickens (2.47 kg/bird) at slaughter and higher carcass yield (80.31%), in addition to higher weights of liver, gizzard and foot. When evaluating the commercial cuts (Table 5), the inclusion level of 7.5% of PCPUM in the diet of slow-growing broilers showed higher ($p \leq 0.05$) yields for breast, thigh and drumstick. These results contrasted with the control group, where lower yields of these commercial cuts were observed.

In the centesimal composition of the breasts (Table 6), no significant differences ($p > 0.05$) were found between the treatments for any of the parameters evaluated. This suggests that the inclusion of PCPUM in the diet did not significantly affect the proximal composition of the chicken breast, maintaining the quality of the final product.

Table 5. Slaughter weight, carcass yield, viscera and commercial cuts of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Stage	Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Carcass and viscera	SAW	2.15[c]	2.26[b]	2.31[b]	2.47[a]	2.23[b]	0.04	8.96	0.23	$Y = 2.1257 + 0.0822x – 0.0067x^2$	0.68
	CAY	77.99[b]	73.93[c]	76.10[b]	80.31[a]	79.19[ab]	0.01	4.02	-0.18	$Y = 76,879 - 0,5539x + 0,0905x^2$	0.67
	FOT	82.58[c]	84.41[b]	85.08[b]	90.25[a]	82.16[c]	0.02	9.99	0.08	$Y = 81.705 + 1.9531x – 0.1753x^2$	0.66
	LIV	23.36[bc]	24.26[b]	26.65[ab]	27.14[a]	21.85[c]	0.05	12.81	-0.16	$Y = 22.64 + 1.6264x – 0.1632x^2$	0.73
	GIZ	42.31[c]	45.41[b]	47.11[ab]	49.37[a]	45.56[b]	0.05	11.29	0.24	$Y = 41.966 + 1.9338x – 0.1515x^2$	0.88
	HER	9.30	9.10	9.30	9.03	8.29	0.57	10.40	-	-	-
Commercial cuts	BRE	28.18[c]	29.64[b]	30.07[a]	30.33[a]	29.82[ab]	0.04	9.05	-0.15	$Y = 28.227 + 0.6285x – 0.047x^2$	0.98
	DRU	15.38[c]	15.50[c]	16.07[b]	17.46[a]	16.93[b]	0.04	8.06	0.46	$Y = 15.187 + 0.2573x – 0.0055x^2$	0.78
	THI	11.63[c]	12.78[b]	12.83[b]	13.73[a]	12.83[b]	0.03	10.62	0.34	$Y = 11.626 + 0.5054x – 0.0371x^2$	0.84
	BAC	27.14	24.35	23.22	20.38	22.39	0.29	8.67	-	-	-
	WIN	11.04	11.05	11.18	11.80	11.76	0.25	6.83	-	-	-
	NEC	6.63	6.68	6.63	6.30	6.27	0.22	9.30	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] SAW = Slaughter weight (kg/bird). CAY = Carcass Yield (kg/bird). FOT = Foot (g/bird). LIV = Liver (g/bird). GIZ = Gizzard (g/bird). HER = Heart (g/bird). BRE = Breast (%). DRU = Drumstick (%). THI = Thigh (%). BAC = Back (%). WIN = Wings (%). NEC = Neck (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Table 6. Proximate composition of breasts samples of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MOS	73.07	73.32	73.11	73.58	73.49	0.24	1.30	-	-	-
PRO	1.09	0.98	1.01	0.78	0.97	0.39	1.96	-	-	-
FAT	1.75	1.57	1.48	1.51	1.24	0.31	1.41	-	-	-
MIN	24.09	24.13	24.40	24.13	24.30	0.22	1.79	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] MOS = Moisture (%). PRO = Proteins (%). FAT = Fats (%). MIN = Minerals (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

DISCUSSION

Primally, we observed that the nutritional composition of PCPUM contributed to the improved performance of broilers, positively impacting most performance variables, particularly enhancing feed conversion. PCPUM proved to be a moderate source of protein and fiber, with a considerable energy content, making it a potentially interesting ingredient for broiler feed. Dietary fiber in poultry nutrition has gained prominence (Jha and Mishra, 2021). Although traditionally classified as an antinutritional component, studies show that balanced inclusion of dietary fiber can have positive effects on digestive physiology and promote modulation of the intestinal microbiota (Jha and Mishra, 2021; Singh and Kim, 2021; Mateos et al., 2012; Rufino et al., 2021), contributing to zootechnical performance (Mateos et al., 2012; Rufino et al., 2021).

However, its effects on poultry physiology represent a significant challenge, as many of these alternative ingredients consist of by-products derived from food processing industries, primarily composed of peels and seeds, which naturally have a high fiber content (Rufino et al., 2015; Cruz and Rufino, 2017; Rufino et al., 2021). The fiber concentration in alternative feed ingredients can vary considerably, and when present in high levels, it may negatively affect the metabolism of nutrients such as proteins and soluble carbohydrates, resulting in impaired bird performance (Liu et al., 2018; Rufino et al., 2021; Sanches et al., 2023; Cho et al., 2024).

The inclusion of PCPUM yielded interesting results, with positive outcomes in feed intake and weight gain. It is worth noting that agro-industrial by-products contain bioactive compounds of nutritional value, capable of exhibiting characteristics similar to the original products from which they are derived, with high concentrations of nutrients such as carbohydrates, proteins, lipids, vitamins, and phenolic compounds (Vinocunga-Pillajo and Jiménez Tamayo, 2025). These compounds have the potential to optimize nutrient utilization and promote a more efficient physiological response in poultry (Cruz and Rufino, 2017).

Malhado et al. (2022) found that the inclusion of up to 12% barley residue in diets for Label Rouge broilers did not affect weight gain, feed conversion, or carcass yield, and it can be used from 49 to 90 days of age without reducing zootechnical performance. Chaves et al. (2024) observed that the inclusion of 15% tucumã meal in diets for slow-growing broilers of the Label Rouge lineage during the initial stage did not alter feed intake. However, there was an impact on weight gain and feed efficiency in both the initial and final stages, suggesting a possible influence on nutrient utilization from the diet. Complementing these studies, Santos et al. (2024) found that the inclusion of 10% *Paullinia cupana* peel meal in the diet of slow-growing broilers provided the best results, with beneficial effects on productive performance, as well as improvements in meat quality and the yield of high-value commercial cuts such as breast, thigh, and drumstick.

The significant increase in hemoglobin levels, hematocrit, and mean corpuscular hemoglobin (MCH) with the inclusion of 7.5% PCPUM suggests a positive effect on the blood health of the animals. Studies related to hematological parameters in birds indicate that various factors can influence reference values. For example, in broilers, variations in hematocrit levels have been observed, ranging between 29.6% and 33.2%, as well as in total erythrocyte count, which ranged from 1.69 to 2.03 x 10^6/µL (Borsa, 2009). Factors such as age, environmental conditions, and geographic location have been identified as variables that can significantly alter hematological parameters in birds (Cardoso and Tessari, 2003). However, Muneer et al. (2021) and Al-Khalaifah et al. (2022) indicate that reference values for hematocrit in birds generally fall within the range of 25% to 50%. Values below this range may indicate anemia, while levels above this limit may suggest conditions such as dehydration or polycythemia.

Studies involving the inclusion of biological silage from tambaqui (*Colossoma macropomum*) at concentrations between 1% and 2% showed positive effects, promoting improvements in egg quality, feed efficiency, and some hematological parameters, without compromising the health or productivity of the birds (Guimarães et al., 2025). Research on *Paullinia cupana* suggests potential health benefits and effects on hematological parameters.

The aqueous extract of guarana demonstrated antioxidant properties and attenuated renal and hematological side effects in rats, including the restoration of white blood cell counts (Belló et al., 2021).

The observed reduction in total protein, triglycerides, glucose, and uric acid levels in response to the increased inclusion of PCPUM in the diet suggests a possible modulating effect on energy and protein metabolism. Elevated triglyceride concentrations can negatively impact growth performance (Zhou et al., 2020; Hu et al., 2021). The decrease in triglyceride and glucose levels may be attributed to guarana's ability to promote lipolysis and lipid oxidation, as well as influence blood glucose regulation. These effects align with studies highlighting the thermogenic and metabolism-regulating properties associated with guarana, as evidenced by (Lima et al., 2018; Bortolin et al., 2019).

There was a significant increase in cholesterol concentrations observed with the inclusion of PCPUM in the diet. Studies demonstrate that the addition of guarana to diets can have significant effects on lipid metabolism and cholesterol levels. Ruchel et al. (2017) observed that guarana was able to reduce total cholesterol and low-density lipoprotein cholesterol in rats with hypercholesterolemia, pointing to potential anti-inflammatory properties of this plant. On the other hand, Lima et al. (2018) found that guarana supplementation in mice fed a high-fat diet did not alter cholesterol levels but promoted improvements in metabolic parameters, suggesting a stimulation of energy metabolism and mitochondrial biogenesis. It is worth noting that hematological and serum biochemical parameters are essential indicators for understanding the results, as they provide relevant information about the nutritional status of birds subjected to the evaluated diets (Campbell, 2004).

The results presented in the study demonstrate that the inclusion of 7.5% PCPUM in the diet of slow-growing broilers significantly influenced slaughter weight and carcass yield, as well as higher weights of liver, gizzard, and paws, and greater yields of breast, thigh, and drumstick. These findings suggest that PCPUM may have a positive effect on the body development of the birds, possibly due to bioactive compounds in guarana that stimulate metabolism (Silva et al., 2019), which influenced feed efficiency through diet composition and genetic factors (Del Vesco et al., 2015).

The improvement in the yield of premium cuts, such as the breast, is particularly relevant, given the high demand for this part of the carcass in the consumer market. Holanda et al. (2015), while investigating the impact of adding whole cassava meal to the diet of free-range broilers, did not observe any effect of the treatments on the percentage yields of commercial cuts and carcass viscera. They concluded that it is possible to include up to 48% of this ingredient in the feed without compromising the zootechnical performance of the birds.

The inclusion of PCPUM in the diet did not exert a significant impact on the proximal composition of breast meat, maintaining the quality of the product. The absence of changes in the centesimal composition suggests that PCPUM does not interfere with the basic nutritional properties of the meat, which is relevant for the poultry industry, which seeks to maintain consistent quality standards. Meat quality is influenced by physicochemical characteristics, as highlighted by Ferreira et al. (2023). Additionally, Monte et al. (2012) and Moura et al. (2015) corroborate the importance of chemical and physical analyses in evaluating meat quality, emphasizing that quality should be measured through objective tests rather than subjective judgments.

Regarding the animals used in the study, slow-growing broilers exhibit lower mortality rates and fewer locomotor problems (Dixon, 2020; Rayner et al., 2020). In general, they display greater physical activity and more favorable welfare indicators compared to fast-growing breeds (Dixon, 2020; Rayner et al., 2020; van der Eijk et al., 2022), making them a promising segment (Morais et al., 2015). According to Cordeiro et al. (2014), in areas with high temperatures, the selection of breeds that demonstrate adaptability and resistance to thermal stress is crucial to ensure the production of quality meat, as environmental factors significantly influence the development and productivity of broilers (Souza et al., 2015).

CONCLUSION

Based on the results obtained, the inclusion of 7.5% PCPUM in the diet of slow-growing broilers showed positive impacts on growth performance, improving feed efficiency and slaughter weight without compromising meat quality. Additionally, an increase in hemoglobin and hematocrit levels was observed, as well as a reduction in triglyceride and glucose levels, indicating metabolic benefits from the inclusion of this agro-industrial by-product. The absence of adverse effects on the proximate composition of the breast meat reinforces the feasibility of using PCPUM in poultry feed as a sustainable alternative. Thus, utilizing this feedstuff can represent a promising strategy to reduce production costs and promote sustainability in poultry farming, especially in regions such as the Amazon, where logistical challenges increase the cost of conventional diets.

Data availability

The data of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors have no conflicts of interest to declare.

Declaration of funding

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REFERENCES

Al-Khalaifah H, Al-Nasser A, Al-Surrayai T, Sultan H, Al-Attal D, Al-Kandari R, Al-Saleem H, Al-Holi A, Dashti F (2022) Effect of ginger powder on production performance, antioxidant status, hematological parameters, digestibility, and plasma cholesterol content in broiler chickens. *Animals (Basel)* 12, 901. https://doi.org/10.3390/ani12070901

Aride PHR, Oliveira AM, Batista RB, Ferreira MS, Pantoja-Lima J, Ladislau DS, Castro PDS, Oliveira AT (2018) Changes on physiological parameters of tambaqui (Colossoma macropomum) fed with diets supplemented with Amazonian fruit Camu camu (Myrciaria dubia). *Brazilian Journal of Biology* 78(2), 360-367. http://dx.doi.org/10.1590/1519-6984.169442

AOAC-Association of Official Agricultural Chemists (2019) *Official Methods of Analysis of AOAC International (21th ed.)*. (AOAC: Rockville, USA)

Belló C, Prestes AP, Schemberger JA, Hacke ACM, Pereira RP, Manente FA, Carlos IZ, Andrade CR, Fernandes D, Cruz IBM, Unfer TC, Vellosa JCR (2021) Aqueous extract of Paullinia cupana attenuates renal and hematological effects associated with ketoprofen. *Journal of Food Biochemistry* 45, e13560. https://doi.org/10.1111/jfbc.13560

Bortolin RC, Vargas AR, Ramos V, Gasparotto J, Chaves PR, Schnorr CE, Martinello K, Silveira AK, Gomes HM, Rabelo TK, Grunwald MS, Ligabue-Braun R, Gelain DC, Moreira JCF (2019) Guarana supplementation attenuated obesity, insulin resistance, and adipokines dysregulation induced by a standardized human Western diet via brown adipose tissue activation. *Phytotherapy Research* 33(5), 1394–1403. https://doi.org/10.1002/ptr.6330

Borsa A (2009) Hematological values in industrially raised broiler chickens. *Colloquium Agrariae* 5(1), 25-31. https://doi.org/10.5747/CA.V5I1.331

Campbell TW (2004) Clinical Chemistry of Birds. In: Thrall MA (ed) *Veterinary Hematology and Clinical Chemistry*. (Lippincott Williams & Wilkins: Philadelphia)

Cardoso ALSP, Tessari ENC (2003) Study of the haematogogical parameters in broilers. *Arquivos do Instituto de Biologia* 70(4), 419-424. https://doi.org/10.1590/1808-1657v70p4192003

Carvalho LVN, Cordeiro MF, Lins TUL, Sampaio MCDP, De Mello GSV, Da Costa VCM, Marques LLM, Klein T, De Mello JCP, Cavalcanti IMF, Pitta IR, Pitta MGR, Rêgo MJBM (2016) Evaluation of antibacterial, antineoplastic, and immunomodulatory activity of Paullinia cupana seeds crude extract and ethyl-acetate fraction. *Evidence-Based Complementary and Alternative Medicine* 2016, 1203274. https://doi.org/10.1155/2016/1203274

Chatterjee S, Hadi AS (2006) *Regression analysis by example (4th ed.)*. (John Wiley & Sons: New Jersey, USA)

Chaves FAL, Guimarães LL, Guimarães CC, Souza LSS, Rufino JPF, Pereira AM (2024) Tucumã bran as an alternative food to diets for slow-growing broilers. *Revista em Agronegócio e Meio Ambiente* 17(3), e11782. https://doi.org/10.17765/2176-9168.2024v17n3e11782

Cho S, Shi H, Sureshkumar S, Kim I (2024) The effects of the dietary inclusion of by-products obtained after the extraction of vitamin B2 from fermented soybean on the performance and meat quality of growing–finishing pigs. *Applied Sciences* 14, 803. https://doi.org/10.3390/app14020803

Cordeiro M, Freitas HD, Aquino E, Sousa E (2014) Evaluation of heat stress in country chickens in summer conditions in the western Amazon. *Enciclopédia Biosfera* 10, 358-363.

Cruz FGG, Rufino JPF, Melo RD, Feijó JC, Damasceno JL, Costa APGC (2016) Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. *Revista em Agronegócio e Meio Ambiente* 9, 371–391. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Cruz FGG, Rufino JPF (2017) *Formulation and manufacture of feed (poultry, pigs and fish)*. (EDUA: Manaus, Brazil) [in Portuguese]

Da Silva GS, Santana GM, Gomes RL, De Jesus RM (2024) Physical-Environmental Characterization of Areas for the Cultivation of Guaraná (Paullinia cupana) in Bahia, Brazil. *Revista Brasileira de Geografia Física* 17(2), 1226–1250. https://doi.org/10.26848/rbgf.v17.2.p1226-1250

Del Vesco AP, Gasparino E, Soares MAM, Voltolini DM, Khatlab AS (2015) Effects of nutrition, genetic and its interaction on animal metabolism. *Acta Tecnológica* 10(1), 9-17. https://doi.org/10.35818/acta.v10i1.143

De Souza T, Rufino JPF, Dias PG, Souza LF, Araújo KF, Machado NJB (2024) Use of regional alternative feeds in poultry diets in the Amazon rainforest. *Observatorio de la Economía Latinoamericana* 22(12), 01-24. https://doi.org/10.55905/oelv22n12-287

De Oliveira ALL, Muniz MP, Da Silva FMA, Do Nascimento AH, Dos Santos-Barnett TC, Gomes FB, Krug C (2024) Chemical composition of guarana flowers and nectar and their ecological significance. *Biochemical Systematics and Ecology* 112, 104769. https://doi.org/10.1016/j.bse.2023.104769

Dixon LM (2020) Slow and steady wins the race: The behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed. *PlosONE* 15, e0231006. https://doi.org/10.1371/journal.pone.0231006

Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JRG, Gruber B, Lafourcade B, Leitão PJ, Mkemler T, McClean C, Osborne PE, Reineking B, Schrer B, Skidmore AK, Zurell D, Lautenbach S (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36, 27–46. https://doi.org/10.1111/j.1600-0587.2012.07348.x

Dos Reis APL, Ferreira RSM, Fonseca MF, Farias AR (2024) Analysis of production costs of pig and poultry farms and aquaculture in the state of Paraná. *Revista Contemporânea* 4(3), 1-11. https://doi.org/10.56083/RCV4N3-094

Dou Z, Toth JD, Westendorf ML (2018) Food waste for livestock feeding: Feasibility, safety, and sustainability. *Global Food Security* 17, 154-161. https://doi.org/10.1016/j.gfs.2017.12.003

Ferreira ACS, Almeida GV, Ribeiro RA, Fagundes WO, Adami APV (2023) Basic characteristics that interfere with the quality of pork meat associated with physical-chemical characteristics of sausages sold in Pouso Alegre – MG. *Enciclopédia Biosfera* 20(46), 308. https://doi.org/10.18677/encibio_2023d4

Guimarães CC, Nóbrega TC, Santos ANA, Barai AA, Mourão LS, Gomes MFS, Ferreira WS, Chaves FAL, Junior JLS, Mendonça MAF, Silva AJI, Rufino JPF, Oliveira AT (2025) Biological silage from tambaqui (Colossoma macropomum) byproducts on the productive performance, hematological parameters and egg quality of older commercial hens. *Tropical Animal Health and Production* 57, 20. https://doi.org/10.1007/s11250-024-04273-8

Goldenfarb PB, Bowyer FP, Hall E, Brosius E (1971) Reproducibility in the hematology laboratory: the microhematocrit determination. *American Journal of Clinical Pathology* 56, 35-39. https://doi.org/10.1093/ajcp/56.1.35

Holanda MAC, Holanda MCR, Vigoderes RB, Dutra Junior WM, Albino LFT (2015) Performance of broilers redneck fed cassava meal. *Revista Brasileira de Saúde e Produção Animal* 16(1), 106-117. https://doi.org/10.1590/S1519-99402015000100012

Hu X, Li X, Xiao C, Kong L, Zhu Q, Song Z (2021) Effects of dietary energy level on performance, plasma parameters, and central AMPK levels in stressed broilers. *Frontiers in Veterinary Science* 8, 681858. https://doi.org/10.3389/fvets.2021.681858

Jha R, Mishra P (2021) Dietary fiber in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: a review. *Journal of Animal Science and Biotechnology* 12, 51. https://doi.org/10.1186/s40104-021-00576-0

Lima NS, Teixeira L, Gambero A, Ribeiro ML (2018) Guarana (Paullinia cupana) stimulates mitochondrial biogenesis in mice fed high-fat diet. *Nutrients* 10, 165. https://doi.org/10.3390/nu10020165

Liu WC, Zhou SH, Kim YM, Lee SI, Pang HY, Kim IH (2018) Impacts of rapeseed meal, canola meal and their mixture substitute for soybean meal on performance of lactating sows and their offspring. *Indian Journal of Animal Research* 53, 124-128. https://doi.org/10.18805/ijar.B-837

Logan M (2010) *Biostatistical design and analysis using R: a practical guide*. (John Wiley & Sons: New Jersey, USA)

Machado KN, Freitas AA, De Cunha LH, Faraco AAG, Pádua RM, De Braga FC, Vianna-Soares CD, Castilho RO (2018) A rapid simultaneous determination of methylxanthines and proanthocyanidins in Brazilian guaraná (Paullinia cupana Kunth.). *Food Chemistry* 239, 180–188. https://doi.org/10.1016/j.foodchem.2017.06.089

Malhado ALN, Alves JR, D'avilla Lima HJ, Rosa MS (2022) Barley residue levels in the diet of Label Rouge broilers. *Revista Acadêmica: Ciência Animal* 20, e20002. https://doi.org/10.7213/acad.2022.20002

Mateos GG, Jiménez-Moreno E, Serrano MP, Lázaro RP (2012) Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. *Journal of Applied Poultry Research* 21, 156–174. https://doi.org/10.3382/japr.2011-00477

Mendes AA, Patrício IS (2004) Controls, records and performance evaluation of broilers. In: Mendes AA, Nääs IA, Macari M (Eds) *Broiler production*. pp. 323–336. (FACTA: Campinas, Brazil) [in Portuguese]

Monte ALS, Gonsalves HRO, Villarroel ABS, Damaceno MN, Cavalcante ABD (2012) Quality of goats and lambs meat: a review. *Agropecuária Científica no Semiárido* 8(3), 11-17. https://doi.org/10.30969/acsa.v8i3.161

Morais J, Ferreira BP, Jacome DTMI, Mello R, Breda CF, Rorato NRP (2015) Growth curve of different strains of broiler chickens. *Ciência Rural* 45(10), 1872-1878. https://doi.org/10.1590/0103-8478cr20130867

Moura JWF, Medeiros FM, Alves MGM, Batista ASM (2015) Fatores influenciadores na qualidade da carne suína. *Revista Científica de Produção Animal* 17(1), 18-29. https://doi.org/10.15528/2176-4158/rcpa.v17n1p18-29

Muneer M, Bilal M, Ditta A (2021) A comparative study of some hematological parameters of broiler and indigenous breeds of poultry. SVU-*International Journal of Agricultural Science* 3, 189-198. https://doi.org/10.21608/svuijas.2021.99388.1146

Pacheco JC, Neto JMM, Da Silva EA (2018) Environmental impacts and ration formulation for broiler. *Latin American Journal of Life Cycle Assessment* 2(2 esp.), 97–109. https://doi.org/10.18225/lalca.v1iEspec.4327

Pinotti L, Ferrari L, Fumagalli F, Luciano A, Manoni M, Mazzoleni S, Govoni C, Rulli MC, Lin P, Bee G, Tretola M (2023) Review: Pig-based bioconversion: the use of former food products to keep nutrients in the food chain. *Animal* 17(suppl. 2), 100918. https://doi.org/10.1016/j.animal.2023.100918

Rayner AC, Newberry RC, Vas J, Mullan S (2020) Slow-growing broilers are healthier and express more behavioural indicators of positive welfare. *Scientific Reports* 10, 15151. https://doi.org/10.1038/s41598-020-72198-x

Rostagno HS, Albino LFT, Calderano AA, Hannas MI, Sakomura NK, Costa FGP, Rocha GC, Saraiva A, Abreu MLT, Genova JL, Tavernari FC (2024) *Brazilian tables for poultry and swine: food composition and nutritional requirements* (5th ed.). (Federal University of Viçosa Press: Viçosa, Brazil) [in Portuguese]

Ruchel JB, Braun JBS, Adefegha SA, Manzoni AG, Abdalla FH, de Oliveira JS, Trelles K, Signor C, Lopes STA, da Silva CB, Castilhos LG, Rubin MA, Leal DBR (2017) Guarana (Paullinia cupana) ameliorates memory impairment and modulates acetylcholinesterase activity in Poloxamer-407-induced hyperlipidemia in rat brain. *Physiology & Behavior* 168, 11–19. https://doi.org/10.1016/j.physbeh.2016.10.003

Rufino JPF, Cruz FGG, Miller WPM, Melo RD, Feijó JC, Chagas EO (2015) Economical analysis of the inclusion of flour residue of tucumã (Astrocaryum vulgare, Mart) in the feeding of laying hens. *Revista Brasileira de Saúde e Produção Animal* 16(1), 1–9.

https://doi.org/10.1590/S1519-99402015000100001

Rufino JPF, Cruz FGG, Brasil RJM, Oliveira Filho PA, Melo RD, Feijó JC (2021) Relationship between the level and the action period of fiber in diets to laying hens. *Acta Scientiarum Animal Sciences* 43, e49033. https://doi.org/10.4025/actascianimsci.v43i1.49033

Sakomura NK, Rostagno HS (2016) *Research methods in monogastric nutrition* [in Portuguese]. (Funep: Jaboticabal, SP)

Sanches DS, Garcia ERM, Kiefer C (2023) Alternative diets for poultry and swine: A brief review. *Revista Eletrônica Multidisciplinar de Investigação Científica* 2(1), 1–11. https://doi.org/10.56166/remici.2023.2.v2n1.2.3

Sandström V, Chrysafi A, Lamminen M, Troell M, Jalava M, Piipponen J, Siebert S, Hal OV, Virkki V, Kummu M (2022) Untapped power of food system by-products to increase global food supply. Nature Food 3, 729–740. https://doi.org/10.1038/s43016-022-00589-6

Santos ANA, Rufino JPF, Viana AL, Guimarães CC, Gomes MFS, Barai AA, Nóbrega TC, Ribeiro MWS, Silva AJI, Chaves FAL, Mendonça MAF, Silva Junior JL, Costa Neto PQ, Oliveira AT (2024) Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. *Animal Production Science* 64, AN24137. https://doi.org/10.1071/AN24137

Santos AL, Sales JJM, Barbosa Filho JAD, Meireles ACM, Oliveira CW, Simplicio YR, Lopes IRV, Freitas ER (2024) Brooding density and its effect on the performance of slow-growing broilers. *Revista Contemporânea* 4(7), e5059. https://doi.org/10.56083/RCV4N7-096

Schimpl FC, da Silva JF, Gonçalves JFC, Mazzafera P (2013) Guarana: revisiting a highly caffeinated plant from the Amazon. *Journal of Ethnopharmacology* 150(1), 14–31. https://doi.org/10.1016/j.jep.2013.08.023

Silva CP, Soares-Freitas RAM, Sampaio GR, Camargo AC, Silva EAF (2019) Guarana as a source of bioactive compounds. *Journal of Food Bioactives* 6, 1–5. https://doi.org/10.31665/JFB.2019.6182

Singh AK, Kim WK (2021) Effects of dietary fiber on nutrients utilization and gut health of poultry: a review of challenges and opportunities. *Animals (Basel)* 11, 181. https://doi.org/10.3390/ani11010181

Souza BB, Silva RC, Rodrigues LR, Rodrigues VP, Arruda AS, Souza BB (2015) Analysis of thermal stress effect about production, physiology and diet of birds. *Revista Agropecuária Científica no Semiárido* 11(2), 22–26. https://doi.org/10.30969/acsa.v11i2.644

Souza AL, Lopez-Losano JL, Angelo PCS, Souza-Neto JN, Cordeiro IB, Astolfi-Filho S, Andrade EV (2017) A proteomic approach to guarana seed and pericarp maturation. *Genetics and Molecular Research* 16(3), gmr16039642. http://dx.doi.org/10.4238/gmr16039642

Shurson GC (2020) "What a waste": can we improve sustainability of food animal production systems by recycling food waste streams into animal feed in an era of health, climate, and economic crises?. *Sustainability* 12, 7071. https://doi.org/10.3390/su12177071

Tavares-Dias M, Moraes FR (2004) *Hematology of teleost fish* [in Portuguese]. (Villimpress: Ribeirão Preto)

van der Eijk JAJ, Bakker JGBC, van Krimpen MM, Molenaar R, van den Brand H, de Jong IC (2022) Providing organic macro minerals and an elevated platform improved tibia characteristics, and increased locomotion and performance of fast- and slower-growing broilers. *Poultry Science* 101, 101973. https://doi.org/10.1016/j.psj.2022.101973

Van Hal O, De Boer IJM, Muller A, De Vries S, Erb K-H, Schader C, Gerrits WJJ, Van Zanten HHE (2019) Upcycling food leftovers and grass resources through livestock: impact of livestock system and productivity. *Journal of Cleaner Production* 219, 485–496. https://doi.org/10.1016/j.jclepro.2019.01.329

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vinocunga-Pillajo DR, Jiménez Tamayo FM (2025) Análisis de las propiedades funcionales de productos a partir de subproductos agroindustriales: Revisión sistemática. *Revista Académica Ciencia y Tecnología* 10(1), 1–19. https://doi.org/10.59410/RACYT-v10n01ep01-0153

Wintrobe MM (1934) Relation of variations in mean corpuscular volume to number of reticulocytes in pernicious anemia: the significance of increased bone marrow activity in determining the mean size of red corpuscles. *Journal of Clinical Investigation* 13, 669–676. https://doi.org/10.1172/JCI100613

Wu Y, Huang J, Quan S, Yang Y (2022) Light regimen on health and growth of broilers: an update review. *Poultry Science* 101, 101545. https://doi.org/10.1016/j.psj.2021.101545

Zhou Y, Chen Z, Lin Q, Yang Y, Hang, Zhou X, Wu C, Xie Z (2020) Nuciferine reduced fat deposition by controlling triglyceride and cholesterol concentration in broiler chickens. *Poultry Science* 99, 7101–7108. https://doi.org/10.1016/j.psj.2020.09.013

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CHAPTER 7: Growth performance and economic feasibility of guarana by-products in diets for slow-growing broilers[1]

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Abstract: The study evaluated the inclusion of guaraná by-products, guaraná peel meal (GPEM) and guaraná pulp meal (GPUM), in diets for slow-growing broilers to assess their impact on growth performance and economic feasibility. To evaluate the effects of guarana by-products, two experiments were conducted. In both experiments, 240 slow-growing male broilers of the Label Rouge strain were used. Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the product being tested) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. GPEM, with higher fiber content, improved feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM, with higher energy content, showed optimal performance at intermediate levels (7.5%). Both by-products enhanced meat production and economic re-turns compared to the basal diet. The results suggest that GPEM is suitable for systems prioritizing feed efficiency and cost-effectiveness, while GPUM is better suited for phases requiring higher energy intake and weight gain. Additionally, the use of these agro-industrial residues promotes sustainability by integrating circular economy prac-tices into poultry production. The findings highlight the potential of guaraná by-products as alternative feed ingredients to improve productivity and reduce costs, particularly in regions with abundant availability of these residues.

Keywords: alternative food, Amazon, feed efficiency, *Paullinia cupana*, sustainability.

INTRODUCTION

In various regions of Brazil, especially in the Amazon, logistics for inputs significantly increase the cost of feddstuffs used in the formulation and production of balanced diets (Cruz *et al*., 2016). This scenario encourages research testing alternative feeds, especially these from agro-industrial residues under the premise of reducing feed costs, which can account for 60% to 80% of total production costs in activities such as poultry farming (Rufino *et al*., 2015; Cruz *et al*., 2016; Costa *et al*., 2018a,b; Aride *et al.,* 2020, 2018, 2016; Polese *et al.,* 2022). These residues are often processed into meals and incorporated into poultry diets as a nutritional supplement, while also providing competitive advantages for producers (Cruz & Rufino, 2017).

The Amazon region presents numerous native species with economic, technological, and nutritional potential, which have sparked scientific interest in various fields such as food, pharmaceuticals, cosmetics, flavorings, and essences, as well as their potential applications in animal feeding (Clement *et al*., 2005; Oliveira *et al*., 2010). In this context, one fruit that is produced intensively and generates a large amount of residue during the harvest season, with potential for use in animal feed, is guarana (*Paullinia cupana*) (Ferreira *et al*., 2022). This fruit, even native to the Amazon, is cultivated in several parts of Brazil and holds great economic and social importance due to its high demand from the beverage industry for the production of soft drinks and energy drinks (Espinola *et al*., 1997; Marques *et al*., 2016; Ferreira *et al*., 2022).

Among the poultry farming segments that require these alternative feeds, slow-growing broiler production has stood out, particularly for small and medium producers (Machado *et al*., 2018; Sarica *et al*., 2020; Cruz *et al*., 2023). These broilers exhibit greater tolerance to temperature variations and resistance to certain microorganisms (Sarica *et al*., 2020), along with a more gradual and proportional growth rate compared to fast-growing strains (Machado *et al*., 2018; Cruz *et al*., 2023). However, their longer growth period can lead to higher production costs, making these strains less economically attractive for large-scale production, though they remain appealing for alternative production systems (Lusk *et al*., 2019; Sarica *et al*., 2020).

References to the use of guarana or its by-products in poultry diets are very scarce in the literature (Santos *et al*., 2024). However, considering its rich nutritional properties, the volume of production that generates residues, and its importance to Brazilian agribusiness, guarana by-products may exhibit good biological and productive potential as well as economic viability for inclusion in poultry diets (Cruz & Rufino, 2017; Costa *et al*., 2018a,b; Santos *et al*., 2024). Moreover, they contribute to a sense of circular economy within these production chains (Cruz & Rufino, 2017; Oliveira, 2018; Ali *et al*., 2021). Based on this information, the present study aimed to evaluate the growth performance and economic feasibility of slow-growing broilers fe diets containing increase levels of guarana by-products.

MATERIALS AND METHODS

The current experiment was conducted at the Faculty of Agrarian Sciences of the Federal University of Amazonas, located in Manaus City, Amazonas State, Brazil. All experimental procedures were conducted in accordance with the guidelines of the Local Experimental Animal Care Committee and were approved by the UFAM ethics committee (protocol number 010/2022).

Acquisition and composition analysis of guarana by-products

The guarana by-products were obtained in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The following steps were performed to obtain guarana peel meal (GPEM): 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The peels were isolated as residues; 5) The seeds were processed for guarana extract extraction, used in the production of carbonated beverages by the beverage industry; 6) The guarana peels were dried in a closed-circulation oven at 105°C for 24 hours; 7) The dried guarana peels were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); and 8) the final product, referred to as GPEM, was bagged and stored in a dry and ventilated location for use in the preparation of experi-mental diets. To obtain guarana pulp meal (GPUM), the following steps were performed: 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The seeds were processed for guarana extract extraction, used in the production of carbonated beverages by the beverage industry; 5) The residues remaining from the seed extraction are separated and dried in a closed-circulation oven at 105°C for 24 hours; 6) these dried residues were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); 7) the final product, referred to as GPUM, is bagged and stored in a dry and ventilated location for use in the preparation of experimental diets.

Before conducting the experimental stage, the proximate composition of both GPEM and GPUM (Table 1) was determined at the Fish Technology Laboratory of UFAM. The dry matter content was determined in an oven at 105 °C following the AOAC 925.10 (2019) method. Mineral content was assessed by incineration in a muffle furnace at 550 °C, in accordance with the AOAC 923.03 (2019) method. Lipid content analysis followed the AOCS Ba 3-38 method. Total protein was determined using the Kjeldahl method, according to AOAC 920.87 (2019). Fiber content (crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF)) was analyzed as described by Van Soest et al. (1991).

Table 1. Composition of guaraná by-products tested.

Variables	Guarana peel meal	Guarana pulp meal
Dry matter, %	89.11	83.93
Crude protein, %	18.72	12.27
Fats, %	5.36	2.41
Minerals, %	5.33	1.01
Crude Fiber, %	44.04	29.17
Neutral detergent fiber, %	61.66	40.84
Acid detergent fiber, %	39.64	26.25
Soluble carbohydrates, %	26.55	55.14
Gross energy, kcal/kg	6,495.65	5,745.42
Metabolizable energy*, kcal/kg	2,258.64	2,828.56

* Determined using the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024).

Facilities, animals and experimental design

To evaluate the effects of guarana by-products on growth performance and economic viability, two experiments were conducted. The first assessed the effects of including GPEM on these parameters, while the second evaluated the effects of including GPUM on the same parameters. In both experiments, a poultry house with a ceiling height of 3.25 m was used, with structural adaptations to improve bird welfare. Temperature and relative humidity were monitored using a small digital weather station, recording averages of 27.6 °C and 62.3%, respectively. Throughout the experimental period, the broilers were monitored for potential signs of heat stress caused by the environment, a condition that was not observed during the entire experimental period in either experiment.

240 slow-growing male broilers of the Label Rouge strain were used in both experiments, sourced from the Hatchery Center of UFAM's Poultry Sector. Initially, 1-day-old chicks were housed in a brooder circle with wood shavings as bedding, tray feeders, and cup drinkers, at a density of 50 birds/m², with a central electric heating source, until they reached 7 days of age. Subsequently, they were allocated to their respective treatments in pens measuring 4 m² each, equipped with tubular feeders, pendulum drinkers, and wood shavings bedding on the floor. The experimental stages were divided into an initial (8–28 days) and a final (29–56 days), during which the birds had ad libitum access to diets and water. A lighting program suitable for slow-growing broilers was implemented (Wu et al., 2022).

Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the product being tested) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. The experimental diets (Tables 2 and 3) were formulated based on the reference values of Rostagno et al. (2024), except for the GPEM and GPUM, which used values from prior compositional analyses of the product. The metabolizable energy values of these guarana by-products were determined using estimation methods described by Sakomura and Rostagno (2016) and Rostagno et al. (2024).

The guarana by-products were a fixed component in the diet calculations, with other feedstuffs values adjusted based on the inclusion levels proposed in the experiments. The diets were formulated using the SuperCrac software (TD Software©, Viçosa, Brazil). The composition of these diets was analyzed to confirm their proximate composition according to the methods described by AOAC (2019), where moisture content was determined following method 925.10, mineral content according to method 923.03, lipid content analyses followed method Ba 3-38, total protein content was determined using method 920.87, and fiber content (crude fiber, NDF, and ADF) was determined according to the methods described by Van Soest et al. (1991).

Table 2. Composition of the experimental diets containing guarana peel meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Guarana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Common salt	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrients	Guarana levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	6.15	7.52	8.89	10.26	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.95	4.83	5.71	6.60	2.84	3.66	4.55	5.44	6.32
Total lysine, %	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine, %	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine, %	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan, %	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg =

Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.
[2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.
[3] Levels analyzed and calculated on a dry matter basis.

Table 3. Composition of the experimental diets containing guarana pulp meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	56.27	53.17	50.10	47.00	63.34	61,57	58,49	55,4	52,31
Soybean meal 46%	38.32	38.35	35.77	35.66	35.55	35.43	32.53	30,5	30,39	30,28	30,17
Guarana pulp meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2,50	5,00	7,50	10,00
Limestone	0.93	0.82	0.83	0.82	0.81	0.81	1.02	0,76	0,75	0,75	0,74
Dicalcium phosphate	1.79	1.79	1.82	1.84	1.85	1.87	1.55	1,58	1,60	1,61	1,63
Common salt	0.30	0.10	0.27	0.28	0.28	0.28	0.53	0,28	0,28	0,28	0,29
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.14	0.15	0.16	0,18	0.03	0,05	0,06	0,07	0,08
Soybean oil	0.00	0.27	1.90	2.58	3.25	3.93	0.50	2,26	2,93	3,61	4,28
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrients	Guarantee levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.86	87.67	87.58	87.50	87.89	87.76	87.59	87.42	87.35
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.15	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	3.94	4.61	5.27	5.93	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	5.52	6.45	7.38	8.30	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.55	4.15	4.74	5.34	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.14	1.12	1.11	1.10	1.06	1,00	0,99	0,98	0,97
Total methionine, %	0.45	0.45	0.47	0.47	0.48	0.49	0.35	0,35	0,35	0,36	0,37
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0,66	0,66	0,66	0,66
Total threonine, %	0.87	0.87	0.82	0.81	0.80	0.79	0.79	0,75	0,73	0,72	0,71
Total tryptophan, %	0.28	0.28	0.27	0.26	0.26	0.26	0.25	0,24	0,23	0,23	0,23

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg =

Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.
[2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.
[3] Levels analyzed and calculated on a dry matter basis.

Experimental analysis

In both experiments, during 56 days, performance data (feed intake and weight gain) were collected from the birds for use in the economic feasibility analysis following the methodological procedures described by Costa et al. (2018a,b) and Rufino et al. (2018). At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter by cutting the jugular vein. The carcasses were then scalded in hot water (60 °C for 62 seconds), defeathered, and eviscerated following the recommendations of Mendes and Patricio (2004).

For determining feed costs and production expenses, only the per-kilogram prices of the feedstuffs used and their updated prices in the region during the experiment were considered. The prices were as follows: corn, R$ 1.66; soybean meal, R$ 3.65; limestone, R$ 0.73; dicalcium phosphate, R$ 4.50; common salt, R$ 0.83; DL-Methionine 99%, R$ 51.00; and mineral and vitamin supplements (F1 - starter; F2 - grower; and F3 - finisher), R$ 28.35/kg (average price). The cost of GPEM and GPUM was calculated considering only transportation and handling expenses (labor), with estimated prices of R$ 0.30 and R$ 0.35 per kilogram, respectively. Fixed costs included depreciation of facilities and equipment (maintenance, water, electricity, etc.), where interest on capital remained unchanged in the short term and was considered constant across all treatments. Variable costs included only bird feed expenses and labor.

The variables were calculated based on the production of each plot. The Productive Efficiency Index (PEI) was determined using the formula:

PEI=(DWG*VIAB*100)/FCR

Where:

DWG = daily weight gain of the plot (kg)

VIAB = viability of the plot (%)

FCR = feed conversion ratio of the plot (kg/kg)

The feed cost (FC, R$), the only production cost used as an analysis variable, was determined through the acquisition of ingredients and feed preparation, estimated by the formula:

FC=AFI*AP

Where:

AFI = accumulated feed intake of the plot (kg)

AP = average price per kilogram of feed, considering both stages (R$/kg)

For total meat production (kg) and meat production per square meter (kg/m²), the carcass yield of slaughtered, scalded, defeathered, and cleaned animals was considered, as described by Costa et al. (2018b) and Rufino et al. (2018). To calculate the production cost per kilogram of meat (PCKG, R$/kg), the following formula was used:

PCKG=CA/PRODKG

Where:

FC = feed cost of the plot (R$)

PRODKG = meat production of the plot (kg)

To determine the production cost per square meter of meat (PCPSM, R$/m²), the following formula was used:

PCPSM=CA/PRODSM

Where:

FC = feed cost of the plot (R$)

PRODSM = meat production per square meter of the plot (kg/m²)

The gross revenue (REV, R$) was calculated based on the relationship between meat production and the selling price per kilogram of the product, using:

REV=Q*SP

Where:

Q = quantity of meat produced by the plot (kg)

SP = selling price per kilogram of meat produced (R$/kg)

It is important to note that the selling price per kilogram of chicken, applying a gross margin value-added calculation, was determined based on the market price in the region, fixed at R$ 8.00 per kg. Gross profit (PRO, R$) was calculated as the monetary difference between the total revenue from the estimated sale of the chickens (kilograms of chicken meat) and the discounted production cost, which derived from the feed cost, using the formula:

PRO=REV-FC

Where:

REV = gross revenue of the plot (R$)

FC = feed cost of the plot (R$)

The profitability index (PI, %), which indicates the capital available after covering costs (in this case, feed costs), was derived from the relationship between gross added value and gross revenue, using the formula:

PI=(PRO/REV)*100

Where:

PRO = gross profit of the plot (R$)

REV = gross revenue of the plot (R$)

For the break-even point (BE, kg), the quantity of production required to achieve zero return, covering all costs, was considered. In this case, it represents a partial break-even point, as it reflects the production volume necessary to cover feed costs. The formula used was:

BE=REV/SP

Where:

REV = gross revenue of the plot (R$)

SP = selling price per kilogram of meat produced (R$/kg)

Statistical analyses

The statistical model adopted was as follows:

$Y_{ik}=\mu+\alpha_i+\epsilon_{ik}$

Where:

Y_{ik} = Observed value for the variable under study

μ = Overall experiment mean

α_i = Effect of GPEM or GPUM levels

ϵ_{ik} = Experimental error

All data were analyzed using one-way ANOVA with R software (2021). Commands were executed following Logan's (2010) guidelines. Tukey's Honest Significant Difference (HSD) test was used to examine significant differences among the GPEM or GPUM levels (independent variable) for each dependent variable evaluated. Results are presented as means, and the significance level for differences was set at 0.05.

Subsequently, results for significant variables ($p<0.05$) were subjected to correlation and polynomial regression analysis to evaluate the influence of the independent variable on the dependent variables (Chatterjee & Hadi, 2006; Logan, 2010). The mathematical model, either linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax2$), was selected based on the influence of the independent variable on the dependent variable analyzed (Dormann et al., 2013). R-squared values were also considered as a criterion to determine the best model (Chatterjee & Hadi, 2006; Dormann et al., 2013).

RESULTS AND DISCUSSION

Experiment 1

The growth performance analysis of slow-growing broilers in the starter stage indicated a significant effect ($p<0.05$) of GPEM inclusion on feed intake and weight gain (Table 4), with the increasing inclusion of GPEM causing a linear increase in these variables, that is, the 10% inclusion level of GPEM providing higher results. However, in the final stage, feed intake and feed efficiency showed an opposite behavior, with the increasing inclusion of GPEM reducing ($p<0.05$) the broilers' feed intake, and the 10% inclusion level of GPEM providing better feed efficiency result. In this sense, weight gain in this stage increased ($p<0.05$) linearly as the inclusion of GPEM in the diets increased.

When observing the cumulative growth performance, it was found that the inclusion of GPEM did not significantly affect ($p>0.05$) the cumulative feed intake considering the entire evaluated period. However, the cumulative results of weight gain and feed efficiency showed that these variables were significantly influenced ($p<0.05$) by the inclusion of GPEM, with weight gain increasing linearly and feed efficiency improving as the levels of GPEM in the diets increased, that is, the 10% inclusion level of GPEM providing better cumulative weight gain and feed efficiency results.

The inclusion of GPEM positively impacted most growth performance variables, notably producing heavier broilers with improved feed efficiency. This result is particularly significant given that GPEM contains a considerable amount of fiber, which increased the dietary fiber levels from 4% to 7%. Despite this rise in fiber content, broiler performance was not adversely affected by the progressive inclusion of GPEM. Fiber in poultry diets has traditionally posed challenges for researchers and the industry, as the avian gastrointestinal tract exhibits limited enzymatic activity for fiber digestion, particularly in broilers, potentially restricting nutrient utilization (Azizi et al., 2021). Nonethe-less, studies by González-Alvarado et al. (2010), Mateos et al. (2012), Rufino et al. (2021) and Santos et al. (2024) suggest that moderate fiber levels in poultry diets play a crucial role in enhancing physiological responses, nutrient utilization, and overall growth performance. Jiménez-Moreno et al. (2009a,b) and Svihus (2011) further emphasized that the beneficial effects of moderate fiber levels are linked to improved digestibility through continuous gizzard stimulation, enhanced small intestine activity, and a positive impact on intestinal microbiota due to the prebiotic effects of fiber.

In this sense, Pushpakumara et al. (2017) found that including up to 15% palm kernel meal in broiler diets improved feed efficiency and weight gain. Malhado et al. (2022) reported no significant effects ($p>0.05$) on weight gain, final weight, or feed effi-ciency when using barley residues in slow-growing broilers but noted a linear increase ($p<0.05$) in feed intake with higher barley levels. Similarly, Costa et al. (2018a) observed improved weight and production efficiency with tucumã meal inclusion, though levels above 25% negatively affected these indices.

The high fiber content in many alternative feeds, derived from food processing residues, can challenge nutrient metabolism and growth performance (Rufino et al., 2015; Cruz & Rufino, 2017; Liu et al., 2018; Rufino et al., 2021; Cho et al., 2024). However, residues from guarana processing, like GPEM, may provide additional benefits due to bioactive compounds with antioxidant, antimicrobial, and stimulating properties, po-tentially enhancing nutrient utilization and physiological responses (Marques et al., 2016; Yonekura et al., 2016; Cruz & Rufino, 2017).

Table 4. Growth performance of slow-growing broilers fed diets containing increase levels of guarana peel meal[1].

Stage	Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Starter	FI	1.43[b]	1.48[b]	1.69[a]	1.71[a]	1.74[a]	<0.01	7.52	0.47	$Y = 1.44 + 0.034x$	0.96
	WG	0.87[b]	0.94[b]	0.98[ab]	1.01[a]	1.06[a]	<0.01	2.33	0.42	$Y = 0.882 + 0.018x$	0.94
	FE	1.64	1.57	1.72	1.69	1.64	0.10	8.28	-	-	-
Final	FI	2.95[a]	3.01[a]	2.98[a]	3.01[a]	2.63[b]	0.05	12.64	-0.08	$Y = 2.9269 + 0.0681x - 0.0094x^2$	0.95
	WG	1.03[b]	1.04[b]	1.01[b]	1.03[b]	1.16[a]	0.05	10.69	0.20	$Y = 1.004 + 0.01x$	0.92
	FE	2.86[a]	2.89[a]	2.95[a]	2.92[a]	2.27[b]	0.05	4.59	-0.36	$Y = 2.8049 + 0.1197x - 0.0166x^2$	0.93
General	FI	4.38	4.49	4.67	4.72	4.37	0.09	5.35	-	-	-
	WG	1.90[b]	1.98[b]	1.99[b]	2.04[ab]	2.22[a]	<0.01	4.69	0.29	$Y = 1.886 + 0.028x$	0.89
	FE	2.31[a]	2.27[a]	2.35[a]	2.31[a]	1.97[b]	<0.01	4.58	-0.34	$y = 2.262 + 0.058x - 0.0083x^2$	0.91

[1] All data represent the average of 48 replicates (broilers) per treatment.
[2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg).
[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.
[4] CV = Coefficient of variation.
[5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed.
[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

According to the evaluated results regarding the economic analysis of the performance of slow-growing broilers fed diets containing GPEM (Table 5), no significant difference ($p>0.05$) was observed among the treatments for the breakeven point variable. However, all other variables were significantly affected by the inclusion of GPEM.

In the variables of productive efficiency, total production of chicken meat in kilograms, and meat production per square meter, all broilers fed diets containing GPEM showed better results, with a gradual improvement in efficiency as the inclusion level of this alternative product increased. These findings align with results obtained by Costa et al. (2018a, b), who reported improved broiler productivity when including increasing levels of tucumã residue flour in their diets.

As mentioned above, the use of alternative foods in broiler diets often presents challenges related to the balance between their composition and the effects on bird productivity. Many of these feeds are by-products of the food processing industry, mainly composed of peels and seeds, which naturally contain high fiber levels (Cruz & Rufino, 2017; Rufino et al., 2021). However, depending on the specific feed used, its fiber content may vary and can be outweighed by other nutrients of nutritional interest, such as proteins and soluble carbohydrates, which affect feed efficiency and, consequently, productivity (Rufino et al., 2021; Rufino et al., 2023).

These results of productive indexes directly influence economic variables, such as feed cost, production cost per kilogram, and production cost per square meter, which were higher in several treatments that included GPEM. According to Rufino et al. (2015), higher inclusion levels of alternative foods can result in fluctuations in the production volume required to cover feed costs, affecting production costs either by increasing them, as seen in this study, or lowering them as compensation for using cheaper ingredients.

Feed cost represents a significant component of production expenses, and the use of agricultural residues in diets can impact these costs by replacing or reducing conventional ingredients (Nogueira et al., 2014; Cruz & Rufino, 2017). Economic analyses of alternative foods for poultry show that factors such as procurement logistics, production volume, and price fluctuations are crucial in deciding whether to use alternative ingredients (Silva et al., 2009; Rufino et al., 2015; Melo et al., 2017; Costa et al., 2018a,b; Batalha et al., 2019). These parameters confirm the economic viability of alternative feeds, closely tied to performance results (Pelizer et al., 2007; Costa et al., 2009).

In terms of gross income, gross profit, and profitability index, higher inclusion levels of GPEM yielded better results, demonstrating a positive economic impact. Despite apparent increases in production costs, productivity improvements effectively compensated for these, leading to favorable economic outcomes. According to Furtado et al. (2011), Rufino et al. (2015), Cruz and Rufino (2017), and Brelaz et al. (2021), including alternative foods in poultry diets can offer positive effects by utilizing regional agro-industrial by-products unsuitable for human consumption, reducing production costs without compromising bird performance, or enhancing productivity to offset costs. These impacts are especially significant for small and medium-scale poultry operations.

Conducting an economic and financial feasibility analysis of investments is essential, as it estimates and analyzes financial performance perspectives based on production outcomes (Rufino et al., 2018). If alternative feeds fail to achieve comparable productive and economic results to conventional feeds, they must be excluded from feed formulations or reconsidered for use under different conditions (Rufino et al., 2015).

According to Cruz and Rufino (2017), an alternative feed must meet four essential criteria to validate its use in animal production diets: (1) Proven biological composition with potential for use without anti-nutritional factors; (2) Accessible logistics, sufficient production volume, and year-round availability; (3) Cost similar to or lower than conventional feeds; and (4) A positive impact on productivity, comparable to or exceeding that of conventional diets. These criteria ensure effective technical decisions regarding the use of alternative feeds in poultry diets (Melo et al., 2017; Rufino et al., 2021; Rufino et al., 2023).

Table 5. Economic analysis of the performance of slow-growing broilers fed diets containing increase levels of guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
PRE-INI, R$/kg	3.09	3.11	3.14	3.18	3.21	-	-	-	-	-
PRE-FIN, R$/kg	2.97	2.90	2.91	2.94	2.97	-	-	-	-	-
PEI	169.91^{b}	204.82^{a}	204.74^{a}	207.05^{a}	208.47^{a}	<0.01	6.19	0.76	$Y = 173.9 + 10.556x – 0.7382x^2$	0.86
FC, R$	132.95^{b}	135.05^{b}	141.61^{a}	144.86^{a}	135.71^{b}	0.03	5.45	0.48	$Y = 131.28 + 3.5629x – 0.295x^2$	0.71
PRODKG, kg	22.92^{c}	23.76^{b}	23.88^{b}	24.60^{b}	26.76^{a}	<0.01	7.23	0.92	$Y = 22.68 + 0.3408x$	0.85
PCKG, R$/kg	5.80^{a}	5.68^{b}	5.93^{a}	5.89^{a}	5.07^{c}	0.03	8.24	-0.56	$Y = 5.6826 + 0.1431x – 0.0193x^2$	0.73
PRODSM, kg/m²	5.73^{c}	5.94^{b}	5.97^{b}	6.15^{a}	6.69^{a}	<0.01	7.23	0.92	$Y = 5.67 + 0.0852x$	0.85
PCPSM, R$/m²	33.24^{b}	33.76^{b}	35.40^{a}	36.21^{a}	33.93^{b}	0.03	5.45	0.48	$Y = 32.823 + 0.8881x – 0.0735x^2$	0.71
REV, R$	160.44^{c}	166.32^{c}	167.16^{c}	172.20^{b}	187.32^{a}	<0.01	7.23	0.92	$Y = 158.76 + 2.3856x$	0,85
PRO, R$	27.49^{b}	31.27^{b}	25.55^{b}	27.34^{b}	51.61^{a}	0.01	5.25	0.64	$Y = 30.717 – 3.7693x + 0.5542x^2$	0.78
PI,	17.13^{b}	18.80^{b}	15.28^{b}	15.88^{b}	27.55^{a}	0,03	4,86	0.56	$Y = 18.79 – 2.0398x + 0.2757x^2$	0.73
BE, kg	18.99	19.29	20.23	20.69	19.39	0.51	5.45	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point.

[3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

Experiment 2

The growth performance analysis (Table 6) of slow-growing broilers in the starter stage showed that increasing GPUM levels significantly ($p<0.05$) influenced feed intake and weight gain, with 7.5% GPUM inclusion yielding higher results for these parameters. Regarding feed efficiency, GPUM inclusion had a positive effect, as all slow-growing broilers fed diets containing GPUM demonstrated better feed efficiency than those fed the basal diet, with 5% GPUM inclusion providing the best results for feed efficiency. In the final stage, similarly, slow-growing broilers fed diets with 7.5% GPUM inclusion exhibited higher ($p<0.05$) feed intake. However, in this stage, broilers fed diets with 2.5% GPUM inclusion achieved better feed efficiency. Cumulatively, all slow-growing broilers fed diets containing GPUM showed higher ($p<0.05$) feed intake and weight gain compared to those fed the basal diet, with 7.5% inclusion providing optimal results. Feed efficiency during this period exhibited significant ($p<0.05$) improvement up to 7.5% inclusion, beyond which no further improvements were observed.

When comparing the results of experiment 2 using GPUM with those obtained in experiment 1 using GPEM, it stands out that GPUM promoted higher feed intake across all stages, especially at the 7.5% inclusion level, whereas GPEM showed a reduction in consumption during the final stage. This reduction may be associated with the higher fiber content, which, although potentially limiting intake, stimulates gizzard function and enhances nutrient digestibility (Sacranie et al., 2012; Jiménez-Moreno et al., 2019; Santos et al., 2024). In terms of weight gain, both guaraná by-products had positive impacts, but the effect of GPEM was linear and more pronounced at higher inclusion levels (10%), while GPUM showed optimal results at 7.5%, suggesting that its nutritional profile effectively supports growth at moderate inclusion levels. Regarding feed efficiency, GPEM showed significant improvements across all stages, with the best cumulative performance at 10% inclusion, whereas GPUM achieved peak efficiency at moderate inclusion levels (5%-7.5%).

These observed differences can be primarily attributed to the fiber profile of each by-product. The higher fiber content in GPEM may have stimulated increased gizzard activity, promoting more efficient digestibility and consequently better feed efficiency, as reported in studies highlighting the benefits of moderate fiber levels in poultry diets (Sacranie et al., 2012; Abdollahi et al., 2019; Jiménez-Moreno et al., 2019; Santos et al., 2024). In contrast, GPUM, with its lower fiber content and higher metabolizable energy (2,828.56 kcal/kg for GPUM versus 2,258.64 kcal/kg for GPEM), favored more consistent feed intake and higher weight gains, which aligns with findings from other studies using agricultural by-products with moderate fiber levels (Jiménez-Moreno et al., 2009; Costa et al., 2018b; Oliveira, 2018; Rufino et al., 2024).

These results reinforce important insights reported in the literature, which suggest that the impact of fiber in poultry diets depends not only on its quantity but also on its composition and interaction with other nutrients (Sanchez et al., 2021; Tejeda & Kim, 2021; Santos et al., 2024). Previous studies indicate that insoluble fibers, such as those in GPEM, may be more effective at stimulating gastrointestinal motility and improving digestibility in slow-growing broilers, whereas soluble fibers, present in smaller proportions in GPUM, tend to have a lesser effect on gastrointestinal function (Mateos et al., 2012; Sanchez et al., 2021; Tejeda & Kim, 2021; Machado et al., 2022).

Thus, the cumulative effects observed in both experiments underscore the importance of energy balance and nutrient profile when choosing a guaraná by-product for the diet of slow-growing broilers. Overall, while GPEM demonstrated a greater ability to sustain performance throughout the production cycle, GPUM exhibited superior performance during the early and intermediate stages. This difference could have significant practical implications depending on the production system's objectives. In systems prioritizing feed efficiency and cost reduction, GPEM emerges as a more advantageous choice (Willems et al., 2013; Zampiga et al., 2021). Conversely, GPUM may be better suited for systems aiming to maximize feed intake and weight gain during critical growth periods, particularly in nutritional strategies focused on accelerating initial growth (Willems et al., 2013; Prakash et al., 2020; Zampiga et al., 2021).

Table 6. Growth performance of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Stage	Variables[2]	Guarana pulp meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.50	5.00	7.50	10.00					
Starter	FI	1.30[c]	1.51[b]	1.52[b]	1.63[a]	1.50[b]	0.04	10.72	0.47	$Y = 1.3051 + 0.0871x – 0.0066x^2$	0.89
	WG	0.50[c]	0.75[b]	0.78[ab]	0.82[a]	0.74[b]	<0.01	8.31	0.60	$Y = 0.5151 + 0.0963x – 0.0074x^2$	0.95
	FE	2.61[a]	1.99[b]	1.94[b]	2.00[b]	2.02[b]	<0.01	14.93	-0.53	$Y = 2.5446 – 0.2057x + 0.0159x^2$	0.87
Final	FI	2.83[b]	2.95[b]	3.10[a]	3.16[a]	3.04[ab]	<0.01	5.17	0.59	$Y = 2.8086 + 0.0903x – 0.0065x^2$	0.93
	WG	1.13	1.20	1.19	1.19	1.05	0.10	8.34	-	-	-
	FE	2.49[c]	2.45[c]	2.59[b]	2.65[b]	2.90[a]	0.02	8.62	0.65	$Y = 2.412 + 0.0408x$	0.82
General	FI	4.13[c]	4.46[b]	4.63[b]	4.80[a]	4.55[b]	<0.01	6.44	0.57	$Y = 4.1123 + 0.1798x – 0.0133x^2$	0.95
	WG	1.64[c]	1.96[a]	1.98[a]	2.01[a]	1.80[b]	<0.01	9.42	0.30	$Y = 1.654 + 0.1348x – 0.012x^2$	0.95
	FE	2.52[a]	2.27[c]	2.33[b]	2.38[b]	2.53[a]	<0.01	5.67	0.13	$Y = 2.276 + 0.2908x – 0.0488x^2$	0.82

[1] All data represent the average of 48 replicates (broilers) per treatment.
[2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg).
[3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05.
[4] CV = Coefficient of variation.
[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.
[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

In the results of the economic analysis (Table 7), all variables evaluated in experiment 2 were statistically significant ($p<0.05$). Overall, these economic results from experiment 2 showed interesting differences compared to those observed in experiment 1, reflecting the distinct nutritional characteristics of the guaraná by-products evaluated. Increasing levels of GPUM inclusion resulted in a proportional rise in feed cost, reaching the highest value at the 7.5% inclusion level. This was also reflected in the cost per kilogram of meat produced, which significantly increased at higher inclusion levels. These results contrast with those of experiment 1, where GPEM demonstrated greater stability in production costs, even at higher inclusion levels. As mentioned above, this difference can be partly attributed to the positive effects of GPEM's insoluble fibers, which optimized digestibility and offset costs through superior feed efficiency (Sacranie et al., 2012; Abdollahi et al., 2019; Jiménez-Moreno et al., 2019).

In terms of meat production and gross revenue, both by-products showed positive gains compared to the control, but with distinct patterns. GPUM inclusion led to higher meat production and gross revenue at intermediate levels, from 2.5% to 7.5%, reflecting its higher soluble carbohydrate content and metabolizable energy, which favored short-term productive performance (Jiménez-Moreno et al., 2009; Costa et al., 2018b; Oliveira, 2018; Rufino et al., 2024). In contrast, GPEM exhibited consistent increases in meat production and revenue across all inclusion levels.

Gross profit and profitability index indicators also highlighted important economic differences between the two by-products. GPUM showed better economic performance at intermediate levels, but its viability was compromised at extreme levels, particularly at 10% inclusion, where additional costs were not offset by increased production. This contrasts sharply with GPEM results, which maintained consistent economic outcomes across the entire range of inclusion levels, with the best results observed at 10%. This reflects GPEM's ability to sustain stable productive and economic performance throughout the production cycle.

In general, the key point in the contrast observed in the economic results of both experiments lies in the relationship between the nutritional profiles and the economic costs of the products and their productive responses. Although the higher fiber content of GPEM may limit feed intake at certain times, it also promotes more efficient nutrient utilization, offsetting the additional costs associated with diet formulation (Mateos et al., 2012; Melo et al., 2017; Lusk et al., 2019). Conversely, GPUM, with its lower fiber content and higher energy density, is more sensitive to higher inclusion levels, as energy saturation can lead to reduced feed efficiency, directly affecting economic viability (Sacranie et al., 2012; Oliveira, 2018;

Abdollahi et al., 2019).

Additionally, the difference in profitability results also reflects the composition of the by-products. GPUM, with a lower protein content (12.27%) and mineral content (1.01%), lacks some structural benefits provided by GPEM, such as greater metabolic stability and support for intestinal microbiota development (Jiménez-Moreno et al., 2019; Sanchez et al., 2021; Tejeda & Kim, 2021). This may explain why GPUM's profitability is more affected at extreme inclusion levels, while GPEM maintains positive results due to the broader support provided by its nutritional profile. It is also important to highlight that both options contribute to a more sustainable approach to poultry production, promoting the use of agro-industrial residues and potentially reducing indirect costs (Rufino et al., 2015; Costa et al., 2018b; Batalha et al., 2019; Brelaz et al., 2019).

Table 7. Economic analysis of the performance of slow-growing broilers fed diets containing guarana pulp meal.[1]

Variables[2]	Guarana pulp meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
PRE-INI, R$/kg	3,16	3,18	3,20	3,24	3,25	-	-	-	-	-
PRE-FIN, R$/kg	3,04	3,06	3,08	3,10	3,12	-	-	-	-	-
PEI	186.55[b]	214.01[a]	187.38[b]	184.17[b]	164.62[c]	0.02	12.12	-0.47	$Y = 192 + 5.1206x - 0.8069x^2$	0.72
FC, R$	153.96[c]	167.25[bc]	174.60[b]	182.84[a]	173.69[b]	<0.01	7.06	0.66	$Y = 153.17 + 7.2294x - 0.5027x^2$	0.95
PRODKG, kg	19.70[c]	23.59[a]	23.85[a]	24.22[a]	21.65[b]	<0.01	9.42	0.30	$Y = 19.866 + 1.6452x - 0.1464x^2$	0.95
PCKG, R$/kg	7.82[ab]	7.08[c]	7.32[bc]	7.56[b]	8.04[a]	<0.01	5.87	0.29	$Y = 7.7286 - 0.2421x + 0.0279x^2$	0.87
PRODSM, kg/m²	4.92[c]	5.89[a]	5.96[a]	6.05[a]	5.41[b]	<0.01	9.42	0.30	$Y = 4.9609 + 0.4113x - 0.0366x^2$	0.95
PCPSM, R$/m²	38.49[c]	41.81[bc]	43.65[b]	45.70[a]	43.42[b]	<0.01	7.06	0.66	$Y = 38.294 + 1.806x - 0.1256x^2$	0.95
REV, R$	162.78[c]	188.76[a]	190.82[a]	193.78[a]	173.20[b]	0.01	9.12	0.22	$Y = 163.52 + 11.574x - 1.0539x^2$	0.96
PRO, R$	8.81[b]	21.50[a]	16.21[ab]	10.94[b]	-0.48[c]	0.03	9.51	-0.39	$Y = 10.338 + 4.343x - 0.5509x^2$	0.91
PI, %	4.92[b]	11.38[a]	8.46[a]	5.47[b]	-0.57[c]	0.02	9.75	-0.42	$Y = 5.7286 + 2.1895x - 0.2865x^2$	0.92
BE, kg	19.24[c]	20.90[bc]	21.82[b]	22.85[a]	21.71[b]	<0.01	7.06	0.66	$Y = 19.142 + 0.903x - 0.0627x^2$	0.95

[1] All data represent the average of 48 replicates (broilers) per treatment.
[2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point.
[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.
[4] CV = Coefficient of variation.
[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.
[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

CONCLUSIONS

The inclusion of guaraná by-products (GPEM and GPUM) in diets for slow-growing broilers has proven to be a viable alternative to enhance growth performance and economic feasibility, promoting the sustainable use of agro-industrial residues. GPEM, despite its higher fiber content, delivered better results in feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM was more efficient at intermediate levels (7.5%). Both by-products contributed to greater meat production and economic returns compared to the basal diet, with positive impacts varying according to inclusion levels. The results highlight the importance of considering the specific goals of the production system when selecting the most suitable by-product. The use of GPEM is recommended for systems prioritizing feed efficiency and cost-effectiveness, while GPUM appears to be more appropriate for phases that require higher energy intake and weight gain.

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REFERENCES

Abdollahi MR, Zaefarian F, Hunt H, *et al*. Wheat particle size, insoluble fibre sources and whole wheat feeding influence gizzard musculature and nutrient utilisation to different extents in broiler chickens. Journal of Animal Physiology and Animal Nutrition. 2019;103:146–161. https://doi.org/10.1111/jpn.13019

Ali A, Ponnampalam EN, Pushpakumara G, *et al*. Cinnamon: a natural feed additive for poultry health and production - a review. Animals (Basel) 2021;11:2026. http://dx.doi.org/10.3390/ani11072026

AOAC - Association of Official Agricultural Chemists. Official Methods of Analysis of AOAC International. 21st ed. Rockville, MD, USA: AOAC; 2019.

Aride PHR, Oliveira AM, Ferreira MS, *et al.* Growth and hematological responses of tambaqui, *Colossoma macropomum* fed different levels of rice, *Oryza* spp.. Brazilian Journal of Biology 2020;81:1-7. https://doi.org/10.1590/1519-6984.232560

Aride PHR, Oliveira AM, Baptista RB, *et al.* Changes on physiological parameters of tambaqui (*Colossoma macropomum*) fed with diets supplemented with Amazonian fruit Camu camu (*Myrciaria dubia*). Brazilian Journal of Biology 2018;78:360-367. https://doi.org/10.1590/1519-6984.169442

Aride PHR, Oliveira AT, Oliveira AM, *et al.* Growth and hematological responses of tambaqui fed different amounts of cassava (*Manihot esculenta*). Arquivo Brasileiro de Medicina Veterinária e Zootecnia 2016;68:1697-1704. https://doi.org/10.1590/1678-4162-8704

Azizi MN, Loh TC, Foo HL, *et al*. Is palm kernel cake a suitable alternative feed ingredient for poultry? Animals (Basel) 2021;11:338. https://doi.org/10.3390/ani11020338

Batalha OS, Alfaia SS, Cruz FGG, *et al*. Análise econômica da farinha de silagem ácida de resíduos de pirarucu em rações de poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2019;12:363-375. https://doi.org/10.17765/2176-9168.2019v12n2p363-375

Brelaz KCBTR, Cruz FGG, Rufino JPF, *et al*. Viabilidade econômica do óleo do resíduo de pescado na alimentação de poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2021;14:e007618. https://doi.org/10.17765/2176-9168.2021v14n1e007618

Chatterjee S, Hadi AS. Regression Analysis by Example. 4th ed. New Jersey, USA: John Wiley & Sons Ltd; 2006.

Cho S, Shi H, Sureshkumar S, *et al*. The effects of the dietary inclusion of by-products obtained after the extraction of vitamin B2 from fermented soybean on the performance and meat quality of growing–finishing pigs. Applied Sciences 2024;14:803. https://doi.org/10.3390/app14020803

Clement CR, Lleras PE, van Leeuwen J. O potencial das palmeiras tropicais do Brasil: acertos e fracassos das últimas décadas. Agrociencias 2005;9(1/2):67-71.

Costa FGP, Goulart CC, Costa JS, *et al*. Desempenho, qualidade de ovos e análise econômica da produção de poedeiras semipesadas alimentadas com diferentes níveis de raspa de mandioca. Acta Scientiarum. Animal Sciences 2009;31(1):13-18. https://doi.org/10.4025/actascianimsci.v31i1.457

Costa APGC, Cruz FGG, Rufino JPF, *et al*. Tucumã meal in diets for broilers on performance, carcass traits and serum biochemical profile. Archivos de Zootecnia 2018a;67:137-142. https://doi.org/10.21071/az.v67i257.3501

Costa APGC, Cruz FGG, Rufino JPF, *et al*. Viabilidade econômica da farinha do resíduo de tucumã na alimentação de frangos de corte. Agropecuária Técnica (UFPB) 2018b;38(4):225-233. https://doi.org/10.25066/agrotec.v38i4.28894

Cruz FGG, Rufino JPF, Melo RD, *et al*. Perfil socioeconômico da avicultura no setor primário do Estado do Amazonas, Brasil. Revista em Agronegócio e Meio Ambiente 2016;9(2):371-391. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Cruz FGG, Rufino JPF. Formulação e fabricação de rações (Aves, Suínos e Peixes). Manaus, Brazil: EDUA; 2017.

Cruz FL, Carvalho FP, Marçal JO, *et al*. Fatty acid profile of slow-growing broilers supplemented with biocomplexed minerals. Ciência Rural 2023;53(5):e20210525. https://doi.org/10.1590/0103-8478cr20210525

Dormann CF, Elith J, Bacher S, *et al*. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 2013;36:27-46. https://doi.org/10.1111/j.1600-0587.2012.07348.x

Espinola EB, Dias RF, Mattei R, *et al*. Pharmacological activity of Guaraná (*Paullinia cupana* Mart) in laboratory animals. Journal of Ethnopharmacology 1997;55:223-229. https://doi.org/10.1016/s0378-8741(96)01506-1

Ferreira FAM, Ferreira BB, Bragança VAN, *et al*. Guaraná (*Paullinia cupana* Kunth), marapuama (*Ptychopetalum olacoides* Benth.), gentian (*Gentiana lutea* L.), quassia (*Quassia amara* L.) and their properties: a brief review. Research, Society and Development 2022;11(2). https://doi.org/10.33448/rsd-v11i2.24592

Furtado DA, Carvalho Junior SB, Lima ISP, *et al*. Desempenho e características de carcaça de aves caipiras alimentadas com feno de erva-sal (*Atriplex nummularia* lindl.). Revista Caatinga 2011;24:182-191.

González-Alvarado JM, Jimenez-Moreno E, González-Sanchez D, *et al*. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. Animal Feed Science and Technology 2010;162:37-46. https://doi.org/10.1016/j.anifeedsci.2010.08.010

Jiménez-Moreno E, González-Alvarado JM, Coca-Sinova A, *et al*. Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. Animal Feed Science and Technology 2009;154:93-101. https://doi.org/10.1016/j.anifeedsci.2009.06.020

Jiménez-Moreno E, González-Alvarado JM, Lázaro R, *et al*. Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. Poultry Science 2009;88:1925-1933. https://doi.org/10.3382/ps.2009-00193

Jiménez-Moreno E, González-Alvarado JM, de Coca-Sinova A, *et al*. Insoluble fiber sources in mash or pellets diets for young broilers. 2. Effects on gastrointestinal tract development and nutrient digestibility. Poultry Science. 2019;98(6):2531–2547. https://doi.org/10.3382/ps/pey599

Liu CW, Zhou HS, Kim MY, *et al*. Impacts of rapeseed meal, canola meal and their mixture substitute for soybean meal on performance of lactating sows and their offspring. Indian Journal of Animal Research 2018;53:124-128. https://doi.org/10.18805/ijar.B-837

Logan M. Biostatistical design and analysis using R: a practical guide. New Jersey, USA: John Wiley & Sons Ltd; 2010.

Lusk JL, Thompson NM, Weimer SL. The cost and market impacts of slow-growth broilers. Journal of Agricultural and Resource Economics 2019;44(3):536-550. https://doi.org/10.22004/ag.econ.292330

Machado NJB, Lima CAR, Brasil RJM, *et al*. Digestible threonine for slow-growing broilers: performance, carcass characteristics, intestinal mucin, and duodenal morphometry. Revista Brasileira de Zootecnia 2018;47:e20170193. https://doi.org/10.1590/rbz4720170193

Machado ALN, Alves JR, Lima HJD, *et al*. Barley residue levels in the diet of Label Rouge broilers. Revista Acadêmica Ciência Animal 2022;20:e20002. https://doi.org/10.7213/acad.2022.20002

Marques LLM, Panizzon GP, Aguiar BAA, *et al*. Guaraná (*Paullinia cupana*) seeds: Selective supercritical extraction of phenolic compounds. Food Chemistry 2016;212:703-711. https://doi.org/10.1016/j.foodchem.2016.06.028

Mateos GG, Jiménez-Moreno E, Serrano MP, *et al*. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of Applied Poultry Research 2012;21:156-174. https://doi.org/10.3382/japr.2011-00477

Melo RD, Cruz FGG, Feijó JC, *et al*. Viabilidade econômica da farinha de cará na alimentação de poedeiras comerciais leves. Revista Brasileira de Saúde e Produção Animal 2017;18(2):221-230. https://doi.org/10.1590/S1519-99402017000200001

Mendes AA, Patrício IS. Controles, registros e avaliação do desempenho de frangos de corte. In: Mendes AA, Nääs IA, Macari M. Produção de frangos de corte. Campinas, Brazil: FACTA; 2004.

Nogueira MA, Cruz FGG, Tanaka ES, *et al*. Suplementação de óleo de dendê (*Elaeis guineensis* Jaquim) na alimentação de poedeiras leves em clima tropical. Revista Acadêmica Ciência Animal 2014;12(2):103-111.

Oliveira PR, Costa CA, Bem GF, *et al*. Effects of an extract obtained from fruits of Euterpe oleracea Mart. in the components of metabolic syndrome induced in C57BL/6J mice fed a high-fat diet. Journal of Cardiovascular Pharmacology 2010;56(15):619-626. https://doi.org/10.1097/fjc.0b013e3181f78da4

Oliveira DHR. Alternative food for broiler chickens: an overview. Scientific Electronic Archives 2018;11:112-117. https://doi.org/10.36560/1152018691

Pelizer LH, Pontieri MH, Moraes IO. Utilização de resíduos agroindustriais em processos biotecnológicos como perspectiva de redução de impacto ambiental. Journal of Technology Management & Innovation 2007;2(1):118-127.

Prakash A, Saxena VK, Singh MK. Genetic analysis of residual feed intake, feed conversion ratio and related growth parameters in broiler chicken: a review. World's Poultry Science Journal. 2020;76(2):304–317. https://doi.org/10.1080/00439339.2020.1735978

Polese MF, Polese MF, Radael MC, *et al.* Zootechnical parameters of Corn feed particle size in performance, digestibility and rate of passage in juvenile tambaqui *Colossoma macropomum*. Brazilian Journal of Biology 2022;82,1-13. https://doi.org/10.1590/1519-6984.232612

Pushpakumara DMS, Priyankarage N, Nayananjalie WAD, *et al*. Effect of inclusion of palm (*Elaeis guineenses*) kernel cake in broiler chicken rations. International Journal of Livestock Research 2017;7:103-109. http://dx.doi.org/10.5455/ijlr.20170201053413

Rostagno HS, Albino LFT, Calderano AA, *et al*. Tabelas brasileiras para aves e suínos: composição dos alimentos e exigências nutricionais. 5th ed. Viçosa, Brazil: Editora da Universidade Federal de Viçosa; 2024.

Rufino JPF, Cruz FGG, Miller WPM, *et al*. Análise econômica da inclusão de farinha do resíduo de tucumã (*Astrocaryum vulgare*, Mart) na alimentação de poedeiras comerciais. Revista Brasileira de Saúde e Produção Animal 2015;16(1):1-9. https://doi.org/10.1590/S1519-99402015000100001

Rufino JPF, Cruz FGG, Feijó JC, *et al*. Análise econômica de patos submetidos a diferentes planos nutricionais fásicos e densidades de alojamento. Revista em Agronegócio e Meio Ambiente 2018;11(3):767-781. https://doi.org/10.17765/2176-9168.2018v11n3p767-781

Rufino JPF, Cruz FGG, Brasil RJM, *et al*. Relationship between the level and the action period of fiber in diets to laying hens. Acta Scientiarum. Animal Sciences 2021;43:e49033. https://doi.org/10.4025/actascianimsci.v43i1.49033

Rufino JPF, Cruz FGG, Oliveira Filho PA, *et al*. Farelo de açaí (*Euterpe precatoria*) como alimento alternativo em dietas para poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2023;16:e11466. https://doi.org/10.17765/2176-9168.2023v16n4e11466

Sacranie A, Svihus B, Denstadli V, *et al*. The effect of insoluble fiber and intermittent feeding on gizzard development, gut motility, and performance of broiler chickens. Poultry Science. 2012;91(3):693–700. https://doi.org/10.3382/ps.2011-01790

Sakomura NK, Rostagno HS. Métodos de pesquisa em nutrição de monogástricos. Jaboticabal, Brazil: Funep; 2016.

Sanchez J, Barbut S, Patterson R, *et al*. Impact of fiber on growth, plasma, gastrointestinal and excreta attributes in broiler chickens and turkey poults fed corn- or wheat-based diets with or without multienzyme supplement. Poultry Science. 2021;100(8):101219. https://doi.org/10.1016/j.psj.2021

Santos ANA, Rufino JPF, Viana AL, *et al*. *Paullinia cupana* peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science 2024;64:AN24137. https://doi.org/10.1071/AN24137

Sarica M, Yamak U, Boz M, *et al*. Performance of fast, medium and slow growing broilers in indoor and free-range production systems. South African Journal of Animal Science 2020;49:1127-1138. https://doi.org/10.4314/sajas.v49i6.16

Silva EP, Rabello CBV, Dutra Júnior WM, *et al*. Análise econômica da inclusão dos resíduos de goiaba e tomate na ração de poedeiras comerciais. Revista Brasileira de Saúde e Produção Animal 2009;10(4):774-785.

Svihus B. The gizzard: function, influence of diet structure and effects on nutrient availability. World's Poultry Science Journal 2011;67:207-224. https://doi.org/10.1017/S0043933911000249

Tejeda OJ, Kim WK. Effects of fiber type, particle size, and inclusion level on the growth performance, digestive organ growth, intestinal morphology, intestinal viscosity, and gene expression of broilers. Poultry Science. 2021;100(10):101397. https://doi.org/10.1016/j.psj.2021.101397

Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 1991;74:3583-3597. https://doi.org/10.3168/jds.s0022-0302(91)78551-2

Willems OW, Miller SP, Wood BJ. Aspects of selection for feed efficiency in meat producing poultry. World's Poultry Science Journal. 2013;69(1):77–88. https://doi.org/10.1017/S004393391300007X

Wu Y, Huang J, Quan S, *et al*. Light regimen on health and growth of broilers: an update review. Poultry Science 2022;101:101545. https://doi.org/10.1016/j.psj.2021.101545

Yonekura L, Martins CA, Sampaio GR, *et al*. Bioavailability of catechins from guaraná (*Paullinia cupana*) and its effect on antioxidant enzymes and other oxidative stress markers in healthy human subjects. Food & Function 2016;7:2970-2978. https://doi.org/10.1039/c6fo00513f

Zampiga M, Calini F, Sirri F. Importance of feed efficiency for sustainable intensification of chicken meat production: implications and role for amino acids, feed enzymes and organic trace minerals. World's Poultry Science Journal. 2021;77(3):639–659. https://doi.org/10.1080/00439339.2021.1959277

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CHAPTER 8: Proximate composition and sensory evaluation of breast meat from slow-growing broilers fed diets containing guarana by-products

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BREAST MEAT FROM GUARANA-FED BROILERS

ABSTRACT: The objective of this study was to evaluate the effect of including guarana by-products in the diets of slow-growing broilers on the proximate composition and sensory attributes of breast meat. Two trials were conducted using guarana peel meal (GPEM) and guarana pulp meal (GPUM). In each trial, 240 broilers were allocated to diets containing 0, 2.5, 5, 7.5, or 10% inclusion levels. At 56 days of age, the birds were slaughtered, and breast samples were analyzed for proximate composition and sensory characteristics. For GPEM, a linear increase in moisture and lipid content was observed, along with a linear decrease in mineral and protein content. Sensory analysis showed improved flavor and appearance at 10% inclusion and optimal texture at 5%. For GPUM, no significant changes were detected in the proximate composition. However, there was a linear improvement in flavor, texture, and appearance, with optimal color observed at 2.5% inclusion. Aroma was not affected in either trial. GPUM preserved the nutritional profile while enhancing sensory qualities at all inclusion levels. Although GPEM altered the proximate composition, it improved flavor and appearance at higher inclusion levels (10%). It is concluded that both by-products show potential as sustainable ingredients in poultry nutrition.

Keywords: broiler, meat quality, organoleptic properties, Paullinia cupana.

Practical Application: The inclusion of guarana by-products in diets for slow-growing broilers represents an innovative and sustainable strategy to enhance meat sensory quality without compromising its nutritional profile. Guarana pulp meal, in particular, preserved the proximate composition and improved flavor, texture, and appearance at all tested levels. These findings highlight the potential of Amazonian agro-industrial residues to reduce feed costs, promote circular economy practices, and add value to regional products in poultry farming systems.

Relevance of the work: This study contributes to the valorization of Amazonian by-products by evaluating the inclusion of guarana residues in the diet of slow-growing broiler chickens. The results show that these by-products can improve the sensory attributes of meat without compromising its nutritional composition, especially when using pulp meal. The research promotes sustainable alternatives for poultry farming, with the potential to reduce costs and environmental impacts, while adding value to regional agro-industrial residues, aligning with the principles of bioeconomy and circular economy in animal production.

INTRODUCTION

The poultry production chain continues to expand, consolidating its prominent position in both production volume and per capita consumption rates (Piccolo et al., 2024), reaching records above 45 kg/inhabitant/year. Brazil is the second-largest producer and the leading exporter of poultry meat (ABPA, 2024). However, feed remains the primary economic challenge in poultry farming, accounting for approximately 60–70% of total production costs (Pérez-Palencia & Bolívar-Sierra, 2023). In response to this challenge, the use of alternative feedstuffs emerges as a viable solution (Valentim et al., 2021; Cruz et al., 2016), with guarana (Paullinia cupana) residues, by-products of a fruit native to the Amazon, standing out as promising options (Schimpl et al., 2013). Nonetheless, further research is required to assess their effects on animal growth, carcass quality, and the organoleptic characteristics of the meat (Pinotti et al., 2023).

Although alternative feeds may offer nutritional and economic advantages, it is essential to ensure that they do not negatively affect product quality (Brandão et al., 2023; Sanches et al., 2023). In this context, sensory analysis plays a critical role in quality control (Oliveira et al., 2022), helping to assess consumer acceptance and to standardize industrial processes (Arias-Giraldo & López-Mejía, 2022). Chicken meat is widely recognized for its balanced nutritional profile (Bowles et al., 2019), primarily due to its low lipid content, high protein concentration, and the presence of essential micronutrients (Vannier et al., 2022).

Consumers associate organoleptic attributes such as color, odor, flavor, and palatability with overall product quality, key determinants of perceived value and acceptance (Vannier et al., 2022), and these are the main attributes evaluated (Sánchez & Albarracín, 2010). Various sensory methods, ranging from traditional to modern approaches, are applied to evaluate the quality and market potential of meat products (Oliveira et al., 2022). The selection of a sensory evaluation method depends on the specific characteristics of the product (Sánchez & Albarracín, 2010), and such analyses are essential for product development, market competitiveness, and meeting consumer expectations.

Moreover, evaluating the chemical composition of meat from animals fed with alternative ingredients is fundamental to developing cost-effective diets that utilize regional feed resources (Brandão et al., 2023). Therefore, it was hypothesized that the inclusion of guarana by-products in the diets of slow-growing broilers would not negatively affect the proximate composition of breast meat. Furthermore, it was expected that these by-products could enhance the sensory attributes of the meat, especially flavor, texture, and appearance, depending on the inclusion level. Thus, the objective of this study was to assess the effects of including guarana by-products (guarana peel meal (GPEM) and guarana pulp meal (GPUM)) in the diets of slow-growing broilers on the proximate composition and sensory attributes of breast meat.

MATERIAL AND METHODS

This study was conducted at the facilities of the Poultry Sector of the Faculty of Agricultural Sciences, Federal University of Amazonas (UFAM), located in the southern sector of the university campus in Manaus, AM, Brazil. The experimental protocol was submitted to the Ethics Committee on the Use of Animals of the aforementioned university (Protocol No. 010/2022).

The guarana by-products were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. After separating the fruit fractions, the peels were dried in an oven (45 °C for 24 hours). The seeds were roasted, crushed, and subjected to extract removal, generating the guarana cake, which was also dried in an oven (45 °C for 24 hours). All materials were transported by river to Manaus and ground using a 4 mm sieve crusher, resulting in GPEM and GPUM. The by-products were bagged and stored in a dry environment until use in the experimental diets.

Before the trials, the proximate composition of the guarana by-products (Table 1) was determined at the Fish Technology Laboratory of the Faculty of Agricultural Sciences, UFAM. Moisture content was determined using an oven at 105 °C, according to AOAC method 925.10 (2019); ash content by calcination in a muffle furnace at 550 °C, following AOAC method 923.03 (2019); lipid analysis followed the AOCS Ba 3-38 methodology; total protein was determined using the Kjeldahl method, as per AOAC method 920.87 (2019); and fiber content was determined according to Van Soest et al. (1991).

Table 1. Composition of guaraná by-products tested.

Variables	Guarana peel meal	Guarana pulp meal
Dry matter, %	89.11	83.93
Crude protein, %	18.72	12.27
Fats, %	5.36	2.41
Minerals, %	5.33	1.01
Crude Fiber, %	44.04	29.17
Neutral detergent fiber, %	61.66	40.84
Acid detergent fiber, %	39.64	26.25
Soluble carbohydrates, %	26.55	55.14
Gross energy, kcal/kg	6,495.65	5,745.42
Metabolizable energy*, kcal/kg	2,258.64	2,828.56

* Determined using the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno et al. (2024).

To evaluate the influence of guarana by-products on meat sensory characteristics, two performance trials were conducted. The first trial assessed the effects of GPEM inclusion, and the second examined the effects of GPUM. In both trials, 240 slow-growing male broilers of the Label Rouge strain were used. Initially, one-day-old chicks were housed in a protective circle with wood shavings as bedding, along with feeders and drinkers, until seven days of age. They were then allocated to their respective treatments in pens equipped with tubular feeders, pendulum drinkers, and wood shavings. The experimental period was divided into two phases: initial (8–28 days) and final (29–56 days), with ad libitum access to feed and water. A suitable lighting program for slow-growing broilers was adopted (Wu et al., 2022).

Experiments 1 (GPEM) and 2 (GPUM) followed a completely randomized design. Treatments consisted of a control diet (0% inclusion) and four inclusion levels of the tested product (2.5, 5.0, 7.5, and 10%), each with four replicates of 12 birds. The experimental diets (Tables 2 and 3) were formulated based on the reference values of Rostagno et al. (2024), except for GPEM and GPUM, which used values obtained from prior chemical analysis. Metabolizable energy values of the guarana by-products were estimated using the methodologies described by

Sakomura and Rostagno (2016) and Rostagno et al. (2024). The guarana by-products were treated as fixed components in diet formulation, and other ingredients were adjusted accordingly. Diets were formulated using SuperCrac software (TD Software©, Viçosa, Brazil).

Table 2. Composition of the experimental diets containing guarana peel meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Guarana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Common salt	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrients	Guarantee levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	6.15	7.52	8.89	10.26	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.95	4.83	5.71	6.60	2.84	3.66	4.55	5.44	6.32
Total lysine, %	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine, %	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine, %	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan, %	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[3] Levels analyzed and calculated on a dry matter basis.

Table 3. Composition of the experimental diets containing guarana pulp meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	56.27	53.17	50.10	47.00	63.34	61,57	58,49	55,4	52,31
Soybean meal 46%	38.32	38.35	35.77	35.66	35.55	35.43	32.53	30,5	30,39	30,28	30,17
Guarana pulp meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2,50	5,00	7,50	10,00
Limestone	0.93	0.82	0.83	0.82	0.81	0.81	1.02	0,76	0,75	0,75	0,74
Dicalcium phosphate	1.79	1.79	1.82	1.84	1.85	1.87	1.55	1,58	1,60	1,61	1,63
Common salt	0.30	0.10	0.27	0.28	0.28	0.28	0.53	0,28	0,28	0,28	0,29
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.14	0.15	0.16	0,18	0.03	0,05	0,06	0,07	0,08
Soybean oil	0.00	0.27	1.90	2.58	3.25	3.93	0.50	2,26	2,93	3,61	4,28
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrients	Guarantee levels[3]										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.86	87.67	87.58	87.50	87.89	87.76	87.59	87.42	87.35
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.15	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	3.94	4.61	5.27	5.93	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	5.52	6.45	7.38	8.30	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.55	4.15	4.74	5.34	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.14	1.12	1.11	1.10	1.06	1,00	0,99	0,98	0,97
Total methionine, %	0.45	0.45	0.47	0.47	0.48	0.49	0.35	0,35	0,35	0,36	0,37
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0,66	0,66	0,66	0,66
Total threonine, %	0.87	0.87	0.82	0.81	0.80	0.79	0.79	0,75	0,73	0,72	0,71
Total tryptophan, %	0.28	0.28	0.27	0.26	0.26	0.26	0.25	0,24	0,23	0,23	0,23

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg.

[3] Levels analyzed and calculated on a dry matter basis.

At 56 days of age, after a 12-hour fasting period, 12 birds per treatment were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter via jugular vein incision. Carcasses were scalded in hot water (60 °C for 62 seconds), plucked, and eviscerated according to Mendes and Patricio (2004). Breast meat samples were collected and immediately transported to the laboratory for proximate composition analysis, which included moisture, mineral, fat, and protein contents. Mineral content was determined by muffle furnace calcination at 550 °C following AOAC Method 923.03 (2019). Lipid content was determined using the AOCS Ba 3-38 method, and total protein using the Kjeldahl method, following AOAC Method 920.87 (2019). For sensory evaluation, breast cuts were collected, labeled by treatment, and frozen. On the day of analysis, samples were thawed, wrapped in aluminum foil, and cooked in an oven until reaching an internal temperature of 87 °C (Dutcosky, 1996).

Fifty untrained evaluators of both sexes were randomly selected. A 9-point hedonic scale was used to assess the following attributes: color, flavor, aroma, texture, and appearance, ranging from "disliked extremely" (1) to "liked extremely" (9), according to Dutcosky (1996). Sensory evaluations were conducted in individual booths under white lighting at the Sensory Analysis Laboratory of UFAM. Broilers breast meat was cut into uniform 1 cm cubes and served hot (approximately 40 °C) in 50 ml disposable cups, each marked with a randomized 3-digit code corresponding to one of the treatments. Each evaluator received one sample from each treatment and a glass of mineral water to cleanse the palate between samples.

The collected data were analyzed by ANOVA using the R software (version 4.1.3). Means were compared by Tukey’s test at a 5% significance level. In addition, linear regression analyses were performed to evaluate the effects of inclusion levels on the response variables.

RESULTS

In the proximate composition of the breast meat (Table 4), a linear increase ($p < 0.05$) in moisture and lipid content was observed as the levels of GPEM increased in the diets of slow-growing broilers. Conversely, a linear decrease ($p<0.05$) in mineral and protein contents was noted. However, no significant differences were found in the proximate composition of breast meat from broilers fed increasing levels of GPUM (Table 5), indicating that GPUM inclusion preserved the basic nutritional profile of poultry meat.

Regarding the sensory characteristics of breast meat from slow-growing broilers, the inclusion of GPEM produced significant results (Table 6). The scores ranged from 4.96 to 6.18 on the 9-point hedonic scale, where 1 indicates "disliked extremely" and 9 "liked extremely." The most frequent ratings by panelists were 5 (indifferent) and 6 (slightly liked). Flavor and appearance exhibited a linear increase from the control (0%) to the highest inclusion level (10%), indicating greater acceptability at this level. This trend was supported by positive correlations for both variables. For texture and color, a quadratic relationship was observed: texture peaked at 5% inclusion, while color peaked at 7.5% GPEM inclusion. In contrast, aroma did not differ significantly across GPEM inclusion levels, indicating that GPEM had no perceptible effect on the aroma of broiler breast meat.

The inclusion of GPUM in the diets of slow-growing broilers demonstrated distinct and significant effects on the sensory attributes of breast meat (Table 7). Flavor was the most responsive parameter, showing a linear increase from the control diet (0%) to the highest inclusion level (10%). Texture also improved consistently and significantly with increasing GPUM inclusion, while appearance followed a similar linear trend. The robustness of the regression models and the significant correlation reinforce the potential of guarana pulp as a sensory-enhancing ingredient. A quadratic response was observed for color, with the highest score at 2.5% inclusion. In contrast, aroma showed no significant differences among treatments.

Table 4. Proximate composition of breast fillets from slow-growing broilers fed diets containing Guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MO	70.48±0.69[c]	71.20±0.23[b]	71.15±0.35[b]	73.04±0.76[a]	73.65±0.47[a]	<0.01	1.83	0.63	$Y = 70.268 + 0.3272x$	0.90
MI	1.21±0.02[a]	1.14±0.06[b]	1.12±0.17[b]	1.04±0.23[c]	1.02±0.15[c]	<0.01	6.63	-0.79	$Y = 1.202 - 0.0192x$	0.96
FA	1.69±0.11[b]	1.39±0.15[c]	1.53±0.18[b]	1.58±0.13[b]	1.81±0.23[a]	<0.01	10.12	0.38	$Y = 1.6526 - 0.0937x + 0.0111x^2$	0.84
PR	26.62±0.59[a]	26.27±0.15[a]	26.20±0.18[a]	24.34±0.28[b]	23.52±0.36[c]	<0.01	5.05	-0.65	$Y = 27.016 - 0.3252x$	0.87

[1] All data represent the average of 12 replicates (broilers) per treatment.

[2] MO = Moisture (%). MI = Minerals (%). FA = Fats (%). PT = Proteins (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (PCPM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (PCPM levels) on the dependent variable.

Table 5. Proximate composition of breasts samples of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
MOS	73.07±1.12	73.32±2.37	73.11±0.58	73.58±0.94	73.49±0,96	0.24	1.30	-	-	-
PRO	1.09±0.20	0.98±0.33	1.01±0.23	0.78±0,20	0.97±0.17	0.39	1.96	-	-	-
FAT	1.75±0.34	1.57±0.13	1.48±0.24	1.51±0.35	1.24±0.22	0.31	1.41	-	-	-
MIN	24.09±2.87	24.13±4.45	24.40±3.56	24.13±2.96	24.30±3.13	0.22	1.79	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] MOS = Moisture (%). PRO = Proteins (%). FAT = Fats (%). MIN = Minerals (%).

[3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05.

[4] CV = Coefficient of variation.

[5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Table 6. Sensory analysis of breasts samples of slow-growing broilers fed diets containing increase levels of guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
APE	5.12±2.00[c]	5.62±2.33[b]	5.84±2.19[b]	5.92±2.20[ab]	6.10±2.22[a]	0.03	18.54	0.63	$Y = 5.268 + 0.0904x$	0.89
TEX	5.52±1.88[c]	6.38±2.23[a]	6.42±2.03[a]	6.12±2.30[b]	5.92±2.43[b]	0.05	16.13	0.33	$Y = 5.6126 + 0.3027x – 0.0281x^2$	0.85
ARO	5.76±2.15	6.24±1.83	5.78±2.06	6.18±2.08	5.86±2.00	0.87	13.94	-	-	-
COL	5.42±2.03[b]	5.50±2.27[b]	5.66±1.97[b]	5.98±1.95[a]	5.28±1.80[c]	0.05	16.15	0.34	$Y = 5.328 + 0.168x – 0.016x^2$	0.80
FLA	4.96±2.18[c]	5.70±2.37[b]	5.94±2.29[b]	6.12±2.19[a]	6.04±2.49[a]	0.02	10.55	0.64	$Y = 5.236 + 0.1032x$	0.85

[1] All data represent the average of 50 replicates per treatment.
[2] APE = Appearance. TEX = Texture. ARO = Aroma. COL = Color. FLA = Flavor.
[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.
[4] CV = Coefficient of variation.
[5] COR = correlation coefficient between the independent variable (Guarana peel meal levels) and the dependent variable analyzed.
[6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

Table 7. Sensory analysis of breasts samples of slow-growing broilers fed diets containing increase levels of guarana pulp meal[1].

Variables[2]	Guarana pulp meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.50	5.00	7.50	10.00					
APE	6.22±1.57[b]	6.11±1.63[b]	6.27±1.55[b]	6.59±1.59[ab]	6.77±1.55[a]	0.05	14.86	0.52	$Y = 6.076 + 0.0632x$	0.81
TEX	6.25±1.55[b]	5.96±1.99[c]	6.25±2.00[b]	6.81±1.82[a]	6.81±1.79[a]	0.04	18.81	0.42	$Y = 6.022 + 0.0788x$	0.87
ARO	6.35±1.76	6.61±1.65	6.07±1.72	6.11±1.83	6.42±1.81	0.64	17.85	-	-	-
COL	6.24±1.69[b]	6.74±1.51[a]	6.20±1.55[b]	6.27±1.65[b]	6.25±1.29[b]	0.05	14.25	0.45	$Y = 6.3686 + 0.0311x – 0.0049x^2$	0.76
FLA	5.42±2.49[c]	6.20±2.27[b]	6.20±2.41[b]	6.33±2.27[a]	6.37±1.90[a]	0.05	17.53	0.57	$Y = 0.0812x + 5.698$	0.87

[1] All data represent the average of 50 replicates per treatment.
[2] APE = Appearance. TEX = Texture. ARO = Aroma. COL = Color. FLA = Flavor.
[3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.
[4] CV = Coefficient of variation.
[5] COR = correlation coefficient between the independent variable (Guarana pulp meal levels) and the dependent variable analyzed.

DISCUSSION

The inclusion of GPEM in broiler diets resulted in a linear increase in moisture and lipid contents, as well as a linear reduction in the mineral and protein contents of breast meat. GPEM contains a considerable amount of fiber in its composition (Santos et al., 2024), which can influence the metabolism of other nutrients (Rufino et al., 2021; Cho et al., 2024) and promote water retention in muscle tissues. According to Carvalho & Brochier (2008), dietary components can also influence meat composition; in their study, increasing brewery waste levels in lamb diets led to higher muscle moisture.

The high concentration of soluble fiber in GPEM, corresponding to 61.34% of neutral detergent fiber (NDF) (Santos et al., 2024), can increase intestinal viscosity and potentially impair nutrient absorption (Hung et al., 2022), which may explain the observed reductions in mineral and protein contents in chicken breast meat. In contrast, no significant differences were found in the proximate composition of breast meat from broilers fed GPUM, supporting the findings of Costa et al. (2020), who also reported no alterations in the proximate composition of broiler meat. Other studies have shown that the inclusion of unconventional ingredients such as rice bran, cassava leaves, leucaena hay, and tucumã bran at levels up to 10–15% in poultry diets does not significantly affect meat quality parameters or chemical composition (Faria et al., 2012; Chaves et al., 2024). Chemical and physical analyses are crucial to assess parameters such as protein, lipid content, pH, and water retention capacity (Moura et al., 2015).

The samples with the highest flavor acceptability came from broilers fed with the 10% inclusion level of both GPEM and GPUM. Flavor perception is a complex multisensory experience involving taste, smell, and oral-somatosensory stimuli (Spence, 2015). Although aroma scores did not differ significantly among treatments, olfactory perception plays a critical role in the overall flavor experience (Durán & Costell, 1999).

Texture acceptability peaked at 5% GPEM inclusion, whereas for GPUM, the highest inclusion levels yielded better sensory results. Although texture influences flavor perception (Durán & Costell, 1999), this relationship was not evident in the present study. As Denardin et al. (2023) noted, meat's internal moisture content directly affects its juiciness and tenderness.

The highest acceptability for color was observed at 7.5% GPEM inclusion and 2.5% GPUM inclusion. Appearance responded positively to the increasing inclusion levels of both by-products, with the highest scores recorded at 10%.

The poultry industry continues to face challenges in meeting consumer demands for high meat quality. Sensory traits such as color, aroma, juiciness, tenderness, and texture are increasingly prioritized (Osório et al., 2009). Research on chicken meat consumption in Brazil shows that consumers associate intrinsic characteristics, such as aroma, flavor, and juiciness, with overall product quality (Vannier et al., 2022). Regional studies further emphasize the importance of food preservation, facility hygiene, and product appearance in purchasing decisions (Lima et al., 2020; Oliveira et al., 2015).

Another critical factor affecting meat quality, including color, flavor, and shelf life, is lipid oxidation. Chicken and lamb meats are especially vulnerable due to their high levels of unsaturated fatty acids (Mariutti & Bragagnolo, 2009; Lima Júnior et al., 2013). Oxidation is influenced by multiple factors, including processing, storage conditions, and slaughter methods (Lima Júnior et al., 2013). Natural antioxidants such as sage, garlic, and guarana seed extracts have shown promising effects in preserving meat quality (Mariutti & Bragagnolo, 2009; Pateiro et al., 2018). Notably, guarana seed extracts, which are rich in phenolic compounds, are effective in inhibiting lipid and protein oxidation, surpassing synthetic antioxidants like BHT (Pateiro et al., 2018). This may help explain the positive sensory attributes observed in breast meat from broilers fed increasing levels of GPEM and GPUM.

Farias et al. (2020), while producing craft beer with guarana bark, found that higher inclusion levels increased both bitterness and color intensity. This highlights the importance of sensory evaluation in food product development, encompassing discriminative, descriptive, and affective tests to assess sensory attributes and consumer acceptance (Teixeira, 2009). Similarly, Rodrigues et al. (2024) reported high acceptability for rabbit meat kibbeh based on chemical and sensory analyses, while cookies enriched with 5% sesame residue flour achieved higher sensory scores than those with higher inclusion levels (Silva et al., 2023).

These studies reinforce that agricultural by-products can be effectively incorporated into various food products, whether for animal or human consumption, enhancing nutritional value and reducing environmental impact. However, the optimal inclusion level depends on the specific by-product and its intended application (Silva Júnior et al., 2020).

CONCLUSION

This study evaluated the effects of including GPEM and GPUM on the proximate composition and sensory attributes of breast meat from slow-growing broilers. GPUM proved to be more versatile, as it preserved the nutritional quality of the meat and enhanced sensory acceptance at all tested inclusion levels (2.5–10%). Although GPEM altered the proximate composition, it improved key sensory attributes, such as flavor and appearance, at higher inclusion levels (10%). The incorporation of guarana by-products into poultry diets aligns with circular economy principles, contributing to waste reduction and lowering reliance on conventional feed inputs. In summary, both by-products show potential as sustainable ingredients in poultry farming, offering a pathway to increased innovation, cost reduction, and valorization of Amazonian agro-industrial resources.

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REFERENCES

ABPA - Associação Brasileira de Proteína Animal. (2024). Relatório Anual. Disponível em: https://abpa-br.org/abpa-relatorio-anual/. Acesso em: 26 maio 2025.

AOAC - Association of Official Agricultural Chemists. (2019). Official methods of analysis of AOAC International (21st ed.). Rockville, MD, USA: AOAC.

Arias-Giraldo, S., & López-Mejía, M. (2022). Usos, propiedades nutricionales y evaluación sensorial del amaranto, quinua y subproductos de uva y café. Ingeniería y Competitividad, 24(1), e30211000. https://doi.org/10.25100/iyc.v24i1.11000

Brandão, J. S., Souza, B. B., Brandão, P. A., Ferreira, D. H., Nascimento, C. E. O., Benício, T. M. A., Carvalho, A. B., & Silva, M. R. (2023). Alternative foods for feeding quails (Coturnix coturnix) for meat production. Revista Observatorio de la Economía

Latinoamericana, 21(12), 25857–25877. https://doi.org/10.55905/oelv21n12-130

Bowles, N., Alexander, S., & Hadjikakou, M. (2019). The livestock sector and planetary boundaries: A ‘limits to growth’ perspective with dietary implications. Ecological Economics, 160, 128–136. https://doi.org/10.1016/j.ecolecon.2019.01.033

Carvalho, S. E., & Brochier, M. A. (2008). Tissue and centesimal composition and cholesterol of the meat of lambs feedlot with diets with different levels of brewery's residue. Ciência Rural, 38, 2023–2028. https://doi.org/10.1590/S0103-84782008000700035

Chaves, F. A. L., Guimarães, L. L., Guimarães, C. C., Souza, L. S. S., Rufino, J. P. F., & Pereira, A. M. (2024). Tucumã bran as an alternative food to diets for slow-growing broilers. Revista em Agronegócio e Meio Ambiente, 17(3), e11782. https://doi.org/10.17765/2176-9168.2024v17n3e11782

Cho, S., Shi, H., Sureshkumar, S., & Kim, I. (2024). The effects of the dietary inclusion of by-products obtained after the extraction of vitamin B2 from fermented soybean on the performance and meat quality of growing–finishing pigs. Applied Sciences, 14, 803. https://doi.org/10.3390/app14020803

Costa, V. L., Calixto, R. C., Moura, M. I., Costa, G. L., Malaquias Júnior, J. D., & Duarte, F. O. S. (2020). Centesimal composition and color of chicken meat feeded with diet containing soybean oil. Brazilian Journal of Animal and Environmental Research, 3(2), 685–689. https://doi.org/10.34188/bjaerv3n2-025

Cruz, F. G. G., Rufino, J. P. F., Melo, R. D., Feijó, J. C., Damasceno, J. L., & Costa, A. P. G. C. (2016). Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. Revista em Agronegócio e Meio Ambiente, 9, 371-391. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Denardin, I. T., Dionello, N. J. L., Júnior, B. S. B., Mello, R. O., Jardim, R. D., & Klinger, A. C. K. (2023). Qualidade da carne de coelhos oriundos de diferentes cruzamentos. Ciência Animal (UECE), 26(3), 66–76.

Durán, L., & Costell, E. (1999). Revision: Percepción del gusto. Aspectos fisicoquímicos y psicofísicos / Review: Perception of taste. Physiochemical and psychophysical aspects.

Food Science and Technology International, 5(4), 299-309. https://doi.org/10.1177/108201329900500402

Dutcosky, S. D. (1996). Análise sensorial de alimentos (p. 123). Curitiba: Ed. da Champagnat.

Farias, M. S., Alves, W. S., Santos, J. P., Oliveira, R. P. M., & Pereira, C. V. L. (2020). Avaliação sensorial por método descritivo de cerveja artesanal com casca do guaraná (Paullinia cupana). In Tecnologia de Alimentos: Tópicos Físicos, Químicos e Biológicos (vol. 1, cap. 23, p. 308-321). https://doi.org/10.37885/200800912

Faria, P. B., Vieira, J. O., Souza, X. R., Rocha, M. F. M., & Pereira, A. A. (2012). Quality of broiler meat of the free-range type submitted to diets containing alternative feedstuffs. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 64(2), 389-396. https://doi.org/10.1590/S0102-09352012000200019

Hung, Y. T., Zhu, J., Shurson, G. C., Urriola, P. E., & Saqui-Salces, M. (2022). Decreased nutrient digestibility due to viscosity is independent of the amount of dietary fibre fed to growing pigs. British Journal of Nutrition, 127, 177–187. https://doi.org/10.1017/S0007114521000866

Lima, A. M., Melo, W. O., Albuquerque, G. D. P., Nascimento, J. B., & Cândido, E. P. (2020). Consumer market of chicken meat and derivatives in Capanema, Pará. Brazilian Journal of Development, 6(5), 26810-26824. https://doi.org/10.34117/bjdv6n5-220

Lima Júnior, D. M., Rangel, A. H. N., Urbano, S. A., & Moreno, G. M. B. (2013). Oxidação lipídica e qualidade da carne ovina. Acta Veterinaria Brasilica, 7(1), 14-28. https://doi.org/10.21708/AVB.2013.7.1.3119

Mariutti, L. R. B., & Bragagnolo, N. (2009). A oxidação lipídica em carne de frango e o impacto da adição de sálvia (Salvia officinalis, L.) e de alho (Allium sativum, L.) como antioxidantes naturais. Revista do Instituto Adolfo Lutz, 68(1), 1-11. https://doi.org/10.53393/rial.2009.v68.32736

Mendes, A. A., & Patrício, I. S. (2004). Controles, registros e avaliação do desempenho de frangos de corte. In: Mendes, A. A., Nääs, I. A., & Macari, M. (Eds.), Produção de frangos de corte. Campinas: FACTA.

Moura, J. W. F., Medeiros, F. M., Alves, M. G. M., & Batista, A. S. M. (2015). Fatores influenciadores na qualidade da carne suína. Revista Científica de Produção Animal, 17, 18-29. http://dx.doi.org/10.15528/2176-4158/rcpa.v17n1p18-29

Oliveira, C. A. D. E., Andrade, P. L., & Rezende, T. K. L. (2022). [Título do artigo]. Ibero-American Journal of Humanities, Sciences and Education, 8(11), [páginas]. https://doi.org/10.51891/rease.v8i11.7927

Oliveira, A. P., Ferreira, M. R., Santana, H. A. J. R., Santos, M. S., Brito, J. M., & Mendes, F. B. L. (2015). Caracterização do consumidor de carne de frango em Júlio Borges, PI. Revista Científica de Produção Animal, 17(2), 129-141. http://dx.doi.org/10.15528/2176-4158/rcpa.v17n2p129-141

Osório, J. C. S., Osório, M. T. M., & Sañudo, C. (2009). Sensorial characteristics of sheep meat. Revista Brasileira de Zootecnia, 38, 292-300. https://doi.org/10.1590/S1516-35982009001300029

Pateiro, M., Vargas, F. C., Chincha, A. A. I. A., Sant'Ana, A. S., Strozzi, I., Rocchetti, G., Barba, F. J., Domínguez, R., Lucini, L., do Amaral Sobral, P. J., & Lorenzo, J. M. (2018). Guarana seed extracts as a useful strategy to extend the shelf life of pork patties: UHPLC-ESI/QTOF phenolic profile and impact on microbial inactivation, lipid and protein oxidation and antioxidant capacity. Food Research International, 114, 55–63. https://doi.org/10.1016/j.foodres.2018.07.047

Pérez-Palencia, J. Y., & Bolívar-Sierra, A. F. (2023). Alimentos alternativos en combinación con suplementación enzimática para mejorar la eficiencia y sostenibilidad de la producción porcina y avícola. Orinoquía, 27(1), 2. https://doi.org/10.22579/20112629.787

Pinotti, L., Mazzoleni, S., Moradei, A., Lin, P., & Luciano, A. (2023). Effects of alternative feed ingredients on red meat quality: a review of algae, insects, agro-industrial by-products and former food products. Italian Journal of Animal Science, 22(1), 695–710. https://doi.org/10.1080/1828051X.2023.2238784

Piccolo, E. A., Duval, H. C., Gallo, Z., Ferraz, J. M. G. (2024). A contemporaneidade da avicultura: da pré-história à liderança concorrencial brasileira. Revista Políticas Públicas & Cidades, 13(2), e947. https://doi.org/10.23900/2359-1552v13n2-102-2024

Rodrigues, P. G., Santos, L. F. dos, Queiroz, L. O. de, Fraga, D. H. A. G., Pereira, H. B. J., Santos, B. J., & Silva, C. M. (2024). Composição química e análise sensorial de quibe de carne de coelho. Ciência Animal, 33(4), 30–42. Disponível em: https://revistas.uece.br/index.php/cienciaanimal/article/view/12318. Acesso em: 20 jun. 2025.

Rostagno, H.S., Albino, L.F.T., Calderano, A.A., Hannas, M.I., Sakomura, N.K., Costa, F.G.P., Rocha, G.C., Saraiva, A., Abreu, M.L.T., Genova, J.L., Tavernari, F.C. (2024). Brazilian tables for poultry and swine: food composition and nutritional requirements [in Portuguese] (5th Ed.). Viçosa, Brazil: Federal University of Viçosa Press.

Rufino, J. P. F., Cruz, F. G. G., Brasil, R. J. M., Oliveira Filho, P. A., Melo, R. D., & Feijó, J. C. (2021). Relationship between the level and the action period of fiber in diets to laying hens. Acta Scientiarum. Animal Sciences, 43, e49033. https://doi.org/10.4025/actascianimsci.v43i1.49033

Sakomura, N. K., & Rostagno, H. S. (2016). Métodos de pesquisa em nutrição de monogástricos. Jaboticabal, Brazil: Funep.

Sanches, D. S., Moraes, G., Elis, R. de, & Kiefer, C. (2023). Alternative diets for poultry and swine: a brief review. Multidisciplinary Electronic Journal of Scientific Research, 2(S1). https://doi.org/10.56166/remici.2023.2.v2n1.2.3

Sánchez, I. C., & Albarracín, W. (2010). Sensory analysis of meat. Revista Colombiana de Ciencias Pecuarias, 23(2), 227–239. https://doi.org/10.17533/udea.rccp.324566

Santos, A. N. A., Rufino, J. P. F., Viana, A. L., Guimarães, C. C., Gomes, M. F. S., Barai, A. A., Nóbrega, T. C., Ribeiro, M. W. S., Silva, A. J. I., Chaves, F. A. L., Mendonça, M. A. F., Silva Júnior, J. L., Costa Neto, P. Q., & Oliveira, A. T. (2024). Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science, 64, AN24137. https://doi.org/10.1071/AN24137

Schimpl, F. C., da Silva, J. F., Gonçalves, J. F., & Mazzaféra, P. (2013). Guarana: revisiting a highly caffeinated plant from the Amazon. Journal of Ethnopharmacology, 150, 14–31. https://doi.org/10.1016/j.jep.2013.08.023

Silva, D. R. S., Pessoa, T., Gurjão, F. F., Ferreira, D. J. L., & Farias, F. P. M. (2023). Study of the acceptability of cookies enriched with sesame waste flour. Cadernos Macambira, 8(Esp. 1), 124. https://doi.org/10.59033/cm.v8iespecial1.1177

Silva Júnior, E. B., Mora, N. H. A. P., Possamai, A. P. S., Galvão, L. B., & Barros, E. L. S. (2020). Acceptability of beef burgers enriched with oats and with different levels of inclusion of swine bacon. Revista Agrária Acadêmica, 3(3), 226–236. https://doi.org/10.32406/v3n32020/226-236/agrariacad

Spence, C. (2015). Multisensory flavor perception. Cell, 161, 24–35. https://doi.org/10.1016/j.cell.2015.03.007

Teixeira, L. V. (2009). Análise sensorial na indústria de alimentos/Sensory analysis in the food industry. Revista do Instituto de Laticínios Cândido Tostes, (366), 12–21.

Valentim, J. K., D’Ávila, L. H. J., Marques, B. T., Matos, S. N. E., de Castro, B. M. F., Garófallo, G. R., de Carvalho, P. J., & Barbosa, D. K. (2021). Dried Distiller’s Grains in Broiler Feeding. Essays and Science: Biological, Agricultural and Health Sciences, 25(1), 44–49. https://doi.org/10.17921/1415-6938.2021v25n1p44-49

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science, 74, 3583–3597. https://doi.org/10.3168/jds.s0022-0302(91)78551-2

Vannier, L. R., Tavares Filho, E. R., Pagani, M. M., Cruz, A. G., Teixeira, C. E., Duarte, M. C. K. H., & Esmerino, E. A. (2022). Chicken meat – A study on consumption, attitudes and the Brazilian consumer behavior. The Journal of Engineering and Exact Sciences – jCEC, 8(9). https://doi.org/10.18540/jcecvl8iss9pp14854-01e

Wu, Y., Huang, J., Quan, S., Yang, Y. (2022). Light regimen on health and growth of broilers: an update review. Poultry Science, 101, 101545. https://doi.org/10.1016/j.psj.2021.1015

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CHAPTER 9: Practical guide: Alternative foods for poultry farming in the Amazon

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GUIA PRÁTICO

ALIMENTOS ALTERNATIVOS PARA AVICULTURA NA AMAZÔNIA

UFAM

PPGCARP
Programa de Pós-graduação em Ciência Animal e Recursos Pesqueiros

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SUMÁRIO

SUMÁRIO

APRESENTAÇÃO

A Amazônia é um celeiro de biodiversidade e riqueza natural, mas muitas vezes, os resíduos gerados pela produção de frutos permanecem subutilizados.

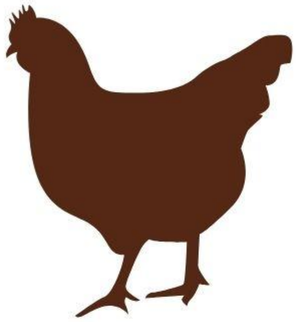
Os resíduos de frutos como o açaí e guaraná são ricos em nutrientes e podem melhorar a saúde e o desempenho das aves, além de proporcionar uma alternativa econômica para os produtores. Este guia prático foi desenvolvido com o objetivo de auxiliar o pequeno produtor rural na adoção desses alimentos alternativos, com informações simples e diretas, para facilitar sua aplicação no dia a dia.

Dividido em tópicos fáceis de seguir, o guia aborda as fontes alimentares disponíveis e as técnicas para a sua correta utilização e preparo, garantindo que as aves recebam uma alimentação balanceada e saudável.

Ótima leitura!

ALIMENTOS ALTERNATIVOS

Para frangos de corte de crescimento lento



- Farelo da casca do guaraná
- Farelo da torta do guaraná
- Farelo da torta do tucumã

Para poedeiras

- Farinha de cará
- Farelo de açaí
- Farinha do resíduo de buriti
- Farelo da casca do tucumã
- Farinha de apara de mandioca
- Farinha de semente de urucum

Para ambas criações

- Farelo de castanha de caju

INTRODUÇÃO

Dona Maria, uma grande produtora de guaraná percebeu que durante a safra é gerado uma grande quantidade da casca do guaraná. Lembrou que leu um artigo sobre o uso do Guaraná na alimentação de frango de corte e de outros resíduos que podem ser usados como alimentos alternativos e resolveu , junto com os criadores da região produzir rações alternativas.

Dona Ana e Senhor João, criadores de frangos de corte e galinha de postura, ficaram felizes com a notícia, pois durante anos criando aves de produção na Amazônia, perceberam que o maior custo da sua produção é com a alimentação. E produzindo rações com alimentos alternativos, usando resíduos que são encontrados na região, diminuirá o custo com a alimentação das aves.

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Subprodutos do fruto do guaraná

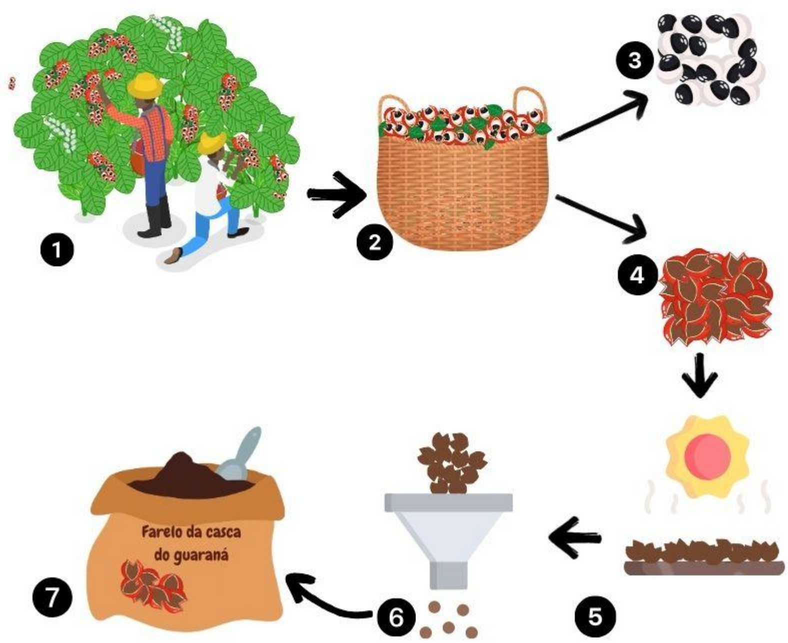
Os subprodutos do guaraná, como a **casca e a torta**, são ricos em fibras, compostos bioativos e antioxidantes, tornando-se potenciais ingredientes na formulação de dietas para aves, com efeitos positivos no desempenho produtivo e na qualidade da carne.

Da produção anual de sementes de guaraná, só se utilizam as amêndoas para a produção do pó do guaraná e para a extração do extrato do guaraná usado pela indústria de gaseificados, enquanto as cascas, que representam 30% do peso total das sementes, são desprezadas.

1. **Colheita do guaraná**
2. **Fruto do guaraná colhido**
3. **Grão de guaraná**
4. **Casca do guaraná**
5. **Secagem da casca do guaraná**
6. **Trituraçao da casca do guaraná**
7. **Farelo da casca do guaraná**

Farelo da casca do guaraná

Fluxograma da cadeia do guaraná até a produção do farelo da casca do guaraná



ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Ração alternativa com o farelo da casca do guaraná

Na tabela a seguir, são encontrados exemplos de uma ração que atenda as exigências dos frangos de corte de crescimento lento na fase inicial e final com a inclusão do farelo da casca do guaraná.

Ração para frangos de corte de crescimento lento (1 à 56 dias)			
Ingredientes (Kg)	Pré- nicial (1 à 7 dias)	Inicial (8 à 28 dias)	Final (29 à 56 dias)
Milho 7,88%	58,07	43,83	52,75
Farelo de Soja 45%	38,32	39,82	31,64
Farelo da casca do guaraná	0,00	10,00	10,00
Calcário calcítico	0,93	0,79	0,74
Fosfato Bicálcico	1,79	1,83	1,61
Sal comum	0,30	0,28	0,28
PREMIX	0,50	0,50	0,50
DL-Metionina	0,10	0,13	0,06
Óleo de soja	0,00	2,82	2,41
Total	100,00	100,00	100,00

A inclusão de 10% do farelo da casca do guaraná apresentou melhores resultados na dieta de frangos de corte de crescimento lento.

Composição química do farelo da casca do guaraná

VARIÁVEIS	VALORES
MATÉRIA SECA, %	89,11
PROTEÍNA BRUTA, %	18,72
LIPÍDEOS (%)	5,36
MINERAIS, %	5,33
FIBRA BRUTA, %	44,04
FIBRA DETERGENTE NEUTRO, %	61,66
FIBRA DETERGENTE ÁCIDO, %	39,64
CARBOIDRATOS SOLÚVEIS, %	26,55
ENERGIA BRUTA, KCAL/KG	6.495,65
ENERGIA METAB. KCAL/KG	2.258,64

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Farelo da torta do guaraná

A torta do guaraná é o resíduo proveniente do processo de extração do extrato do guaraná, a partir das amêndoas torradas.

Fluxograma da cadeia do guaraná até a produção do farelo da torta do guaraná

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Ração alternativa com o farelo da torta do guaraná

Na tabela a seguir, são encontrados exemplos de uma ração que atenda as exigências dos frangos de corte de crescimento lento na fase inicial e final com a inclusão do farelo da torta do guaraná.

Ração para frangos de corte de crescimento lento (1 à 56 dias)			
Ingredientes (Kg)	Pré- nicial (1 à 7 dias)	Inicial (8 à 28 dias)	Final (29 à 56 dias)
Milho 7,88%	58,07	50,10	55,40
Farelo de Soja 45%	38,32	35,55	30,28
Farelo da torta do guaraná	0,00	7,50	7,50
Calcário calcítico	0,93	0,81	0,75
Fosfato Bicálcico	1,79	1,85	1,61
Sal comum	0,30	0,28	0,28
PREMIX	0,50	0,50	0,50
DL-Metionina	0,10	0,16	0,07
Óleo de soja	0,00	3,25	3,61
Total	100,00	100,00	100,00

A inclusão de 7,5% do farelo da torta do guaraná apresentou melhores resultados na dieta de frangos de corte de crescimento lento.

Composição química do farelo da torta do guaraná

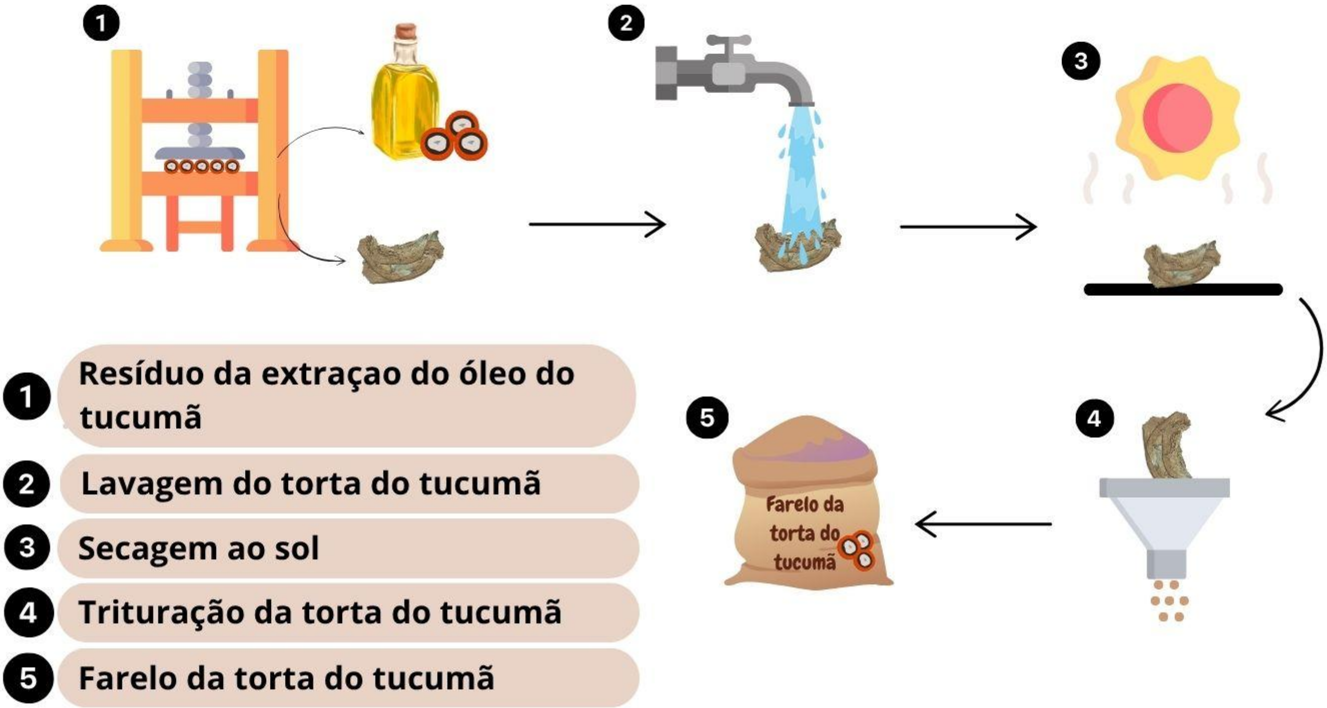
VARIÁVEIS	VALORES
MATÉRIA SECA, %	83,93
PROTEÍNA BRUTA,%	12,27
LIPÍDEOS (%)	2,41
MINERAIS, %	1,01
FIBRA BRUTA, %	29,17
FIBRA DETERGENTE NEUTRO, %	40,84
FIBRA DETERGENTE ÁCIDO, %	26,25
CARBOIDRATOS SOLÚVEIS, %	55,14
ENERGIA BRUTA, KCAL/KG	5,745.42
ENERGIA METAB. KCAL/KG	2,828.56

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Farelo da torta do tucumã

Os resíduos resultantes do despolpamento do tucumã (semente e casca), são conhecidos como **torta de tucumã**.

Fluxograma da produção do farelo da torta do tucumã



Os resíduos gerados no processamento do tucumã, possuem potencial biológico para serem incorporados em dietas para aves, tanto para frangos de corte de crescimento rápido quanto para os de crescimento lento.

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE DE CRESCIMENTO LENTO

Ração alternativa com o farelo da torta do tucumã

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão do farelo da torta do tucumã

Ração para frangos de corte de crescimento lento		
Ingredientes (Kg)	Inicial (1 à 28 dias)	Dieta basal da fase final (29 a 56 dias)
Milho 7,88%	37,44	65,69
Farelo de Soja 45%	40,53	30,40
Farelo da torta do tucumã	15,00	0
Calcário calcítico	0,78	0,77
Fosfato Bicálcico	1,85	1,57
Sal comum	0,28	0,53
PREMIX	0,50	0,50
DL-Metionina	0,15	0,04
Óleo de soja	3,47	0,50
Total	100,00	100,00

A inclusão de 15% de farelo da torta do tucumã em dietas na fase inicial para frangos de corte de crescimento lento da linhagem Label Rouge em confinamento não afetou o consumo de ração.

Composição química do farelo da torta do tucumã

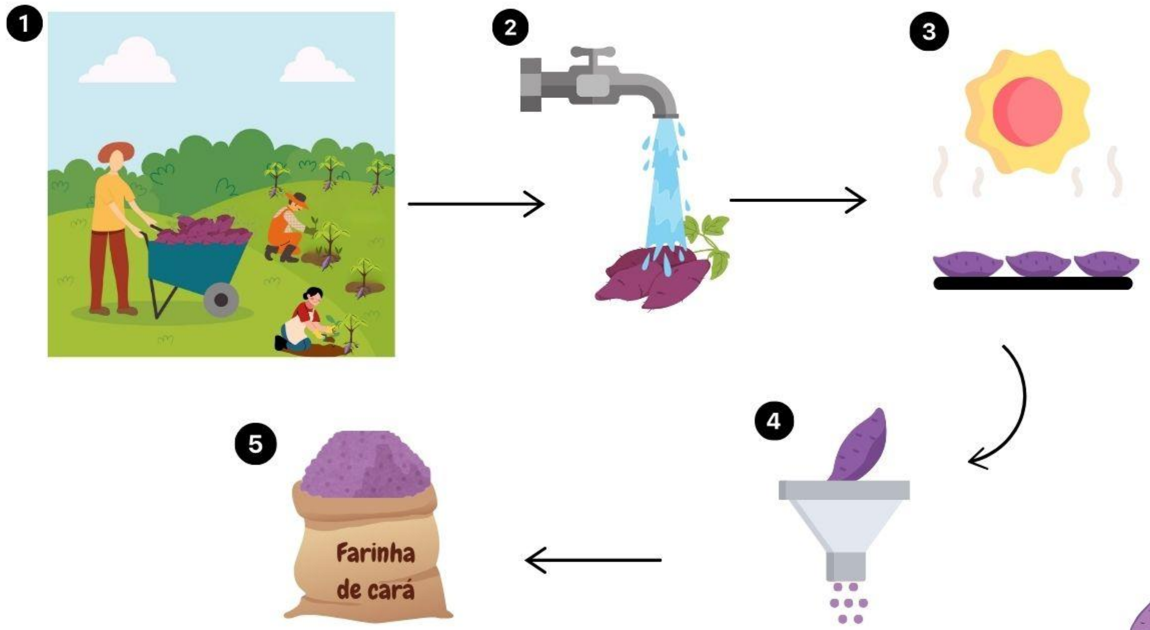
VARIÁVEIS	VALORES
MATÉRIA SECA, %	89,38
PROTEÍNA BRUTA, %	4,99
FIBRA BRUTA (%)	29,09
FIBRA DETERGENTE NEUTRO, %	60,32
FIBRA DETERGENTE ÁCIDO, %	43,37
LIPÍDEOS, %	10,62
CINZAS, %	2,01
CARBOIDRATOS SOLÚVEIS, %	53,29
ENERGIA BRUTA, KCAL/KG	6.110,33
ENERGIA METAB. KCAL/KG	3.180,05

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Farinha de cará

A farinha de cará apresenta grande potencial para inclusão em rações para poedeiras, especialmente devido à produção significativa dessa cultura na região Amazônica, realizada principalmente por pequenos agricultores tradicionais.

Fluxograma da produção da farinha de cará



1. Colheita do cará
2. Lavagem do cará
3. Secagem ao sol do cará
4. Trituração do cará
5. Farinha de cará

O cará é uma espécie de inhame comestível originária da América do Sul. Seus tubérculos são ricos em carboidratos, proteínas, sais minerais e vitaminas, além de possuírem propriedades antimicrobianas, diuréticas e energizantes.

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farinha de cará

Na tabela a seguir,está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão da farinha de cará.

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	56,43
Farelo de Soja 45%	25,98
Farinha de cará	5,00
Calcário calcítico	9,76
Fosfato Bicálcico	1,71
Sal comum	0,35
PREMIX	0,50
DL-Metionina	0,27
Total	100,00

A inclusão de 5% de farinha de cará como alimento alternativo em rações de poedeiras comerciais leves, apresentadou melhor desempenho e resultados de bioquímica sérica.

Composição química da farinha de cará

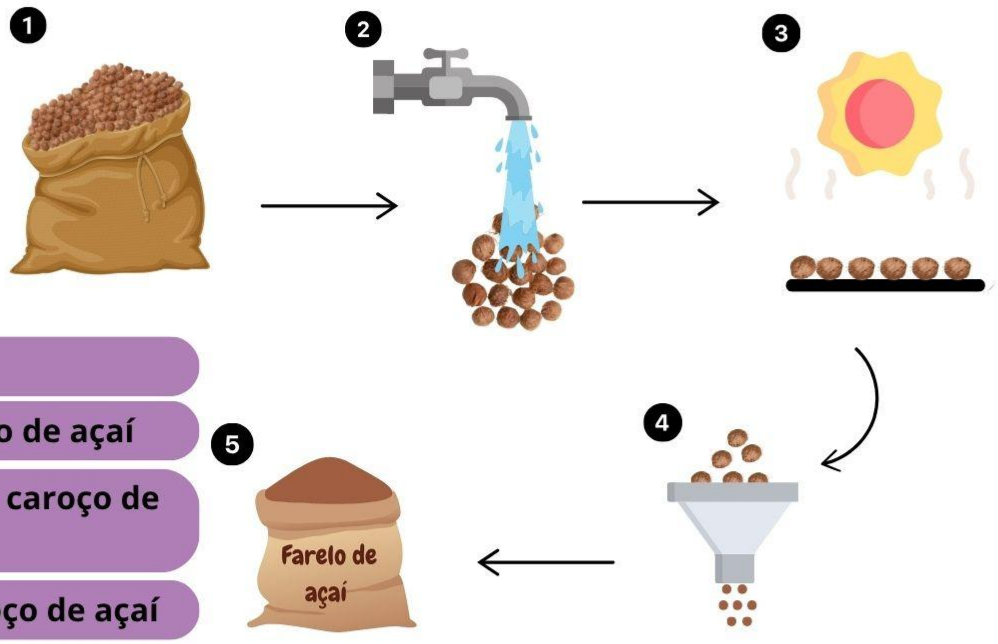
VARIÁVEIS	VALORES
MATÉRIA SECA, %	95,54
PROTEÍNA BRUTA, %	2,65
FIBRA BRUTA (%)	2,69
FIBRA DETERGENTE NEUTRO, %	7,45
FIBRA DETERGENTE ÁCIDO, %	3,64
GORDURA, %	0,31
MATÉRIA MINERAL, %	3,23
EXTRATO NÃO NITROGENADO, %	86,66
ENERGIA BRUTA, KCAL/KG	3730,73
ENERGIA METAB. KCAL/KG	3489,81

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Farelo de açai

A polpa de açaí é o principal produto derivado do processamento do fruto do açaí. Corresponde a apenas 10% da massa total do fruto, enquanto os restantes 90% são descartados como resíduo. Esse descarte gera um volume significativo de resíduos anualmente, que, na maioria das vezes, são eliminados de forma inadequada, sem serem reintegrados em ciclos de reaproveitamento

Fluxograma da produção do farelo de açaí



1. **Caroço de açaí**
2. **Lavagem do caroço de açaí**
3. **Secagem ao sol do caroço de açaí**
4. **Trituração do caroço de açaí**
5. **Farelo de açaí**

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farelo de açai

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão da farelo de açaí.

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	50,46
Farelo de Soja 45%	24,86
Farelo de açaí	10,00
Calcário calcítico	9,76
Fosfato Bicálcico	1,74
Sal comum	0,35
PREMIX	0,50
DL-Metionina	0,11
Óleo de soja	2,22
Total	100,00

A inclusão de 10% de farelo de açaí na dieta de aves de postura da linhagem Hisex White melhorou o desempenho produtivo e a qualidade sensorial dos ovos.

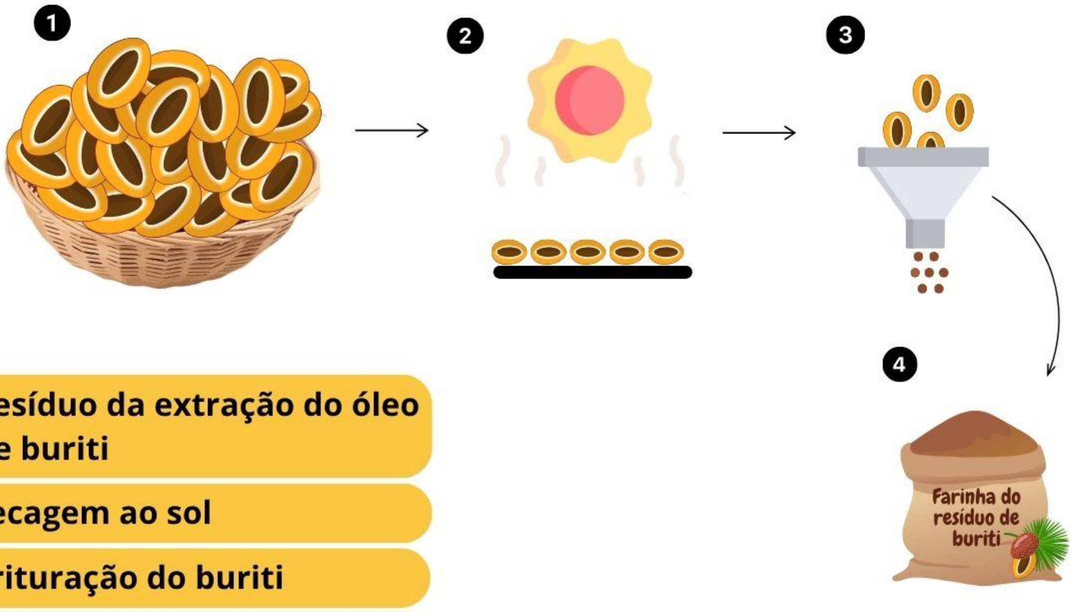
Composição química da farelo de açaí

VARIÁVEIS	VALORES
MATÉRIA SECA, %	89,12
PROTEÍNA BRUTA, %	5,25
FIBRA BRUTA (%)	25,30
FIBRA DETERGENTE NEUTRO, %	61,34
FIBRA DETERGENTE ÁCIDO, %	42,33
GORDURA, %	4,12
MATÉRIA MINERAL, %	6,64
EXTRATO NÃO NITROGENADO, %	58,69
ENERGIA BRUTA, KCAL/KG	5.389,16
ENERGIA METAB. KCAL/KG	2.838,18

Farinha do resíduo de buriti

O fruto do buriti é rico em vitamina A, B e C, possui cálcio, ferro e proteínas. Além de seu consumo in natura, serve na composição de doces, sucos, cremes, sorvetes e licores.

Fluxograma da produção da farinha do resíduo de buriti



1. **Resíduo da extração do óleo de buriti**
2. **Secagem ao sol**
3. **Trituração do buriti**
4. **Farinha do resíduo de buriti**

O resíduo da extração do óleo de buriti pode ser utilizado como ingrediente na ração animal.

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farinha do resíduo de buriti

Na tabela a seguir ,está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão da farinha do resíduo de buriti.

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	35,47
Farelo de Soja 45%	26,85
Farinha do resíduo de buriti	25,00
Calcário calcítico	9,73
Fosfato Bicálcico	1,77
Sal comum	0,35
PREMIX	0,50
DL-Metionina	0,33
Total	100,00

É possível substituir até 25% do milho pela farinha do resíduo de buriti em rações balanceadas para poedeiras comerciais leves sem comprometer a qualidade dos ovos.

Composição química da farinha do resíduo de buriti

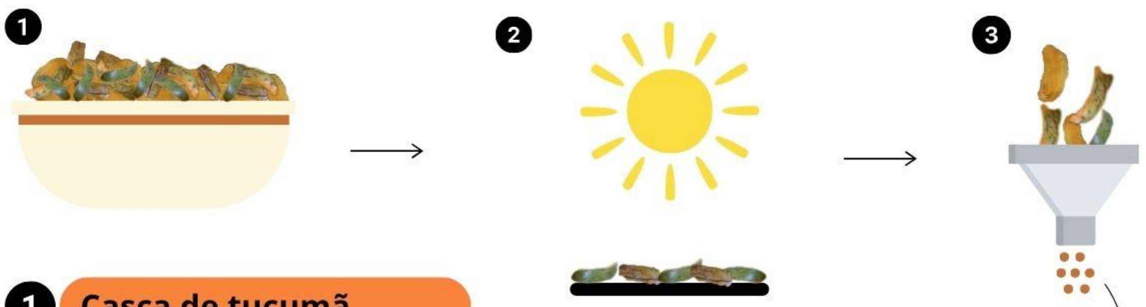
VARIÁVEIS	VALORES
MATÉRIA SECA, %	91,39
PROTEÍNA BRUTA, %	6,63
FIBRA BRUTA (%)	1,97
EXTRATO ETÉREO, %	13,72
MATÉRIA MINERAL, %	3,33
EXTRATO NÃO NITROGENADO, %	65,86
ENERGIA BRUTA, KCAL/KG	4286,94
ENERGIA METAB. KCAL/KG	3927,29

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Farelo da casca do tucumã

Frutos de tucumã são comercializados anualmente em feiras e mercados de Manaus, seu principal centro comercial, gerando um grande volume de resíduos.

Fluxograma da produção do farelo da casca do tucumã



1. Casca de tucumã
2. Secagem ao sol
3. Trituração da casca do tucumã
4. Farelo da casca do tucumã

Esses resíduos, especialmente os provenientes da região do mesocarpo do fruto (casca), possuem um excelente potencial nutricional.

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farelo da casca do tucumã

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão do farelo da casca do tucumã

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	24,90
Farelo de Soja 45%	25,71
Farelo da casca do tucumã	35,34
Calcário calcítico	9,19
Fosfato Bicálcico	1,82
Sal comum	0,35
PREMIX	0,50
DL-Metionina	0,19
Óleo de soja	2,00
Total	100,00

A substituição de até 60% do milho por farelo da casca do tucumã em rações para poedeiras comerciais leves não causa impactos negativos no desempenho das aves nem na qualidade dos ovos.

Composição química do farelo da casca do tucumã

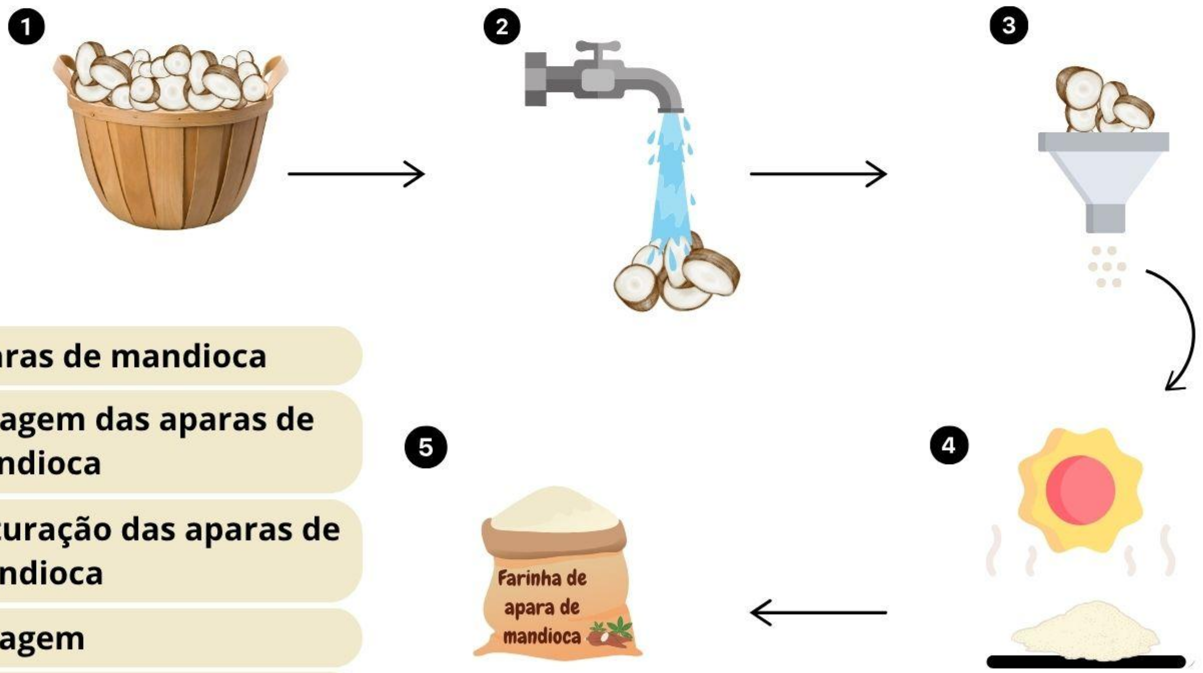
VARIÁVEIS	VALORES
MATÉRIA SECA, %	89,07
PROTEÍNA BRUTA, %	10,39
FIBRA BRUTA (%)	14,04
EXTRATO ETÉREO, %	10,79
CINZAS, %	4,55
CARBOIDRATOS TOTAIS, %	63,34
ENERGIA BRUTA, KCAL/KG	3.942,12
ENERGIA METAB. KCAL/KG	3.748,51

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Farinha de apara de mandioca

A farinha da apara (ponta) da mandioca é obtida por meio de cortes nas pontas da raiz no momento da comercialização ao consumidor, é uma forma tradicional de mostrar que o produto está em boas condições.

Fluxograma da produção da farinha de apara de mandioca



1. **Aparas de mandioca**
2. **Lavagem das aparas de mandioca**
3. **Trituração das aparas de mandioca**
4. **Secagem**
5. **Farinha de apara de mandioca**

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farinha de apara de mandioca

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão da farinha de apara de mandioca

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	0
Farelo de Soja 45%	30,48
Farinha de apara de mandioca	50,33
Farinha de carne e osso	4,00
Óleo de dendê	5,00
Calcário calcítico	8,83
Fosfato Bicálcico	0,76
Sal comum	0,30
PREMIX	0,15
DL-Metionina	0,15
Total	100,00

É possível substituir 100% do milho pela farinha da apara de mandioca sem alterar a produção de ovos e conversão alimentar.

Composição química da farinha de apara de mandioca

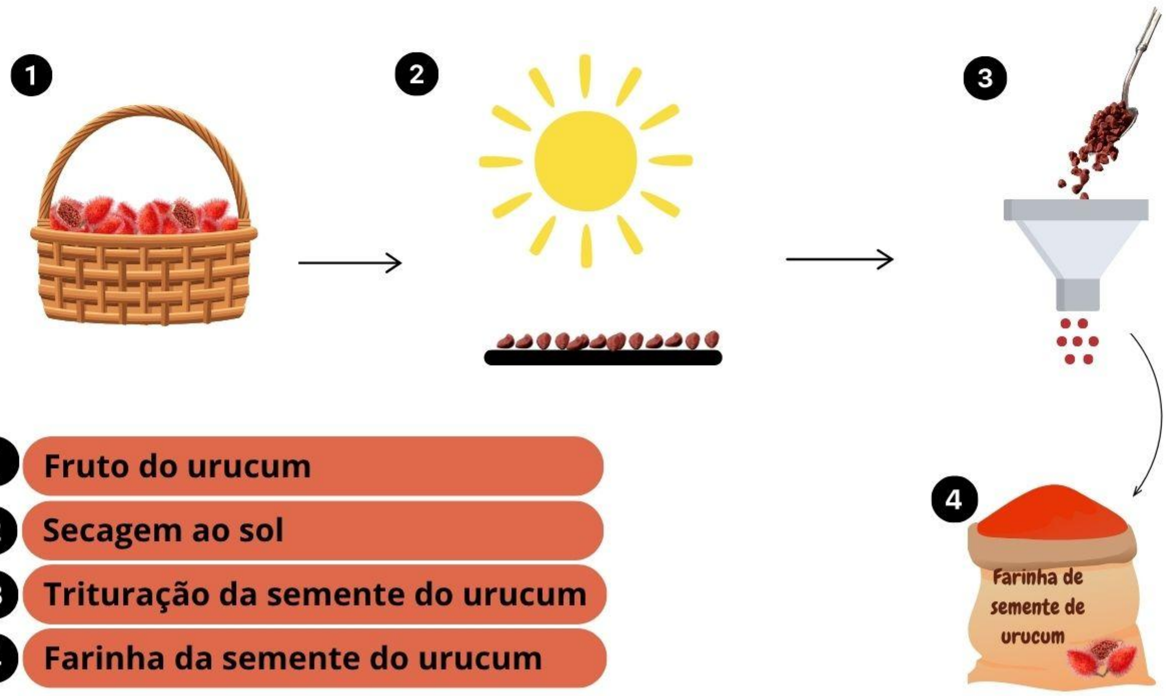
VARIÁVEIS	VALORES
UMIDADE, %	12,23
PROTEÍNA BRUTA, %	2,43
FIBRA BRUTA (%)	4,91
EXTRATO ETÉREO, %	0,35
CINZAS, %	2,03

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Farinha de semente de urucum

O urucum possui sementes ricas em carotenóides, e pode ser empregada em muitos produtos e na alimentação humana e animal. Para aves, as pesquisas concentram-se basicamente em determinar níveis ideais de inclusão dos subprodutos na dieta visando à manutenção da produtividade e melhoria na cor da gema dos ovos e da pele e carne dos frangos.

Fluxograma da produção da farinha de semente de urucum



1. Fruto do urucum
2. Secagem ao sol
3. Trituração da semente do urucum
4. Farinha da semente do urucum

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farinha de semente de urucum

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de galinha poedeira, com a inclusão da farinha de semente de urucum

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	0
Farelo de Soja 45%	20,55
Sorgo	54,50
Farelo de trigo	13,68
Urucum	1,0
Calcário calcítico	7,97
Fosfato Bicálcico	1,36
Sal comum	0,37
PREMIX	0,34
DL-Metionina	0,23
Total	100,00

A inclusão de 0,89% de semente de urucum moída nas rações à base de sorgo não prejudica o desempenho das aves e promove pigmentação da gema dos ovos semelhante à obtida com rações à base de milho, o que mostra que é viável a utilização de semente de urucum moída em substituição aos pigmentantes sintéticos.

Composição química da farinha de semente de urucum

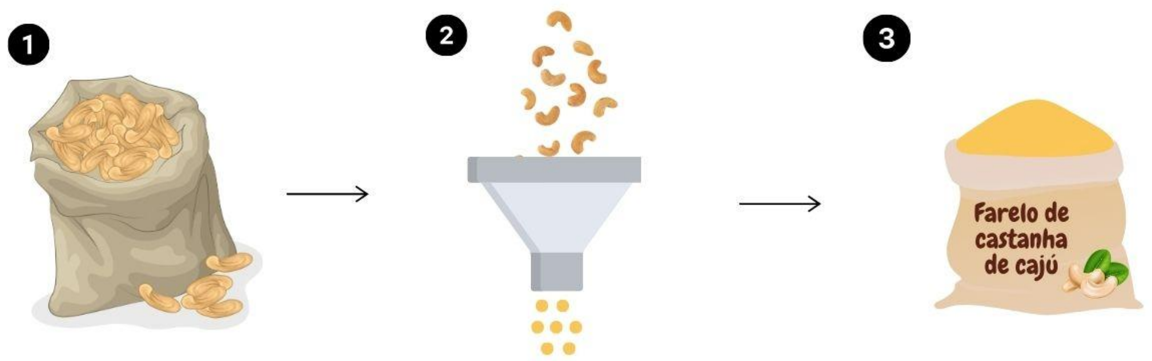
VARIÁVEIS	VALORES
MATÉRIA SECA, %	91,32
PROTEÍNA BRUTA, %	12,99
FIBRA BRUTA (%)	2,34
EXTRATO ETÉREO, %	5,0
MATÉRIA MINERAL,%	5,1
EXTRATO NÃO NITROGENADO, %	74,57

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS E FRANGOS DE CORTE

Farelo de castanha de caju

O farelo de castanha de caju é o subproduto oriundo do beneficiamento da castanha de caju. É constituído por: pedaços de amêndoas com pintas pretas, causadas por pragas e doenças; pedaços com manchas e com películas em conseqüência do processamento; amêndoas inteiras e pedaços mofados pelas condições de armazenamento.

Fluxograma da produção do farelo de castanha de caju



1. **Castanha de cajú descartada**
2. **Trituração da castanha de cajú**
3. **Farelo de castanha de cajú**

Aproximadamente 30% da castanha de caju processada não atinge o padrão mínimo para consumo humano, sendo direcionada para a alimentação animal.

ALIMENTOS ALTERNATIVOS PARA GALINHAS POEDEIRAS

Ração alternativa com farelo de castanha de cajú

Na tabela a seguir ,está apresentado um exemplo de ração que atenda as exigências de **galinha poedeira**, com a inclusão do farelo de castanha de cajú

Ração para galinhas poedeiras	
Ingredientes (Kg)	Quantidade
Milho 7,88%	53,82
Farelo de Soja 45%	24,45
Farelo de castanha de cajú	10,00
Calcário calcítico	8,58
Fosfato Bicálcico	1,78
Sal comum	0,35
PREMIX	0,87
DL-Metionina	0,15
Óleo de soja	0
Total	100,00

O farelo de castanha de caju pode ser incluído na dieta de galinhas poedeiras, o recomendado é que não ultrapasse 10% da ração total.

Composição química do farelo de castanha de cajú

VARIÁVEIS	VALORES
MATÉRIA SECA, %	96,96
PROTEÍNA BRUTA, %	27,50
EXTRATO ETÉREO, %	36,09
MATÉRIA MINERAL,%	3,18
FIBRA DETERGENTE NEUTRO, %	27,25
FIBRA DETERGENTE ÁCIDO, %	20,34
ENERGIA BRUTA, KCAL/KG	6.278,85

ALIMENTOS ALTERNATIVOS PARA FRANGOS DE CORTE

Ração alternativa com farelo de castanha de cajú

Na tabela a seguir, está apresentado um exemplo de ração que atenda as exigências de **frango de corte**, com a inclusão do farelo de castanha de cajú

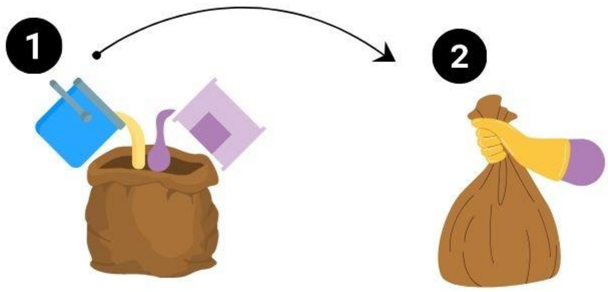
Ração para frangos de corte		
Ingredientes (Kg)	Inicial (1 à 21 dias)	Fase final (21 a 42dias)
Milho 7,88%	43,71	50,00
Farelo de Soja 45%	27,46	21,48
Farelo de castanha de cajú	25,00	25,00
Calcário calcítico	1,12	1,28
Fosfato Bicálcico	1,68	1,33
Sal comum	0,37	0,30
PREMIX	0,45	0,47
DL-Metionina	0,21	0,14
Total	100,00	100,00

A inclusão do farelo de castanha de cajú na ração para frangos de corte, a partir de 10%, melhora o ganho de peso e a conversão alimentar.

FABRICAÇÃO DA RAÇÃO

Para a produção de uma ração alternativa é necessário os seguintes ingredientes :

- Milho ou sorgo
- Soja
- Ingrediente alternativo
- Óleo de soja
- Calcário calcítico
- Fosfato bicálcico
- Sal comum
- PREMIX
- DL-metionina 99%



1 **Primeiramente é necessário realizar a pré- mistura, usando um saco plástico forte. Use farelo de soja moído como base e acrescente o suplemento vitamínico e mineral.**

2 **Mexa o saco várias vezes até que a mistura fique uniforme.**

Obs.: Não adicione sal comum refinado ná pré-mistura, pois ele pode oxidar as vitaminas lipossolúveis.

FABRICAÇÃO DA RAÇÃO

Mistura das matérias-primas sem adição de óleo vegetal

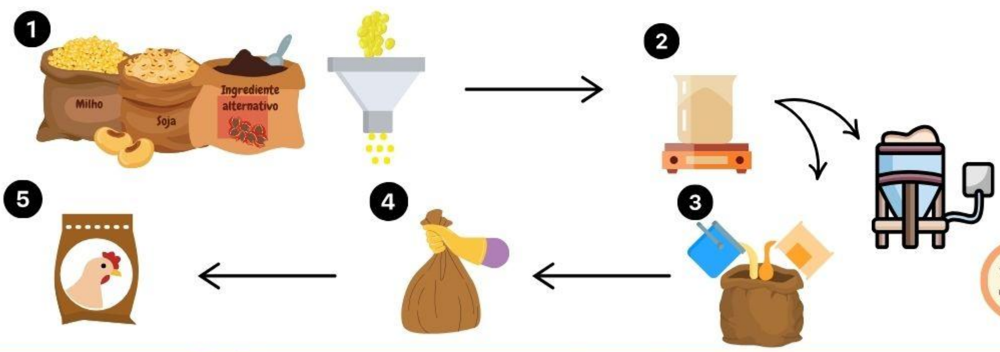
1. Triturar todos os ingredientes
2. Pesar os ingredientes
3. Com o auxíio de um saco resistente que aguente até 10 kg, ou com o auxílio de um misturador de ração, coloque metade da quantidade de milho da mistura;
    - Adicione metade do farelo de soja;
    - Coloque toda a pré-mistura;
    - Adicione todos os ingredientes de origem vegetal;
    - Coloque todo o sal comum refinado;
    - Adicione os ingredientes mais densos, como calcário, fosfato bicálcico;
    - Coloque o restante do milho;
    - Adicione o restante do farelo de soja (lembre-se de descontar a quantidade usada na pré-mistura);
4. Mexa o saco várias vezes até que a mistura fique uniforme;
5. Ração com ingrediente alternativo pronta.

FABRICAÇÃO DA RAÇÃO

Mistura das matérias-primas com adição de óleo vegetal

1. Triturar todos os ingredientes
2. Pesar os ingredientes
3. Com o auxíio de um saco resistente que aguente até 10 kg, ou com o auxílio de um misturador de ração, coloque metade da quantidade de milho da mistura;
   - Adicione metade do farelo de soja;
   - Adicione o óleo vegetal devagar sobre o farelo de soja, pois ele será absorvido pelo farelo.
   - Coloque toda a pré-mistura;
   - Adicione todos os ingredientes de origem vegetal;
   - Coloque todo o sal comum refinado;
   - Adicione os ingredientes mais densos, como calcário, fosfato bicálcico;
   - Coloque o restante do milho;
   - Adicione o restante do farelo de soja (lembre-se de descontar a quantidade usada na pré-mistura);
4. Mexa o saco várias vezes até que a mistura fique uniforme;
5. Ração com ingrediente alternativo pronta.

O uso de um misturador de ração otimiza a produção, podendo produzir quantidades mais elevadas. Para pequenas quantidades, pode-se usar um saco resistente.



REFERÊNCIAS

- CHAVES, F. A. de L,; GUIMARÃES, L.L.; GUIMARÃES, C.C.; SOUZA, L.S.S.; RUFINO, J.P. F; PEREIRA, A. M. Farelo de Tucumã como alimento alternativo em dietas para frangos de corte de crescimento lento. **Revista em Agronegócio e Meio Ambiente**, v. 17, n. 3, e11969, 2024

- CRUZ, F.G. G.; PEREIRA FILHO, M.; CHAVES, F. A. de L. Efeito da substituição do milho pela farinha da apara de mandioca em rações para poedeiras comerciais. **Revista Brasileira de Zootecnia**, v.35, n.6, p.2303-2308, 2006.

- CRUZ, C.e.b.; FREITAS, Ednardo, R.; XAVIER, R.p.s.; FERNANDES, D.r.; NASCIMENTO, G.a.r.; WATANABE, P.h. Farelo da castanha de caju na alimentação de poedeiras marrons. **Ciênc. Agrotec**., Lavras, v.39, n.1, p.68-74, jan./fev., 2015.

- FEIJÓ, J.C.; CRUZ, F.G.G.; MELO, R.D.; RUFINO, J. P.F.; DAMASCENO, J. L. ; COSTA, A. P.G.C.; NEGREIROS, T. de J. N. Farinha de cará (*Dioscorea trifida L.*) sobre o desempenho, qualidade do ovo e bioquímica sérica de poedeiras comerciais leves. **Rev. Bras. Saúde Prod.** Anim., Salvador, v.17, n.3, p.413-423 jul./set., 2016.

- FREITAS, E.R.; FUENTES, M.f.f.; SANTOS JÚNIOR, A.dos; GUERREIRO, M.E.F.; ESPÍNDOLA, G.B. Farelo de castanha de caju em rações para frangos de corte. **Pesq. Agropec. Bras.**, Brasília, v.41, n.6, p.1001-1006, jun. 2006.

- RUFINO, J.P.F.; CRUZ, F.G.G.; TANAKA, E.S.; MELO, R.D.; FEIJÓ, J.C. Análise econômica da inclusão de farinha do resíduo de buriti na alimentação de poedeiras comerciais. **Revista Ciencia Agronomica**, v. 48, n. 4, p. 732-738, 2017.

- RUFINO, J. P. F., CRUZ, F. G. G., OLIVEIRA FILHO, P. A. de, CHAVES, F. A. de L., MENDONÇA, M. A. de F., & SILVA JUNIOR, J. L. da . (2023). Farelo de açaí (*Euterpe precatoria*) como alimento alternativo em dietas para poedeiras comerciais leves. **Revista Em Agronegócio E Meio Ambiente,** 16(4), 1–18.

- SANTOS, A.N.A.; et al. Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. **Animal Production Science** 64, AN24137. 2024.

- SILVA, A. F.; CRUZ, F. G. G.; RUFINO, J. P. F.; COSTA, V. da R.; GUIMARÃES, C. C.; & MELO, R. D. Substituição do milho pelo farelo de Tucumã em rações para poedeiras comerciais leves. **Revista em Agronegócio e Meio Ambiente**, 16(2), 1–12, 2023.

CONCLUSION OF THE THESIS

This thesis demonstrated, in an integrated manner and with methodological rigor, the significant potential of including guarana (*Paullinia cupana*) byproducts, specifically guarana peel and pulp, in diets for slow-growing broilers, offering a technically, economically, and environmentally viable solution for poultry farming in the Amazon region. Based on a solid theoretical foundation on the management and production of these birds (Chapter 1) and a comprehensive mapping of alternative feeds already investigated in Brazil (Chapter 2), the work focused on a regional resource abundant at a particular time of the year, guarana.

The detailed characterization of Amazonian production over 13 years (Chapter 3) not only contextualized the availability of the raw material but also highlighted the opportunity to add value to by-products generated on a significant scale. The chemical and bioactive analysis (Chapter 4) was crucial, demonstrating that both guarana peel and pulp are rich sources of phenolic compounds and possess high antioxidant activity, which are valuable attributes for animal nutrition. They did not exhibit significant cytotoxicity under the conditions tested, indicating their safety. The field experiments (Chapters 5 and 6) constituted the core of the practical validation. The results consistently demonstrated that the inclusion of adequate levels of guarana peel and pulp in the diets did not compromise the zootechnical performance (weight gain, feed intake, feed conversion) of slow-growing broilers. More significantly, a positive modulation of blood biochemical parameters was observed, suggesting possible beneficial effects on the metabolism and antioxidant status of the birds. Carcass evaluation revealed satisfactory yields, and meat quality analysis remained within desirable standards, confirming the maintenance of the final product's standard.

Economic viability, a critical factor for adopting new practices, was robustly demonstrated in Chapter 7. The analysis revealed that partially replacing conventional ingredients with these regional byproducts can significantly reduce feed production costs, making the strategy financially attractive for producers, particularly given the proximity of the raw material source. Furthermore, Chapter 8, dedicated to the sensory analysis of chicken breast, provided a crucial element for consumer acceptance. The results confirmed that the meat from birds fed guarana by-products did not present significant negative sensory differences compared to the meat from the control group, eliminating a potential market barrier.

Finally, Chapter 9, presented as a technical primer on alternative feeds for broilers in the Amazon, fulfills the purpose of transferring the knowledge generated, consolidating the information from this thesis and other relevant sources into a practical and accessible tool for producers and technicians. In it, guarana peel and pulp are highlighted as scientifically validated options. Therefore, the incorporation of guarana peel and pulp into the diet of slow-growing broiler emerges as a robust applied technology, validated in its multiple dimensions (technical, economic, sensory and product quality), offering a concrete path to increase the competitiveness and sustainability of poultry production in the Amazon region, with potential for replication in other systems that value precision nutrition and the use of by-products.

ANNEX

ANNEX 1: Abstracts of papers presented at scientific events

Event: International Congress of Zoology.

Simple Abstract

SERUM HEMATOLOGICAL AND BIOCHEMICAL PARAMETERS OF SLOW-GROWING BROILER CHICKENS FED DIETS CONTAINING GUARANA PEEL MEAL

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Keywords: Alternative food, Poultry farming, Physiology, Paullinia cupana

Guaraná (*Paullinia cupana)* is an Amazonian fruit that is produced extensively and practically exclusively in Brazil. As it is a genuinely Brazilian plant, it has great economic and social importance, especially in the Amazon region, due to the high demand for seeds by the beverage industry to meet the soft drink and energy drink markets. The vegetable by-products from the processing of this product have been seen as potential sources of valuable compounds; however, it is extremely important that before including them in animal feed, they undergo some evaluations, such as physiological parameters. The study aimed to evaluate the effect of including different levels of guarana peel meal on the physiology of slow-growing broiler chickens. The field experiment was conducted at the facilities of the Poultry Sector of the Faculty of Agricultural Sciences of the Federal University of Amazonas. The birds fed with different levels of guarana bark meal (0; 2.5; 5; 7.5 and 10%) were subjected to a 12-hour solid fast, two birds per plot were selected (n=40 birds) and blood samples were collected in the morning. 1 mL of blood was collected from the birds directly from the ulnar vein, mediated by disposable syringes containing heparin anticoagulant (5000 IU). The samples were identified and preserved at -4 °C throughout the collection process and sent to the laboratory for analysis of hematological and blood biochemical parameters. In the results of the hematological parameters, the highest level of inclusion of guarana peel meal in the diet (10%) led to a reduction in the concentration of erythrocytes (2.21 M/mm3) and in the hematocrit percentage (28.12%) of the slow-growing chickens evaluated. In contrast, there was an increase in the

results of mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC), and the inclusion of 7.5% of guarana bark meal obtained the highest result for MCH (44.18 pg/cell) when compared to the other treatments (0; 2.5; 5 and 10%), with values of 36.25; 33.69; 44.18 and 35.41 pg/cell, respectively, as well as for the mean corpuscular volume (MCV), obtaining an increase for the highest level of inclusion of guarana peel meal in the diet (127.83 um^3). In the results of the serum biochemical parameters, only the blood triglyceride concentration of the animals that participated in this study was significantly influenced by the inclusion of guarana peel meal in the diets, where as the inclusion levels increased (0; 2.5; 5; 7.5 and 10%), there was a linear reduction in the concentration of triglycerides in the blood (134.63; 100.97; 57.25; 54.13 and 40.25 mg/dL), respectively. From the results obtained, it was possible to conclude that the highest levels of inclusion of guarana peel meal in the diet presented positive results. These results are of utmost importance for the production sector, since they show that the inclusion of guarana peel meal can be used in the diet of slow-growing broiler chickens without interfering with the physiological parameter and consequently being able to bring improvements in the zootechnical performance of these animals.

Bibliographic References:

Ferreira, F. A. M.; Ferreira, B. B.; Bragança, V. A. N.; Lima, C. L. S.; Brasil, D. S. B. (2022). Guarana (Paullinia cupana Kunth), marapuama (Ptychopetalum olacoides Benth.), gentian (Gentiana lutea L.), quassia (Quassia amara L.) and their properties: a brief review. Research, Society and Development, 11(2).

Oliveira, H.F., Santos, J.S., Cunha, F.S.A. (2014). Utilização de alimentos alternativos na alimentação de codornas. Revista Eletrônica Nutritime – Artigo 272 Volume 11 - Número 05– p. 3683– 3690 Set./Out.

Fontenelle, J. P.; Carvalho, M. R. (2017). Systematic revision of the *Potamotrygon scobina* Garman, 1913 species-complex (Chondrichthyes: Myliobatiformes: Potamotrygonidae), with the description of three new freshwater stingray species from Brazil and comments on their distribution and biogeography. Zootaxa, v. 4310, n. 1, p. 1-63.

Loboda, T. S.; Lasso, C. A.; Rosa, R. S.; Carvalho, M. R. (2021). Two new species of freshwater stingrays of the genus Paratrygon (Chondrichthyes: Potamotrygonidae) from the Orinoco basin, with comments on the taxonomy of *Paratrygon aiereba*. Neotrop Ichthyol. 19(2):e200083. https://doi.org/10.1590/1982-0224-2020-0083.

ANNEX 2: Abstracts of papers presented at scientific events

Event: I Brazilian Congress on Animal Science and Fisheries Resources

Abstract: Poster format

CARCASS YIELD OF SLOW-GROWING BROILER CHICKENS WITH THE INCLUSION OF INCREASING LEVELS OF GUARANA PEEL MEAL (*Paullinia cupana*) IN THE DIET

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Poultry farming in Brazil is severely affected by the low availability of raw materials. This occurs in most regions due to the recurring seasonality of each region and the prices of products that, due to logistics, reach a high value. New research in the area of animal nutrition is of utmost importance to find alternative products that replace conventional products. One plant residue that can be studied is guarana peel, obtained from the processing of the guarana fruit. The objective of the study was to analyze the effects of including of guarana peel meal (GPM) in diets for slow-growing broilers on carcass yield and commercial cuts.

Two hundred and forty slow-growing male broilers, Label Rouge, were distributed in a completely randomized experimental design, with different levels of GPM inclusion (0; 2.5; 5.0; 7.5 and 10%) in the diets, with four replicates of 12 birds each. At 56 days of age, three birds per experimental unit were selected (n=60), individually weighed and slaughtered by electronarcosis followed by bleeding. To calculate the hot carcass yield, the weight of the eviscerated carcass (without head, feet, neck and abdominal fat) was used in relation to the weight of the live bird, and for the cold carcass yield, the weight of the cold carcass in relation to the weight of the live bird was used. For the cut yield (neck, wing, thigh, drumstick, breast and back), the weight of the cold eviscerated carcass was considered.

Higher dietary inclusion levels of FCG (Table 1) resulted in heavier broilers at slaughter and higher carcass yield (>79%). As the dietary inclusion level of FCG increased, there was a linear increase in liver, gizzard and heart weights. Higher inclusion levels of GPM resulted in higher breast, thigh and drumstick yields, however, these chickens exhibited proportionally lower back, wing and neck yields.

The results of this study demonstrate that the inclusion of FCG in chicken feed has the potential to improve carcass yield, especially in cuts with higher commercial value.

Acknowledgements: FAPEAM, CAPES and NEIVA

Table 1. Meat quality of slow-growing broilers fed diets containing *Paullinia cupana* peel meal[1].

Variables[2]	*Paullinia cupana* peel meal levels, %				
	0.00	2.50	5.00	7.50	10.00
SW	1.91±0.29[b]	1.98±0.14[b]	1.99±0.07[b]	2.05±0.09[ab]	2.23±0.12[a]
CY	76.10±4.02[b]	73.93±1.27[b]	77.99±2.57[b]	80.31±1.22[a]	79.19±1.21[a]
FO	4.34±0.44	4.56±0.33	4.98±0.27	4.82±0.42	4.34±0.28
LI	18.33±0.94[b]	18.00±1.63[b]	19.33±3.37[b]	22.00±1.80[a]	25.00±2.58[a]
GI	42.50±2.79[b]	44.83±4.26[b]	47.50±1.37[ab]	44.83±5.57[b]	51.66±3.37[a]
HE	6.22±1.92[c]	7.50±0.63[b]	7.16±1.43[b]	8.00±1.91[b]	9.50±1.37[a]
BR	23.83±5.79[b]	25.86±4.68[b]	28.01±2.27[ab]	30.40±3.35[a]	31.20±4.38[a]
DR	15.31±3.68[b]	16.46±1.92[b]	17.13±0.64[b]	19.05±1.55[b]	21.07±2.19[a]
TH	15.66±4.82[b]	16.13±1.53[b]	18.03±1.34[a]	19.07±1.41[a]	20.77±2.87[a]
BA	22.23±5.09[a]	22.21±4.85[a]	18.10±3.96[b]	14.02±2.21[c]	12.50±3.53[c]
WI	14.44±2.67[a]	10.82±2.01[b]	9.79±0.87[b]	9.31±2.34[b]	6.99±1.30[c]
NE	8.53±1.70[a]	8.52±0.83[a]	8.94±0.37[a]	8.15±0.46[a]	7.47±0.87[b]

[1] All data represent the average of 12 replicates (broilers) per treatment.
[2] SW = Slaughter weight (kg/bird). CY = Carcass yield (%). FO = Foot (g/bird). LI = Liver (g/bird). GI = Gizzard (g/bird).
HE = Heart (g/bird). BR = Breast (%). DR = Drumsticks (%). TH = Thighs (%). BA = Back (%). WI = Wings (%). NE = Neck (%).

ECONOMIC ANALYSIS OF GUARANÁ PEEL MEAL (*Paullinia cupana*) IN DIETS FOR SLOW-GROWING BROILERS

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In several regions of Brazil, especially in the Amazon, the logistics of inputs significantly increases the cost of food used in the formulation of rations. This scenario encourages research testing alternative rations. A fruit that is intensively produced and generates a large amount of waste during the harvest season, with potential for use in animal feed, is guarana, which may present good biological and productive potential, as well as economic viability for inclusion in poultry diets. In addition, it contributes to a sense of circular economy within these production chains. Based on this information, the objective of the research was to evaluate the economic viability of diets for slow-growing broilers with increasing levels of guarana peel meal (GPM).

A total of 240 slow-growing broilers were distributed in a completely randomized experimental design with different levels of FCG inclusion (0; 2.5; 5.0; 7.5 and 10%), 4 replicates of 12 birds each. To determine the price of the feed and the production costs, the values per kg of the raw materials used and the updated price of these in the region during the period of the experiments were used. To calculate the cost of FCG, the expenses with transportation and processing of the product were taken into account. To calculate the price of the feed for each treatment, the average price of the feeds used in the management phases of the broilers was taken into account.

According to the results evaluated regarding the economic analysis of the performance of slow-growing broilers fed diets containing FCG, no significant difference (p>0.05) was observed between the treatments for the break-even point variable. However, all other variables were significantly affected by the inclusion of FCG. In the variables of productive efficiency, total chicken meat production in kilograms and meat production per square meter, all chickens fed diets containing FCG showed better results, with a gradual improvement in efficiency as the level of inclusion of this alternative product increased.

The inclusion of FCG in diets for slow-growing broiler chickens has proven to be a viable alternative to improve economic viability, promoting the sustainable use of agro-industrial waste.

Acknowledgements: FAPEAM, CAPES and NEIVA

Table 1. Economic analysis of the performance of slow-growing broilers fed diets containing increase levels of guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %				
	0.00	2.50	5.00	7.50	10.00
PRE-INI, R$/kg	3.09	3.11	3.14	3.18	3.21
PRE-FIN, R$/kg	2.97	2.90	2.91	2.94	2.97
PEI	169.91^{b}	204.82^{a}	204.74^{a}	207.05^{a}	208.47^{a}
FC, R$	132.95^{b}	135.05^{b}	141.61^{a}	144.86^{a}	135.71^{b}
PRODKG, kg	22.92^{c}	23.76^{b}	23.88^{b}	24.60^{b}	26.76^{a}
PCKG, R$/kg	5.80^{a}	5.68^{b}	5.93^{a}	5.89^{a}	5.07^{c}
PRODSM, kg/m²	5.73^{c}	5.94^{b}	5.97^{b}	6.15^{a}	6.69^{a}
PCPSM, R$/m²	33.24^{b}	33.76^{b}	35.40^{a}	36.21^{a}	33.93^{b}
REV, R$	160.44^{c}	166.32^{c}	167.16^{c}	172.20^{b}	187.32^{a}
PRO, R$	27.49^{b}	31.27^{b}	25.55^{b}	27.34^{b}	51.61^{a}
PI,	17.13^{b}	18.80^{b}	15.28^{b}	15.88^{b}	27.55^{a}
BE, kg	18.99	19.29	20.23	20.69	19.39

[1] All data represent the average of 48 replicates (broilers) per treatment.

[2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point.

ANNEX 3: Abstracts of papers presented at scientific events

Event: III Latin American Agrocongress of Animal Science

Simple Abstract

CENTESIMAL COMPOSITION OF BREAST MEAT FROM SLOW-GROWING BROILER CHICKENS FED WITH GUARANÁ PEEL MEAL

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Keywords: Alternative food; Poultry farming; *Paullinia cupana*; Meat quality.

Although alternative feeds offer potential benefits, it is essential to ensure that they do not negatively impact animal performance and, especially, product quality. Analyzing the chemical composition of meat from animals fed alternative feeds is crucial for developing cost-effective diets with regional ingredients. Therefore, the objective of this study was to evaluate the effect of including guarana peel in diets for slow-growing broilers on the centesimal composition of breast meat. A total of 240 slow-growing male broilers of the Label Rouge line were used, raised in a completely randomized design, with treatments consisting of a control diet (without the inclusion of the test product) and four levels of inclusion of guarana peel meal (2.5%, 5.0%, 7.5% and 10%) in the diets, each with four replicates of 12 birds. At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter by cutting the jugular vein. The carcasses were then scalded in hot water (60 °C for 62 seconds), plucked, and eviscerated. For analysis of the centesimal composition, breast meat samples were collected and promptly transported to the laboratory, which determined the percentages of moisture, minerals, fats, and proteins. In the centesimal composition of the breast, it was observed that the moisture and lipid contents increased linearly ($p<0.05$) as the levels of guarana peel meal increased in the diets of slow-growing broilers. On the other hand, there was a linear reduction ($p<0.05$) in the mineral and protein contents of the breasts of these chickens. Guarana peel meal contains a considerable amount of fiber, which can affect the metabolism of other nutrients and increase water retention in muscle tissue. Dietary factors also influence meat composition, as the inclusion of higher levels of brewery waste in lamb diets led to increased muscle moisture. The soluble fiber present in greater quantities in guarana peel meal can increase intestinal viscosity and potentially reduce nutrient absorption, which may have influenced the reduction of mineral and protein levels in chicken breast. The incorporation of guarana peel meal into poultry diets is in line with circular economy strategies, reducing waste and costs with conventional inputs.

Bibliographic References:

BRANDÃO, J.S. et al. Alternative foods for feeding quails (*Coturnix coturnix*) for meat production. Revista Observatorio de la Economia Latino Americana Curitiba, v.21, n.12, p. 25857-25877, 2023. https://doi.org/10.55905/oelv21n12-130
CARVALHO, S; BROCHIER, M.A. Tissue and centesimal composition and cholesterol of the

meat of lambs feedlot with diets with different levels of brewery's residue. Ciência Rural 38:2023-2028, 2008. https://doi.org/10.1590/S0103-84782008000700035

Cho, S; Shi ,H; Sureshkumar, S; Kim, I. The Effects of the Dietary Inclusion of By-Products Obtained after the Extraction of Vitamin B2 from Fermented Soybean on the Performance and Meat Quality of Growing–Finishing Pigs. Applied Sciences, 14, 803, 2024. https://doi.org/10.3390/app14020803

MENDES, A.A, PATRÍCIO, I.S. Controles, registros e avaliação do desempenho de frangos de corte. In: Mendes AA, Nääs IA, Macari M. Produção de frangos de corte. Campinas, Brazil: FACTA; 2004.

RUFINO, J.P.F; CRUZ, F.G.G; BRASIL, R.J.M; OLIVEIRA FILHO, P.A; MELO, R.D; FEIJÓ, J.C. Relationship between the level and the action period of fiber in diets to laying hens. Acta Scientiarum Animal Sciences 43, e49033, 2021. https://doi.org/10.4025/actascianimsci.v43i1.49033

SANCHES, D.S. et al. Alternative diets for poultry and swine: a brief review. Multidisciplinary Electronic Journal of Scientific Research | Vol. 2 | No. S1.10.56166/remici.2023.2.v2n1.2.3.

SANTOS, A.N.A. et al. Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science 64, AN24137, 2024. https://doi.org/10.1071/AN24137

CENTESIMAL COMPOSITION OF GUARANÁ PEEL AS A POTENTIAL BY-PRODUCT IN POULTRY NUTRITION

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Keywords: Alternative food; Poultry farming; Bromatology; Animal nutrition; *Paullinia cupana*.

Brazil, with its extensive agro-industrial production, generates large volumes of waste that are often discarded due to the lack of information on their reuse. These wastes include by-products from the processing of cereals, fruits, vegetables and products of animal origin, generated in stages such as harvesting, such as guarana peel. The growth in fruit production in 2023 further increased the generation of these wastes in the country. These by-products are particularly relevant due to their low cost, wide availability and richness in bioactive compounds, being an excellent nutritional source for poultry farming. The reuse of these materials not only contributes to reducing costs in animal feed, but also promotes environmental sustainability by minimizing inappropriate disposal. However, it is necessary to verify the centesimal composition of the product. The objective of this study was to analyze the centesimal composition of guarana peel as a potential alternative food for animal feed. Guarana residues were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The guarana peels underwent a drying process in a closed circulation oven at a temperature of 105°C (221°F) for 24 hours and ground in a grain grinder through sieves with hole diameters similar to those used for corn (4 mm); the final product, called guarana peel meal (GPM), was bagged and stored in a dry and ventilated place to be used in the preparation of experimental diets. The centesimal composition of the GPM was determined at the Fish

Technology Laboratory of the Federal University of Amazonas (UFAM). The dry matter content was determined in an oven at 105°C (221°F) according to the AOAC method 925.10 (2019); the mineral content was determined by muffle calcination at 550 °C (1022 °F) following the AOAC method 923.03 (2019); lipid content analyses followed the AOCS Ba 3-38 method; total proteins were determined by the Kjeldahl method following the AOAC method 920.87 (2019); and fiber content (crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF)) was determined according to the methods described by Van Soest et al. (1991). The nutritional composition of GPM reveals characteristics that explain its effects in the diet of broilers. The high content of crude fiber (44.04%) and neutral detergent fiber (61.34%) justifies the progressive increase in fiber in diets with inclusion of GPM, which suggests that moderate fibers can stimulate gastric function and intestinal health. The metabolizable energy (4227.20 kcal/kg), lower than the gross energy (6752.61 kcal/kg), indicates limited digestibility, typical of fibrous by-products. However, the protein (18.72%) and lipid (5.36%) content contributed to maintaining the nutritional profile of the diets, while soluble carbohydrates (26.55%) and minerals (5.33%) provided essential energy substrates and microminerals. Despite its high fiber and moderate digestibility, it demonstrated viability as an alternative ingredient in the diet; its use optimizes underutilized resources, aligning with sustainability in poultry farming.

Bibliographic References:

AOAC-Association of Official Agricultural Chemists (2019) "Official Methods of Analysis of AOAC International (21th ed.)". (AOAC: Rockville, USA).

CORREDDU, F; LUNESU, M.F; BUFFA, G; ATZORI, A.S; NUDDA, A; BATTACONE, G; PULINA, G. Can Agro-Industrial By-Products Rich in Polyphenols be Advantageously Used in the Feeding and Nutrition of Dairy Small Ruminants? Animals (Basel). v. 10, n. 1. 2020. https://doi.org/10.3390/ani10010131.

GAUR, V.K; SHARMA, P; SIROHI, R; AWASTHI, M.K; DUSSAP, C.G; PANDEY, A. Assessing the impact of industrial waste on environment and mitigation strategies: A comprehensive review. Journal of Hazardous Materials. v. 398, p.123019. 2020. https://doi.org/10.1016/j.jhazmat.2020.123019.

SHARMA, P; GAUR, V.K; KIM, S.H; PANDEY, A. Microbial strategies for bio-transforming food waste into resources. Bioresource Technology. v. 299, p. 122580. 2020. https://doi.org/10.1016/j.biortech.2019.122580.

OLIVEIRA, C.A DE; ANDRADE, P.L; REZENDE, T.K.L. Ibero-American Journal of Humanities, Sciences and Education. São Paulo, v.8.n.11. Nov. 2022. https://doi.org/10.51891/rease.v8i11.7927

PERFORMANCE OF SLOW-GROWING BROILER CHICKENS FED WITH GUARANÁ PULP MEAL

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Keywords: Alternative food; Poultry farming; Animal nutrition; Guarana residue.

Animal feed costs represent a significant portion of total expenditures, ranging from 60% to

70%. In more remote regions, such as the Amazon, this impact tends to be even greater due to logistical challenges, as diet production depends on feed from other regions, further increasing final costs. Therefore, seeking alternatives that reduce dependence on conventional inputs and, at the same time, mitigate environmental impacts is crucial for economic viability and sustainability. The present study was conducted with the objective of investigating the effects of guarana pulp meal (GPUM) on the performance of slow-growing broilers. After extracting the guarana fruit extract, the residue from the extraction process was collected, this residue underwent a drying process in a closed circulation oven at 105°C, for 24 hours and ground in a grain grinder, generating the product called guarana pulp meal. Slow-growing broiler chickens of the Label Rouge line (n = 240) were used. The chicks were placed in a protective circle and, at 8 days of age, the animals were housed in their respective plots. The experiment was divided into an initial phase (8-28 days) and a final phase (29-56 days). A completely randomized experimental design was used with treatments consisting of a control diet and four levels of GPUM inclusion (2.5%, 5.0%, 7.5% and 10%) in the diets, with four replicates of 12 birds each. Performance was evaluated both for each stage individually (initial and final) and cumulatively throughout the experimental period. Feed intake was calculated by dividing the total feed consumed by the number of birds in each plot; weight gain was determined by comparing the total weight of the birds in each plot with the weight previously recorded, divided by the number of birds. Feed efficiency was calculated as the ratio between total feed intake and the corresponding weight gain. During the initial phase, feed intake increased with the highest value observed at the inclusion level of 7.5% FTG (1.63 kg/bird), weight gain with maximum weight (0.82 kg/bird) recorded with 7.5% inclusion of , feed GPUM efficiency was higher in the control group (2.61 kg/kg). In the final phase, for consumption, the highest values observed were at the inclusion levels of 7.5% (3.16 kg/bird) and 10% (3.04 kg/bird) of GPUM. When considering the overall growth performance (8-56 days), feed intake increased with the highest value observed at the inclusion level of 7.5% (4.80 kg/bird), weight gain reached the level of 7.5% (2.01 kg/bird). Feed efficiency showed the best values observed at the GPUM level of 2.50%, while intermediate inclusion levels (5% to 7.5%) showed slightly better efficiency values. The inclusion of 7.5% GPUM in the diet of slow-growing broilers showed positive impacts on growth performance, improving feed efficiency and slaughter weight.

Bibliographic References:

CRUZ, F.G.G; RUFINO, J.P.F; MELO, R.D; FEIJÓ, J.C; DAMASCENO, J.L; COSTA, A.P.G.C. Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. Revista em Agronegócio e Meio Ambiente 9, 371–391. 2016. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

CRUZ, F.G.G; RUFINO, J.P.F. Formulation and manufacture of feed (poultry, pigs and fish). (EDUA: Manaus, Brazil). 2017.

DE SOUZA, T; RUFINO, J.P.F; DIAS, P.G; SOUZA, L.F; ARAÚJO, K.F; MACHADO, N.J.B. Use of regional alternative feeds in poultry diets in the Amazon rainforest. Observatorio de la Economía Latinoamericana 22(12), 01-24. 2024. https://doi.org/10.55905/oelv22n12-287

DOS REIS, A.P.L; FERREIRA, R.S.M; FONSECA, M.F; FARIAS, A.R. Analysis of production costs of pig and poultry farms and aquaculture in the state of Paraná. Revista Contemporânea 4(3), 1-11. 2024. https://doi.org/10.56083/RCV4N3-094

PACHECO, J.C; NETO, J.M.M; DA SILVA, E.A. Environmental impacts and ration formulation for broiler. Latin American Journal of Life Cycle Assessment 2(2 esp.), 97–109. 2018. https://doi.org/10.18225/lalca.v1iEspec.4327

SANCHES, D.S; GARCIA, E.R.M; KIEFER, C. Alternative diets for poultry and swine: A brief review. Revista Eletrônica Multidisciplinar de Investigação Científica 2(1), 1–11. 2023. https://doi.org/10.56166/remici.2023.2.v2n1.2.3

VAN HAL, O; DE BOER, I.J.M; MULLER, A; DE VRIES, S; ERB, K.H; SCHADER, C; GERRITS, W.J.J; VAN ZANTEN, H.H.E. Upcycling food leftovers and grass resources through livestock: impact of livestock system and productivity. Journal of Cleaner Production 219, 485–496. 2019. https://doi.org/10.1016/j.jclepro.2019.01.329

INFLUENCE OF INCLUSION OF GUARANA PULP MEAL ON CARCASS YIELD OF SLOW-GROWING BROILER CHICKENS

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Keywords: Alternative food; Poultry farming; Commercial cuts; Animal nutrition; Guarana residue.

Animal feed costs represent a significant portion of total expenditures, ranging from 60% to 70%. In more remote regions, such as the Amazon, this impact tends to be even greater due to logistical challenges, as diet production depends on feed from other regions, further increasing final costs. Therefore, seeking alternatives that reduce dependence on conventional inputs and, at the same time, mitigate environmental impacts is crucial for economic viability and sustainability. The present study was conducted with the objective of investigating the effects of guarana pulp meal (GPUM) on the performance of slow-growing broilers. After extracting the guarana fruit extract, the residue from the extraction process was collected, this residue underwent a drying process in a closed circulation oven at 105°C, for 24 hours and ground in a grain grinder, generating the product called guarana pulp meal. Slow-growing broiler chickens of the Label Rouge line (n = 240) were used. The chicks were placed in a protective circle and, at 8 days of age, the animals were housed in their respective plots. The experiment was divided into an initial phase (8-28 days) and a final phase (29-56 days). A completely randomized experimental design was used with treatments consisting of a control diet and four levels of GPUM inclusion (2.5%, 5.0%, 7.5% and 10%) in the diets, with four replicates of 12 birds each. Performance was evaluated both for each stage individually (initial and final) and cumulatively throughout the experimental period. Feed intake was calculated by dividing the total feed consumed by the number of birds in each plot; weight gain was determined by comparing the total weight of the birds in each plot with the weight previously recorded, divided by the number of birds. Feed efficiency was calculated as the ratio between total feed intake and the corresponding weight gain. During the initial phase, feed intake increased with the highest value observed at the inclusion level of 7.5% GPUM (1.63 kg/bird), weight gain with maximum weight (0.82 kg/bird) recorded with 7.5% inclusion of GPUM, feed efficiency was higher in the control group (2.61 kg/kg). In the final phase, for consumption, the highest values observed were at the inclusion levels of 7.5% (3.16 kg/bird) and 10% (3.04 kg/bird) of GPUM. When considering the overall growth performance (8-56 days), feed intake increased with the highest value observed at the inclusion level of 7.5% (4.80 kg/bird), weight gain reached the level of 7.5% (2.01 kg/bird). Feed efficiency showed the best values observed at the GPUM level of 2.50%, while intermediate inclusion levels (5% to 7.5%) showed slightly better efficiency values. The inclusion of 7.5% GPUM in the diet of slow-growing broilers showed positive impacts on growth performance, improving feed efficiency and slaughter weight.

Bibliographic References:
CRUZ, F.G.G; RUFINO, J.P.F; MELO, R.D; FEIJÓ, J.C; DAMASCENO, J.L; COSTA, A.P.G.C. Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. Revista em Agronegócio e Meio Ambiente 9, 371–391. 2016. https://doi.org/10.17765/2176-9168.2016v9n2p371-391
CRUZ, F.G.G; RUFINO, J.P.F. Formulation and manufacture of feed (poultry, pigs and fish). (EDUA: Manaus, Brazil). 2017.
DE SOUZA, T; RUFINO, J.P.F; DIAS, P.G; SOUZA, L.F; ARAÚJO, K.F; MACHADO, N.J.B. Use of regional alternative feeds in poultry diets in the Amazon rainforest. Observatorio de la Economía Latinoamericana 22(12), 01-24. 2024. https://doi.org/10.55905/oelv22n12-287
DOS REIS, A.P.L; FERREIRA, R.S.M; FONSECA, M.F; FARIAS, A.R. Analysis of production costs of pig and poultry farms and aquaculture in the state of Paraná. Revista Contemporânea 4(3), 1-11. 2024. https://doi.org/10.56083/RCV4N3-094
PACHECO, J.C; NETO, J.M.M; DA SILVA, E.A. Environmental impacts and ration formulation for broiler. Latin American Journal of Life Cycle Assessment 2(2 esp.), 97–109. 2018. https://doi.org/10.18225/lalca.v1iEspec.4327
SANCHES, D.S; GARCIA, E.R.M; KIEFER, C. Alternative diets for poultry and swine: A brief review. Revista Eletrônica Multidisciplinar de Investigação Científica 2(1), 1–11. 2023. https://doi.org/10.56166/remici.2023.2.v2n1.2.3
VAN HAL, O; DE BOER, I.J.M; MULLER, A; DE VRIES, S; ERB, K.H; SCHADER, C; GERRITS, W.J.J; VAN ZANTEN, H.H.E. Upcycling food leftovers and grass resources through livestock: impact of livestock system and productivity. Journal of Cleaner Production 219, 485–496. 2019. https://doi.org/10.1016/j.jclepro.2019.01.329

SENSORY ANALYSIS OF BREAST MEAT FROM SLOW-GROWING BROILER CHICKENS FED WITH GUARANÁ PEEL MEAL

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Keywords: Sensory attributes; Poultry farming; Organoleptic; *Paullinia cupana*.

Feed represents the main economic obstacle in poultry farming, accounting for approximately 60-70% of total costs. Faced with this challenge, the use of alternative feeds emerges as a viable solution, and residues from guarana (*Paullinia cupana*), a fruit endemic to the Amazon, stand out in this context. Although alternative feeds offer potential benefits, it is essential to ensure that they do not negatively impact product quality, and sensory analysis plays a crucial role in the quality control of these products. These analyses help to assess consumer acceptance and standardize processes at an industrial level. The objective of this study was to evaluate the effect of including guarana peel in diets of slow-growing broilers on the sensory properties of the meat. A performance trial was conducted to investigate how the incorporation of guarana peel meal (GPM) influences sensory parameters. 240 slow-growing male broilers of the Label Rouge line were used. Initially, 1-day-old chicks were housed in a protective circle with wood shavings as bedding, feeders and drinkers, until they reached 7 days of age. The experimental stages were divided into an initial stage (8 to 28 days) and a final stage (29 to 56 days). The experiment was conducted in a completely randomized design, consisting of a control diet and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5% and 10%) in the diets, each with four replicates of 12 birds. At 56 days of age, after a 12-h fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock and slaughter by cutting the jugular vein. Breast cuts were collected from slaughtered birds, identified according to each treatment and frozen. The breast cuts were thawed on the day of sensory analysis, wrapped in aluminum foil and baked in the oven until they reached an internal temperature of 87°C. Fifty untrained evaluators of both genders were randomly recruited. The 9-point hedonic scale test was used to evaluate the following attributes: color, flavor, aroma, texture and appearance, using scales from "I liked it extremely" (9) to "I did not like it extremely" (1). The meat was cut into uniform cubes and served in disposable cups previously identified with random 3-digit numbers. Each evaluator received 5 disposable cups with breast samples from each treatment. In addition to the samples, a glass of mineral water was offered to cleanse the palate between samples. For the results of the sensory characteristics of the meat, the parameters were in the range of 4.96 to 6.18 points, that is, according to the hedonic scale that goes from 1 (I extremely disliked it) to 9 (I extremely liked it), the averages of the tasters most indicated were 5 (indifferent) and 6 (I slightly liked it). The GPM improved important sensory attributes, such as flavor and appearance in higher inclusions (10%). In summary, the by-product demonstrated potential as a sustainable ingredient in poultry farming, its adoption can strengthen the competitiveness of Amazonian poultry farming.

Bibliographic References:

ARIAS-GIRALDO, S; LÓPEZ-MEJÍA, M. Usos, propiedades nutricionales y evaluación sensorial del amaranto, quinua y subproductos de uva y café. Ingeniería y competitividad. 24(1)e30211000. 2022. https://doi.org/10.25100/iyc.v24i1.11000.

BRANDÃO, J.S; SOUZA, B.B; BRANDÃO, P.A; FERREIRA, D.H; NASCIMENTO, C.E.O; BENÍCIO, T.M.A; CARVALHO, A.B; SILVA, M.R. Alternative foods for feeding quails (Coturnix coturnix) for meat production. Revista Observatorio de la Economia Latino Americana Curitiba, v.21, n.12, p. 25857-25877. 2023. https://doi.org/10.55905/oelv21n12-130

CRUZ, F.G.G; RUFINO, J.P.F; MELO, R.D; FEIJÓ, J.C; DAMASCENO, J.L; COSTA, A.P.G.C. Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. Revista em Agronegócio e Meio Ambiente 9, 371-391. 2016. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

OLIVEIRA, C.A DE; ANDRADE, P.L; REZENDE, T.K.L. Ibero-American Journal of Humanities, Sciences and Education. São Paulo, v.8.n.11. Nov. 2022. https://doi.org/10.51891/rease.v8i11.7927

PÉREZ-PALENCIA, J.Y; BOLÍVAR-SIERRA, A.F. Alimentos alternativos en combinación con suplementación enzimática para mejorar la eficiencia y sostenibilidad de la producción porcina y avícola. Orinoquía, vol. 27, nº. 1, 2. 2023. https://doi.org/ 10.22579/20112629.787

SANCHES, D.S; MORAES, G; ELIS, R. DE; KIEFER, C. Alternative diets for poultry and swine: a brief review. Multidisciplinary Electronic Journal of Scientific Research | Vol. 2 | No. S1. 2023. https://doi.org/10.56166/remici.2023.2.v2n1.2.3

SCHIMPL, F.C; DA SILVA, J.F; GONÇALVES, J.F; MAZZAFERA, P. Guarana: revisiting a highly caffeinated plant from the Amazon. Journal of Ethnopharmacology. 150, 14-31. 2013. https://doi.org/10.1016/j.jep.2013.08.023

VALENTIM JK, D'ÁVILA LHJ, MARQUES BT, MATOS SNE, DE CASTRO BMF, GARÓFALLO GR, DE CARVALHO PJ, BARBOSA DK. Dried Distiller's Grains in Broiler Feeding. Essays and Science: Biological, Agricultural and Health Sciences, [S. l.], v. 25, n. 1, p. 44–49. 2021. https://doi.org/10.17921/1415-6938.2021v25n1p44-49

ANNEX 4: Abstracts of papers presented at scientific events

Event: Brazilian Interdisciplinary Congress on Science and Technology.

Expanded Abstract

ECONOMIC ANALYSIS OF GUARANA PULP MEAL IN DIETS FOR SLOW-GROWING BROILERS

Abstract: The study evaluated the inclusion of guaraná pulp meal (GPUM), in diets for slow-growing broilers to assess their impact on growth performance and economic feasibility. 240 slow-growing male broilers of the Label Rouge strain were used. The experiment (testing GPUM) was conducted using a completely randomized de-sign, with treatments consisting of a control diet (without the inclusion of the product being tested) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. GPUM, with higher energy content, showed optimal performance at intermediate levels (7.5%), enhanced meat production and economic returns compared to the basal diet. The results suggest that GPUM is better suited for phases requiring higher energy intake and weight gain. Additionally, the use of these agro-industrial residues promotes sustainability by integrating circular economy practices into poultry production. The findings highlight the potential of guaraná by-products as alternative feed ingredients to improve productivity and reduce costs, particularly in regions with abundant availability of these residues.

Keywords: alternative food, Amazon, feed efficiency, *Paullinia cupana*, sustainability.

INTRODUCTION

In various regions of Brazil, especially in the Amazon, logistics for inputs signifi-cantly increase the cost of feddstuffs used in the formulation and production of balanced diets (Cruz et al., 2016). This scenario encourages research testing alternative feeds, especially these from agro-industrial residues under the premise of reducing feed costs, which can account for 60% to 80% of total production costs in activities such as poultry farming (Rufino et al., 2015; Cruz et al., 2016; Costa et al., 2018b; Polese et al., 2022).

The Amazon region presents numerous native species with economic, technological, and nutritional potential, which have sparked scientific interest in various fields such as food, pharmaceuticals, cosmetics, flavorings, and essences, as well as their potential applications in animal feeding (Oliveira et al., 2010). In this context, one fruit that is produced intensively and generates a large amount of residue during the harvest season, with potential for use in animal feed, is guarana (*Paullinia cupana*) (Ferreira et al., 2022).

Among the poultry farming segments that require these alternative feeds, slow-growing broiler production has stood out, particularly for small and medium pro-ducers (Machado et al., 2018; Sarica et al., 2020; Cruz et al., 2023). These broilers exhibit greater tolerance to temperature variations and resistance to certain microorgan-isms (Sarica et al., 2020), along with a more gradual and proportional growth rate compared to fast-growing strains (Machado et al., 2018; Cruz et al., 2023).

However, considering its rich nutritional properties, the volume of production that generates residues, and its importance to Brazilian agri-business, guarana by-products may exhibit good biological and productive potential as well as economic viability for inclusion in poultry diets (Costa et al., 2018 b; Santos et al., 2024). Moreover, they contribute to a sense of circular economy within these production chains (Oliveira, 2018; Ali et al., 2021). Based on this information, the present study aimed to evaluate the growth performance and economic feasibility of slow-growing broiler fe diets containing increase levels of guarana by-products.

MATERIALS AND METHODS

To obtain guarana pulp meal (GPUM), the following steps were performed: 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The seeds were processed for gua-rana extract extraction, used in the production of carbonated beverages by the beverage industry; 5) The residues remaining from the seed extraction are separated and dried in a closed-circulation oven at 105°C for 24 hours; 6) these dried residues were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); 7) the final product, referred to as GPUM, is bagged and stored in a dry and ventilated location for use in the preparation of experimental diets.

During 56 days, performance data (feed intake and weight gain) were collected from the birds for use in the economic feasibility analysis following the methodological procedures described by Costa et al. (2018 b) and Rufino et al. (2018). At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter by cutting the jugular vein. The carcasses were then scalded in hot water (60 °C for 62 seconds), defeathered, and eviscerated following the recommendations of Mendes and Patricio (2004).

For determining feed costs and production expenses, only the per-kilogram prices of the feedstuffs used and their updated prices in the region during the experiment were considered. The prices were as follows: corn, R$ 1.66; soybean meal, R$ 3.65; lime-stone, R$ 0.73; dicalcium phosphate, R$ 4.50; common salt, R$ 0.83; DL-Methionine 99%, R$ 51.00; and mineral and vitamin supplements (F1 - starter; F2 - grower; and F3 - finisher), R$ 28.35/kg (average price). The cost of GPEM and GPUM was calculated considering only transportation and handling expenses (labor), with estimated prices of R$ 0.30 and R$ 0.35 per kilogram, respectively. Fixed costs included depreciation of facilities and equipment (maintenance, water, electricity, etc.), where interest on capital remained unchanged in the short term and was considered constant across all treatments. Variable costs included only bird feed expenses and labor.

The variables were calculated based on the production of each plot. The Productive Efficiency Index (PEI) was determined using the formula:

$$(DWG*VIAB*100)/FCR$$

Where:

DWG = daily weight gain of the plot (kg)

VIAB = viability of the plot (%)

FCR = feed conversion ratio of the plot (kg/kg)

The feed cost (FC, R$), the only production cost used as an analysis variable, was determined through the acquisition of ingredients and feed preparation, estimated by the formula:

$$FC=AFI*AP$$

Where:

AFI = accumulated feed intake of the plot (kg)

AP = average price per kilogram of feed, considering both stages (R$/kg)

For total meat production (kg) and meat production per square meter (kg/m²), the carcass yield of slaughtered, scalded, defeathered, and cleaned animals was considered, as described by Costa et al. (2018b) and Rufino et al. (2018). To calculate the production cost per kilogram of meat (PCKG, R$/kg), the following formula was used:

$$PCKG=CA/PRODKG$$

Where:

FC = feed cost of the plot (R$)

PRODKG = meat production of the plot (kg)

To determine the production cost per square meter of meat (PCPSM, R$/m²), the following formula was used:

$$PCPSM=CA/PRODSM$$

Where:

FC = feed cost of the plot (R$)

PRODSM = meat production per square meter of the plot (kg/m²)

The gross revenue (REV, R$) was calculated based on the relationship between meat production and the selling price per kilogram of the product, using:

$$REV=Q*SP$$

Where:

Q = quantity of meat produced by the plot (kg)

SP = selling price per kilogram of meat produced (R$/kg)

It is important to note that the selling price per kilogram of chicken, applying a gross margin value-added calculation, was determined based on the market price in the region, fixed at R$ 8.00 per kg. Gross profit (PRO, R$) was calculated as the monetary difference between the total revenue from the estimated sale of the chickens (kilograms of chicken meat) and the discounted production cost, which derived from the feed cost, using the formula:

$$PRO=REV-FC$$

Where:

REV = gross revenue of the plot (R$)

FC = feed cost of the plot (R$)

The profitability index (PI, %), which indicates the capital available after covering costs (in this case, feed costs), was derived from the relationship between gross added value and gross revenue, using the formula:

$$PI=(PRO/REV)*100$$

Where:

PRO = gross profit of the plot (R$)

REV = gross revenue of the plot (R$)

For the break-even point (BE, kg), the quantity of production required to achieve zero return, covering all costs, was considered. In this case, it represents a partial break-even point, as it reflects the production volume necessary to cover feed costs. The formula used was:

BE=REV/SP

Where:

REV = gross revenue of the plot (R$)

SP = selling price per kilogram of meat produced (R$/kg)

Statistical analyses

The statistical model adopted was as follows:

$$Y_{ik}=\mu+\alpha_i+\epsilon_{ik}$$

Where:

Yik = Observed value for the variable under study

μ = Overall experiment mean

αi = Effect of GPEM or GPUM levels

ϵik = Experimental error

All data were analyzed using one-way ANOVA with R software (2021). Commands were executed following Logan's (2010) guidelines. Tukey's Honest Significant Difference (HSD) test was used to examine significant differences among the GPEM or GPUM levels (independent variable) for each dependent variable evaluated. Results are presented as means, and the significance level for differences was set at 0.05.

Subsequently, results for significant variables ($p<0.05$) were subjected to correlation and polynomial regression analysis to evaluate the influence of the independent variable on the dependent variables (Chatterjee & Hadi, 2006; Logan, 2010). The mathematical model, either linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax2$), was selected based on the influence of the independent variable on the dependent variable analyzed (Dormann et al., 2013). R-squared values were also considered as a criterion to determine the best model (Chatterjee & Hadi, 2006; Dormann et al., 2013).

RESULTS AND DISCUSSION

The growth performance analysis (Table 1) of slow-growing broilers in the starter stage showed that increasing GPUM levels significantly ($p<0.05$) influenced feed intake and weight gain, with 7.5% GPUM inclusion yielding higher results for these parameters. Regarding feed efficiency, GPUM inclusion had a positive effect, as all slow-growing broilers fed diets containing GPUM demonstrated better feed efficiency than those fed the basal diet, with 5% GPUM inclusion providing the best results for feed efficiency. In the final stage, similarly, slow-growing broilers fed diets with 7.5% GPUM inclusion exhibited higher ($p<0.05$) feed intake. However, in this stage, broilers fed diets with 2.5% GPUM inclusion achieved better feed efficiency.

Cumulatively, all slow-growing broilers fed diets containing GPUM showed higher ($p<0.05$) feed intake and weight gain compared to those fed the basal diet, with 7.5% inclusion providing optimal results. Feed efficiency during this period exhibited significant ($p<0.05$) improvement up to 7.5% inclusion, beyond which no further improvements were observed.

The GPUM achieved peak efficiency at moderate inclusion levels (5%-7.5%). These results reinforce important insights reported in the literature, which suggest that the impact of fiber in poultry diets depends not only on its quantity but also on its composition and interaction with other nutrients (Tejeda & Kim, 2021; Santos et al., 2024). Soluble fibers, present in smaller proportions in GPUM, tend to have a lesser effect on gastrointestinal function (Mateos et al., 2012; Machado et al., 2022).

Table 1. Economic analysis of the performance of slow-growing broilers fed diets containing guarana pulp meal.1

Variables[2]	Guarana pulp meal levels, %				
	0.00	2.50	5.00	7.50	10.00
PRE-INI, R$/kg	3,16	3,18	3,20	3,24	3,25
PRE-FIN, R$/kg	3,04	3,06	3,08	3,10	3,12
PEI	186.55^{b}	214.01^{a}	187.38^{b}	184.17^{b}	164.62^{c}
FC, R$	153.96^{c}	167.25^{b} c	174.60^{b}	182.84^{a}	173.69^{b}
PRODKG, kg	19.70^{c}	23.59^{a}	23.85^{a}	24.22^{a}	21.65^{b}
PCKG, R$/kg	7.82^{ab}	7.08^{c}	7.32^{bc}	7.56^{b}	8.04^{a}
PRODSM, kg/m²	4.92^{c}	5.89^{a}	5.96^{a}	6.05^{a}	5.41^{b}
PCPSM, R$/m²	38.49^{c}	41.81^{bc}	43.65^{b}	45.70^{a}	43.42^{b}
REV, R$	162.78^{c}	188.76^{a}	190.82^{a}	193.78^{a}	173.20^{b}
PRO, R$	8.81^{b}	21.50^{a}	16.21^{ab}	10.94^{b}	-0.48^{c}
PI, %	4.92^{b}	11.38^{a}	8.46^{a}	5.47^{b}	-0.57^{c}
BE, kg	19.24^{c}	20.90^{bc}	21.82^{b}	22.85^{a}	21.71^{b}

1 All data represent the average of 48 replicates (broilers) per treatment.

2 PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point.

3 The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$.

4 CV = Coefficient of variation.

5 COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed.

6 MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

GPUM exhibited superior performance during the early and intermediate stages. This difference could have significant practical implications depending on the production system's objectives. Conversely, GPUM may be better suited for systems aiming to maximize feed intake and weight gain during critical growth periods, particularly in nutritional strategies focused on accelerating initial growth (Prakash et al., 2020; Zampiga et al., 2021).

CONCLUSION

Os dados sugerem que o jogo cumpriu seu objetivo de transformar a aprendizagem em uma experiência mais dinâmica e acessível, corroborando a relevância de abordagens inovadoras no ensino de ciências. Diante disso, este trabalho busca não só enriquecer o debate científico sobre metodologias educacionais, mas também propor caminhos concretos para a reinvenção da prática docente. Ao incentivar a adoção de estratégias que valorizem a diversidade e a participação ativa dos estudantes, pretende-se construir ambientes educativos que transcendam modelos tradicionais, transformando salas de aula em espaços de experimentação e diálogo, onde o conhecimento não seja apenas transmitido, mas cocriado.

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REFERÊNCIAS

Ali, A.; Ponnampalam, E.N.; Pushpakumara, G. et al. Cinnamon: a natural feed additive for poultry health and production - a review. Animals (Basel) 2021;11:2026.

Chatterjee, S.; Hadi, A.S. Regression Analysis by Example. 4th ed. New Jersey, USA: John Wiley & Sons Ltd; 2006.

Costa, A.P.G.C.; Cruz, F.G.G.; Rufino, J.P.F. et al. Viabilidade econômica da farinha do resíduo de tucumã na alimentação de frangos de corte. Agropecuária Técnica (UFPB) 2018b;38(4):225-233.

Cruz, F.G.G.; Rufino, J.P.F.; Melo, R.D. et al. Perfil socioeconômico da avicultura no setor primário do Estado do Amazonas, Brasil. Revista em Agronegócio e Meio Ambiente 2016;9(2):371-391.

Cruz, F.L.; Carvalho, F.P.; Marçal, J.O. et al. Fatty acid profile of slow-growing broilers supplemented with biocomplexed minerals. Ciência Rural 2023;53(5):e20210525.

Dormann, C.F.; Elith, J.; Bacher, S. et al. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 2013;36:27-46.

Ferreira, F.A.M.; Ferreira, B.B.; Bragança, V.A.N. et al. Guaraná (Paullinia cupana Kunth), marapuama (Ptychopetalum olacoides Benth.), gentian (Gentiana lutea L.), quassia (Quassia amara L.) and their properties: a brief review. Research, Society and Development 2022;11(2).

Logan, M. Biostatistical design and analysis using R: a practical guide. New Jersey, USA: John Wiley & Sons Ltd; 2010.

Machado, N.J.B.; Lima, C.A.R.; Brasil, R.J.M.; et al. Digestible threonine for slow-growing broilers: performance, carcass characteristics, intestinal mucin, and duodenal morphometry. Revista Brasileira de Zootecnia 2018;47:e20170193.

Machado, A.L.N.; Alves, J.R.; Lima, H.J.D. et al. Barley residue levels in the diet of Label Rouge broilers. Revista Acadêmica Ciência Animal 2022;20:e20002.

Mateos, G.G.; Jiménez-Moreno, E.; Serrano, M.P. et al. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of Applied Poultry Research 2012;21:156-174.

Mendes, A.A.; Patrício, I.S. Controles, registros e avaliação do desempenho de frangos de corte. In: Mendes, A.A.; Nääs, I.A.; Macari, M. Produção de frangos de corte. Campinas, Brazil: FACTA; 2004.

Oliveira, D.H.R. Alternative food for broiler chickens: an overview. Scientific Electronic Archives 2018;11:112-117.

Oliveira, P.R.; Costa, C.A.; Bem, G.F. et al. Effects of an extract obtained from fruits of Euterpe oleracea Mart. in the components of metabolic syndrome induced in C57BL/6J mice fed a high-fat diet. Journal of Cardiovascular Pharmacology 2010;56(15):619-626.

Polese, M.F.; Polese, M.F.; Radael, M.C. et al. Zootechnical parameters of Corn feed particle size in performance, di-gestibility and rate of passage in juvenile tambaqui Colossoma macropomum. Brazilian Journal of Biology 2022;82,1-13.

Prakash, A.; Saxena, V.K.; Singh, M.K. Genetic analysis of residual feed intake, feed conversion ratio and related growth parameters in broiler chicken: a review. World’s Poultry Science Journal. 2020;76(2):304–317.

Rufino, J.P.F.; Cruz, F.G.G.; Miller, W.P.M. et al. Análise econômica da inclusão de farinha do resíduo de tucumã (Astro-caryum vulgare, Mart) na alimentação de poedeiras comerciais. Revista Brasileira de Saúde e Produção Animal 2015;16(1):1-9.

Rufino, J.P.F.; Cruz, F.G.G.; Feijó, J.C. et al. Análise econômica de patos submetidos a diferentes planos nutricionais fá-sicos e densidades de alojamento. Revista em Agronegócio e Meio Ambiente 2018;11(3):767-781.

Santos, A.N.A.; Rufino, J.P.F.; Viana, A.L. et al. Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science 2024;64:AN24137.

Sarica, M.; Yamak, U.; Boz, M. et al. Performance of fast, medium and slow growing broilers in indoor and free-range production systems. South African Journal of Animal Science 2020;49:1127-1138.

Tejeda, O.J.; Kim, W.K. Effects of fiber type, particle size, and inclusion level on the growth performance, digestive organ growth, intestinal morphology, intestinal viscosity, and gene expression of broilers. Poultry Science. 2021;100(10):101397.

Zampiga, M.; Calini, F.; Sirri, F. Importance of feed efficiency for sustainable intensification of chicken meat production: implications and role for amino acids, feed enzymes and organic trace minerals. World’s Poultry Science Journal. 2021;77(3):639–659.

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ANIMAL PRODUCTION SCIENCE

Paullinia cupana peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers

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ABSTRACT

Context. Animal feed production systems have been suffering from a shortage of feedstuffs because of competition for these resources with human food consumption. The use of by-products can increase efficiency and circularity in production chains, reducing this competition. **Aims.** This study investigated the impacts of *Paullinia cupana* peel meal (PCPM) on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. **Methods.** Two hundred and forty slow-growing male Label Rouge broilers were distributed in a completely randomised experimental design. The treatments consisted of five inclusion levels of PCPM (0%, 2.5%, 5.0%, 7.5%, and 10%) in the diets, with four replicates of 12 birds each. Growth performance data, and haematological and serum biochemical parameters were monitored. Twelve broilers per treatment were slaughtered for meat-quality analysis. **Key results.** In the starter stage, there was a significant increase ($P < 0.05$) in feed intake and weight gain with and increasing inclusion level of PCPM in the diet. However, this effect diminished in the final stage. Even with a reduction ($P < 0.05$) in feed intake during the final stage, the broilers showed an increase ($P < 0.05$) in weight gain and improvement ($P < 0.05$) in feed efficiency in the cumulative performance. Broilers fed diet with a higher inclusion level of PCPM had lower ($P < 0.05$) concentrations of erythrocytes and blood triglycerides, as well as a decreased haematocrit percentage. However, these broilers exhibited higher ($P < 0.05$) results for mean corpuscular haemoglobin and mean corpuscular haemoglobin concentration. Broilers fed diets with a higher inclusion level of PCPM were heavier ($P < 0.05$) at slaughter, with higher ($P < 0.05$) carcass yield, greater ($P < 0.05$) liver, gizzard, and heart weight, increased breast, drumstick, and thigh yields, and higher moisture and lipid contents in the breast. **Conclusions.** The high inclusion levels of PCPM in diets for slow-growing broilers positively affect growth performance, meat quality, and yields of valuable cuts, although they increase moisture and decrease protein in breast meat, affecting some blood parameters. **Implications.** This study showed the potential advantages of using PCPM as an alternative food in diets for slow-growing broilers to improve the productivity and health of a sustainable livestock.

Keywords: alternative food, Amazon, crop residue, feed efficiency, poultry nutrition, poultry science, slow-growing broilers, sustainability.

Introduction

The current structure of the global food system presents a suboptimal availability of feedstuffs for animal feed, as many resources are being used for human consumption (Mottet *et al.* 2017; Sandström *et al.* 2022). In this context, the use of by-products and crop residues from food-production chains as feedstuffs in animal diets has been proposed to meet this demand and improve the efficiency of these production chains (Van Kernebeek *et al.* 2016; Röös *et al.* 2017), consequently reducing competition for food (Van Zanten *et al.* 2018), promoting the concept of a circular economy in these chains (van Hal *et al.* 2019; Billen *et al.* 2021), and causing an economical beneficial owing to their potential widespread availability and low cost (Yang *et al.* 2021).

Rufino *et al.* (2015), Cruz *et al.* (2016), Monteiro *et al.* (2024), Clement *et al.* (2024), and Rosenfeld *et al.* (2024) identified the Brazilian Amazon and its production chains as a notable case where this scenario frequently occurs, with a wide variety of native species being exploited for their economic, technological, and nutritional potential, generating residues that can be used in animal feed. Among these, *Paullinia cupana* stands out because of its great nutritional properties, including volatile and fixed constituents, starch, protein, tannins, and caffeine (Sousa *et al.* 2010; Santana and Macedo 2018), in addition to the fact of its processing yielding organic residues with biological potential for re-use.

Paullinia cupana, also popularly known as *guaraná*, *guaraná-da-amazônia*, *guaranaina*, *guaranauva*, *uarana*, or *narana*, is an Amazon native plant of the *Sapindaceae* family. It exhibits vigorous growth, with branches reaching up to 10 m in height, produces capsule-format fruits with septicidal dehiscence and a developed peduncle. The fruit starts with a dark green colour and matures to shades ranging from yellow–orange to bright red. The seeds are covered by thick white films (Schimpl *et al.* 2013; Filoche and Pinton 2014; Pinho *et al.* 2021). Currently, *Paullinia cupana* plays a significant role in the agribusiness of Latin America, where Brazil is the world's largest producer, catering to major markets such as the USA, EU, Japan, and China (Pinho *et al.* 2021; Ferreira *et al.* 2022).

From this, it was hypothesised that *Paullinia cupana* peel meal (PCPM) could be used as an alternative food in diets for slow-growing broilers because of the rich nutritional properties of *Paullinia cupana* and its potential to produce a considerable volume of residues after the processing (Cruz and Rufino 2017; Oliveira 2018; Ali *et al.* 2021). This approach, paired with sustainable animal production practices such as using breeds with slightly reduced growth or productivity but with proportional growth and better environmental adaptability, contributes to the emerging green revolution in animal production (Schader *et al.* 2015; van Hal *et al.* 2019; Vastolo *et al.* 2022). On the basis of this information, the present study was conducted to investigate the impacts of *Paullinia cupana* peel meal (PCPM) on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers.

Materials and methods

Acquisition and composition analysis of PCPM

Paullinia cupana residues were acquired in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The entire process of processing *Paullinia cupana*, obtaining its by-products, and processing these by-products to obtain PCPM, followed the following steps: (1) the ripe *Paullinia cupana* fruits were manually harvested; (2) the collected fruits were stored in baskets for approximately 3 days, undergoing a fermentation process; (3) the fruits were separated into seeds and peels; (4) the peels were set aside as residues; (5) the seeds were processed for the extraction of *Paullinia cupana* extract, which is used in the production of carbonated beverages by the beverage industry; (6) the *Paullinia cupana* peels underwent a drying process in a closed-circulation oven at a temperature of 105°C (221°F) for 24 h; (7) the dried *Paullinia cupana* peels were ground in a grain grinder by using sieves with hole diameters similar to those used for corn (4 mm); and (8) the final product, called PCPM, was bagged and stored in a dry and airy place to be used in the preparation of experimental diets. It is important to highlight that the yield of PCPM relative to the raw product (peels before drying) was 84.32%.

To determine the price of the feeds and production costs, only the per-kilogram values of the feedstuffs used and their updated prices in the region during the experiment were considered. These were as follows: corn, R$1.66; soybean meal, R$3.65; limestone, R$0.73; dicalcium phosphate, R$4.50; salt, R$0.83; DL-Methionine 99%, R$51.00; and R$28.35/kg (average price) for mineral and vitamin supplements (F1 = initial; F2 = final). For the calculation of PCPM costs, only transportation and handling expenses (labour) were considered, estimating the price per kilogram of the product at R$0.30. Fixed costs consisted of depreciation of facilities and equipment (maintenance, water, electricity, among others), with capital interest remaining unchanged in the short term and considered constant across all treatments. Variable costs included only expenses for bird feed and labour.

Before conducting the experiment, the proximate composition of PCPM (Table 1) was determined at the Fish Technology Laboratory of the Federal University of

Table 1. *Paullinia cupana* peel meal composition.

Variable	Concentration
Dry matter (%)	89.11
Crude protein (%)	18.72
Fats (%)	5.36
Minerals (%)	5.33
Crude fibre (%)	44.04
Neutral detergent fibre (%)	61.34
Acid detergent fibre (%)	33.33
Soluble carbohydrates (%)	26.55
Gross energy (kcal/kg)	6752.61
Metabolisable energy[A] (kcal/kg)	4227.20

[A]Determined by the apparent metabolisable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno *et al.* (2024).

Amazonas (UFAM). The dry-matter content was determined in an oven at 105°C (221°F) according to the Method 925.10 of AOAC (AOAC 2019); minerals content was determined by calcination in a muffle furnace at 550°C (1022°F) following AOAC Method 923.03 (AOAC 2019); lipid content analyses followed AOCS Method Ba 3-38; total proteins were determined using the Kjeldahl method, following AOAC Method 920.87 (AOAC 2019); and the determination of fibre contents (crude fibre, neutral detergent fibre (NDF) and acid detergent fibre (ADF)) was performed according to the methods described by Van Soest *et al*. (1991).

Facilities, animals, diets and experimental design

The current experiment was conducted in an aviary with a ceiling height of 3.25 m, with structural adaptations to improve bird welfare. Ventilation occurred naturally, with the aviary being fully surrounded by trees to ensure a pleasant and comfortable environment for the birds. The temperature and relative humidity were monitored using a small digital weather station, registering averages of 27.6°C (81.68°F) and 62.3% respectively. Throughout the entire experimental period, the broilers were monitored for signs of thermal stress caused by the environment, a situation that was not observed during the experiment. It is important to mention that the experiment was conducted during the rainy season in the Amazon, which occurs between November and April of the following year, where temperatures are cooler and provide a pleasant environment for animal management.

Slow-growing male Label Rouge broilers (n = 240) produced by the incubation centre of the Research Poultry Farm of UFAM were used. Initially, the 1-day-old broilers (43.57 ± 0.59 g) were housed in a protective circle with wood shavings, tray-type feeders, and cup-type drinkers at a density of 50 birds/m^2, with a central electric-heating source, until they reached 7 days old. With 8 days of age, the broilers were distributed into the experimental groups in pens measuring 4 m^2 each, equipped with tubular feeders, hanging drinkers, and wood shavings covering the floor. The experimental stages were divided into starter (8–28 days) and final (29–56 days) periods. The birds had *ad libitum* access to feed and water during all the experimental periods. A lighting program suitable for slow-growing broilers was used (Wu *et al*. 2022).

The experimental design was completely randomised, with treatments comprising a control diet (without PCPM) and four levels of PCPM inclusion (2.5%, 5.0%, 7.5%, and 10%) in the diets, with four replicates of 12 birds each. Experimental diets (Table 2) were formulated on the basis of reference values reported by Rostagno *et al*. (2024), except for PCPM composition, which used values from prior product-composition analyses performed in this study. The metabolisable energy value for PCPM was determined using method described by Sakomura and Rostagno (2016) and Rostagno *et al*. (2024), where a small digestibility trial was conducted prior to the main experiment, with the collected feed and faecal samples being analysed in the laboratory.

PCPM was a fixed component in the diet calculations, with other ingredient values adjusted on the basis of PCPM inclusion levels. Diets were formulated using SuperCrac software (TD Software©, Viçosa, Brazil; Software SuperCrac 6.1 Premium, see https://www.agropecuaria.inf.br/produtos/supercrac). The composition of these diets was analysed to confirm their proximate composition according to the methods described by the AOAC (2019), where moisture content was determined according to Method 925.10, minerals content was determined following Method 923.03, lipid content analyses followed Method Ba 3-38, total protein content was determined according to Method 920.87, and the determination of fibre contents (crude fibre, NDF and ADF) was performed according to the methods described by Van Soest *et al*. (1991).

Growth performance and meat quality

The growth performance of broilers was assessed both individually in each stage (initial and final) and in a cumulative way. The growth performance variables evaluated in this study included feed intake (kg/bird), weight gain (kg/bird), and feed efficiency (kg/kg). Feed intake for each stage was calculated by dividing the total feed consumed by the number of birds in each pen. Weight gain was determined by dividing the total pen weight by the number of birds, relative to the previous weighing. Feed efficiency was computed as the ratio of total feed consumed to weight gain. Combining data from all stages allowed for a comprehensive assessment of these parameters.

At 56 days of age, following a 12-h fast, 12 birds from each treatment were randomly chosen for meat-quality analysis. These birds were weighed, electrically stunned (40 V, 50 Hz), and slaughtered by cutting the jugular vein. Carcasses were then scalded in hot water (60°C/140°F for 62 s), plucked, and eviscerated following recommendations by Mendes and Patrício (2004) to determine carcass yield (%) and the yields of the main economically significant viscera (liver (g/bird), gizzard (g/bird) and heart (g/bird)) and foot (g/bird).

Commercial cuts (neck, breast, wing, back, thigh, and drumstick) were separated and weighed using an analytical balance (0.01 g), calculating their yields as a percentage relative to the clean carcass. Samples of breast meat from these carcasses were collected and immediately sent to the laboratory for determination of their proximate composition (percentages of moisture, minerals, fats, and proteins) determined according to the methods described by AOAC (2019).

Haematological and serum biochemical parameters

Before slaughter, the selected broilers, 12 per treatment, underwent blood collection. One millilitre of blood was collected from the broilers directly from the ulnar vein, using disposable syringes containing heparin anticoagulant (5000 IU per sample). These samples were immediately centrifuged at

Table 2. Composition and guaranteed nutrient concentration (analysed and calculated concentrations in dry matter) of experimental diets with different levels of PCPM inclusion (0%, 2.5%, 5%, 7.5% and 10%).

Item	Pre-starter (1–7 days)	Starter (8–28 days)					Final (29–56 days)				
		0%	2.5%	5%	7.5%	10%	0%	2.5%	5%	7.5%	10%
Feedstuff											
Corn 7.88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Paullinia cupana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Sodium chloride	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
Vitamin and mineral supplement	0.50[A]	0.50[A]	0.50[A]	0.50[A]	0.50[A]	0.50[A]	0.50[B]	0.50[B]	0.50[B]	0.50[B]	0.50[B]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Price (R$/kg)	3.18	3.08	3.11	3.14	3.17	3.20	2.97	2.90	2.90	2.93	2.96
Nutrient											
Metabolisable energy (kcal/kg)	3000.00	3100.00	3100.00	3100.00	3100.00	3100.00	3200.00	3200.00	3200.00	3200.00	3200.00
Dry matter (%)	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein (%)	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium (%)	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus (%)	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium (%)	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fibre (%)	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF (%)	12.07	12.07	11.73	11.37	11.01	10.65	11.84	11.52	11.22	10.87	10.51
ADF (%)	4.97	4.97	4.88	4.79	4.70	4.60	4.70	4.54	4.46	4.36	4.27
Total lysine (%)	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine (%)	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine (%)	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine (%)	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan (%)	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[A]Vitamin/mineral supplement per 1 kg of starter diet: folic acid 4, mg; pantothenic acid, 62.500 mg; antioxidant, 0.0025 g; biotin, 0.2 mg; niacin, 168 mg; selenium, 1.5 mg; vitamin A, 33.500 IU; vitamin B1, 8.75 mg; vitamin B12, 48 µg; vitamin B2, 24 mg; vitamin B6, 12.5 mg; vitamin D3, 8000 IU; vitamin E, 70 mg; vitamin K3, 7.2 mg; manganese, 375 mg; zinc, 250 mg; iron, 250 mg; copper, 40 mg; iodine, 3.75 mg.

[B]Vitamin/mineral supplement per 1 kg final diet: pantothenic acid, 35.35 mg; antioxidant, 0.0025 g; niacin, 102 mg; selenium, 1 mg; vitamin A, 9800 IU; vitamin B12, 23.5 µg; vitamin B2, 12 mg; vitamin D3, 2750 IU; vitamin E, 50 mg; vitamin K3, 2.75 mg; manganese, 375 mg; zinc, 250 mg; iron, 250 mg; copper, 40 mg; iodine, 3.75 mg.

8217*g* for 10 min at 20°C (68°F) to separate the red blood cells for evaluation of haematological parameters and the plasma was used for analysis of serum biochemical parameters.

These samples were identified and preserved at −4°C (24.8°F) throughout the process to be sent to the laboratory. In the analysis of haematological parameters, the collected blood was used for the count of circulating erythrocytes (M/mm^3) by using a Neubauer chamber after dilution in formaldehyde–citrate and toluidine blue, and visualised using an optical microscope (Nikon Eclipse E-50i, DM3000, Tokyo, Japan) with a ×40 objective lens.

The haemoglobin concentration (g/dL) was determined by the cyanomethaemoglobin method, and the haematocrit (%) by the microhaematocrit method (Goldenfarb *et al.* 1971), with centrifugation of heparinised microcapillary tubes at 24,149*g* for 5 min (Aride *et al.* 2018). Through these analyses, the mean corpuscular volume (MCV, μm^3), mean corpuscular haemoglobin (MCH, pg/cell), and mean corpuscular haemoglobin concentration (MCHC, g/dL) were calculated according to Wintrobe (1934) and Tavares-Dias and Moraes (2004).

In the analysis of serum biochemical parameters, the remaining plasma samples after centrifugation were subjected to commercial enzymatic–colorimetric assays by using assay kits according to the manufacturer's specific recommendations, and the readings were taken on a mass spectrophotometer (Model K37-UVVIS, Kasvi©, São José dos Pinhais, Brazil) at a specific wavelength for each assay. The biochemical parameters analysed were the concentrations of total proteins, triglycerides, glucose, cholesterol, and albumin.

Statistical analyses

The adopted statistical model was as follows:

$$Y_{ik} = \mu + \alpha_i + \varepsilon_{ik}$$

where Y_{ik} = observed value for the variable under study, μ = overall mean of the experiment, α_i = effect of the PCPM inclusion level, ε_{ik} = experimental error.

All data were analysed using the R software (version 4.1.3; see https://cran.r-project.org/; R Core Team 2021), with commands executed according to Logan (2010). Initially, the data were subjected to one-way ANOVA, with Tukey's honest significant difference test being applied at a 0.05 significance level. Subsequently, the results of significant ($P < 0.05$) variables were also subjected to correlation and polynomial regression analysis to examine the influence of the independent variable (PCPM inclusion level) on the dependent variables (Chatterjee and Hadi 2006i; Dormann *et al.* 2013). The mathematical model, whether linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax^2$), was chosen on the basis of criteria that determined which model best expressed the data behaviour (Dormann *et al.* 2013), with *R*-squared values considered as one of these criteria (Chatterjee and Hadi 2006; Dormann *et al.* 2013).

Ethics approval

The Animal Ethics Committee of Federal University of Amazonas approved the study under Protocol number 010/2022. All animal manipulations were performed according to the Brazilian Code for the Care and Use of Animals for Scientific Purposes and reported in proportion to guidelines and regulations of animal research: reporting of *in vivo* experiments (ARRIVE).

Results

Growth performance

The growth-performance analysis of slow-growing broilers in the starter stage indicated a significant ($P < 0.05$) effect of PCPM inclusion on feed intake and weight gain (Table 3), with the increasing inclusion of PCPM causing a linear increase in these variables, that is, the 10% inclusion level of PCPM providing higher results. However, in the final stage, feed intake and feed efficiency showed opposite behaviour, with the increasing inclusion of PCPM reducing ($P < 0.05$) the broilers' feed intake, and the 10% inclusion level of PCPM providing better feed-efficiency result. In this sense, weight gain in this stage increased ($P < 0.05$) linearly as the inclusion level of PCPM in the diets increased.

When observing the cumulative growth performance, it was found that the inclusion of PCPM did not significantly ($P > 0.05$) affect the cumulative feed intake considering the entire evaluated period. However, the cumulative results of weight gain and feed efficiency showed that these variables were significantly ($P < 0.05$) influenced by the inclusion of PCPM, with weight gain increasing linearly and feed efficiency improving as the inclusion level of PCPM in the diets increased, that is, the 10% inclusion level of PCPM providing better cumulative weight gain and feed efficiency results.

Haematological and serum biochemical parameters

In the results of haematological parameters (Table 4), higher levels of PCPM inclusion in the diet led to a reduction

Table 3. Growth performance of slow-growing broilers fed diets containing *Paullinia cupana* peel meal.

Stage	Variable	*Paullinia cupana* peel meal inclusion level (%)					*P*-value	CV (%)	COR	MM	R^2
		0.00	2.50	5.00	7.50	10.00					
Starter	FI	1.43 ± 0.13b	1.48 ± 0.15b	1.69 ± 0.28a	1.71 ± 0.16a	1.74 ± 0.03a	<0.01	7.52	0.47	$Y = 1.44 + 0.034x$	0.87
	WG	0.87 ± 0.09b	0.94 ± 0.06b	0.98 ± 0.02ab	1.01 ± 0.03a	1.06 ± 0.02a	<0.01	2.33	0.42	$Y = 0.882 + 0.018x$	0.97
	FE	1.64 ± 0.44	1.57 ± 0.47	1.72 ± 0.58	1.69 ± 0.13	1.64 ± 0.06	0.10	8.28	–	–	–
Final	FI	2.95 ± 0.36a	3.01 ± 0.32a	2.98 ± 0.46a	3.01 ± 0.36a	2.63 ± 0.19b	0.05	12.64	−0.08	$Y = 2.9269 + 0.0681x - 0.0094x^2$	0.85
	WG	1.03 ± 0.14b	1.04 ± 0.11b	1.01 ± 0.03b	1.03 ± 0.04b	1.16 ± 0.01a	0.05	10.69	0.20	$Y = 1.004 + 0.01x$	0.43
	FE	2.86 ± 0.38a	2.89 ± 0.45a	2.95 ± 0.67a	2.92 ± 0.55a	2.27 ± 0.06b	0.05	4.59	−0.36	$Y = 2.8049 + 0.1197x - 0.0166x^2$	0.86
General	FI	4.38 ± 0.28	4.49 ± 0.45	4.67 ± 0.74	4.72 ± 0.34	4.37 ± 0.03	0.09	5.35	–	–	–
	WG	1.90 ± 0.24b	1.98 ± 0.18b	1.99 ± 0.06b	2.04 ± 0.07ab	2.22 ± 0.02a	<0.01	4.69	0.29	$Y = 1.886 + 0.028x$	0.85
	FE	2.31 ± 0.10a	2.27 ± 0.45a	2.35 ± 0.61a	2.31 ± 0.22a	1.97 ± 0.02b	<0.01	4.58	−0.34	$Y = 2.262 + 0.058x - 0.0083x^2$	0.81

All data represent the average of 48 replicates (broilers) per treatment.
The means within a row followed by different lowercase letters differ signficantly (Tukey test, at $P = 0.05$).
FI, feed intake (kg/bird); WG, weight gain (kg/bird); FE, feed efficiency (kg/kg); CV, coefficient of variation; COR, correlation coefficient between the independent variable (PCPM inclusion level) and the dependent variable analysed; MM, mathematical model adjusted according to the influence of the independent variable (PCPM inclusion level) on the dependent variable.

Table 4. Haematological and serum biochemical parameters of slow-growing broilers fed diets containing *Paullinia cupana* peel meal.

Analysis	Variable	*Paullinia cupana* peel meal inclusion level (%)					*P*-value	CV (%)	COR	MM	R^2
		0.00	2.50	5.00	7.50	10.00					
Haematological	HEMOG	10.61 ± 1.81	10.87 ± 1.55	9.79 ± 1.51	9.75 ± 1.28	10.48 ± 1.54	0.16	15.33	–	–	–
	ERI	3.00 ± 0.07a	3.00 ± 0.09a	2.90 ± 0.21a	2.97 ± 0.15a	2.21 ± 0.16b	<0.01	12.05	−0.35	$Y = 2.9451 + 0.0899x - 0.0154x^2$	0.83
	HEMAT	29.75 ± 1.57a	30.25 ± 2.23a	30.18 ± 2.53a	29.81 ± 2.21a	28.12 ± 1.75b	0.03	7.37	−0.13	$Y = 29.764 + 0.2654x - 0.0348x^2$	0.98
	MCV	99.19 ± 6.70c	100.99 ± 8.97b	104.24 ± 10.42b	100.57 ± 14.41b	127.83 ± 6.97a	<0.01	13.61	0.29	$Y = 98.772 + 1.9366x - 0.2188x^2$	0.74
	MCH	35.40 ± 6.22b	36.25 ± 5.01b	33.69 ± 4.27b	44.18 ± 5.45a	35.41 ± 5.82b	<0.01	17.41	0.17	$Y = 36.223 - 1.9408x + 0.3856x^2$	0.79
	MCHC	35.66 ± 5.62	36.11 ± 5.47	32.42 ± 3.51	34.98 ± 5.92	35.36 ± 6.36	0.35	15.72	–	–	–
Biochemical	TP	3.15 ± 0.40	3.54 ± 0.56	3.53 ± 0.38	3.26 ± 0.61	4.72 ± 0.88	0.17	8.78	–	–	–
	TRI	134.63 ± 99.77a	100.97 ± 23.11b	57.25 ± 11.40c	54.13 ± 19.50c	40.25 ± 21.20c	<0.01	7.93	−0.44	$Y = 129.53 - 11.409x$	0.91
	GLU	230.88 ± 35.95	219.97 ± 52.80	214.34 ± 35.52	227.92 ± 57.52	224.43 ± 26.94	0.94	8.54	–	–	–
	CHO	189.46 ± 52.16	175.28 ± 50.13	195.12 ± 42.22	192.66 ± 48.65	189.03 ± 64.25	0.38	2.89	–	–	–
	ALB	3.12 ± 0.70	2.64 ± 0.60	3.40 ± 0.80	3.20 ± 0.44	3.36 ± 0.71	0.20	2.23	–	–	–

All data represent the average of 12 replicates (broilers) per treatment.
The means within a row followed by different lowercase letters differ significantly (Tukey test at $P = 0.05$).
HEMOG, haemoglobin (g/dL); ERI, red blood cell erythrocytes (M/mm^3); HEMAT, haematocrit (%); MCV, mean corpuscular volume (μm^3); MCH, mean corpuscular haemoglobin (pg/cell); MCHC, mean corpuscular haemoglobin concentration (g/dL); TP, total proteins (g/dL); TRI, triglycerides (mg/dL); GLU, glucose (mg/dL); CHO, cholesterol (mg/dL); ALB, albumin (mg/dL); CV, coefficient of variation; COR, correlation coefficient between the independent variable (PCPM inclusion level) and the dependent variable analysed; MM, mathematical model adjusted according to the influence of the independent variable (PCPM inclusion level) on the dependent variable.

($P < 0.05$) in the concentration of erythrocytes and the percentage of haematocrit in the evaluated slow-growing broilers. In contrast, there was a significant ($P < 0.05$) increase in the results of MCH and MCHC in these broilers. In the results of serum biochemical parameters (Table 4), only the concentration of triglycerides was significantly ($P < 0.05$) influenced by the inclusion of PCPM in the diets, where the higher inclusion levels of PCPM in the diet caused a linear reduction in blood triglyceride concentration.

Meat yield and quality

The slaughter weight and carcass yield (Table 5) of slow-growing broilers were significantly ($P < 0.05$) influenced by the inclusion of PCPM in the diet, where higher inclusion levels of PCPM in the diet, especially the 7.5% and 10% inclusion levels, resulted in heavier (>2 kg) broilers at slaughter and with a higher carcass yield (>79%). Similarly, as the inclusion level of PCPM in the diet increased, there was a linear increase ($P < 0.05$) in the weights of the liver, gizzard, and heart of the evaluated slow-growing broilers, where the 7.5% and 10% inclusion levels provided better results.

Evaluating the commercial cuts (Table 5), as the levels of PCPM inclusion in the diet increased, slow-growing broilers showed higher ($P < 0.05$) breast, thigh, and drumstick yields; however, these broilers exhibited proportionally lower ($P < 0.05$) yields of back, wings, and neck. In the proximate composition of the breasts (Table 6), it was observed that the moisture and lipid contents increased linearly ($P < 0.05$) as the level of PCPM in the diets of slow-growing broilers increased. Conversely, there was a linear reduction ($P < 0.05$) in the mineral and protein contents of these broilers' breasts.

Discussion

First, we observed that the inclusion of PCPM in the diet of slow-growing broilers caused a positive impact in most of growth-performance variables, especially providing heavier broilers presenting better feed efficiency. It is a great result, considering that PCPM presents a considerable amount of fibre in its composition and, consequently, influences the fibre level of the diets, ranging from 4% to 7%. However, it appears that this increase in the fibre level did not negatively affect the broilers' response to the increasing inclusion level of PCPM.

The presence of fibre in poultry diets has always been a major challenge for both researchers and the industry because the gastrointestinal tract of birds tends to have low enzymatic activity suitable for digesting fibres, especially the broilers, which can result in restrictions in nutrient use (Azizi *et al.* 2021). However, González-Alvarado *et al.* (2010), Mateos *et al.* (2012) and Rufino *et al.* (2021) reported that recent studies have indicated that moderate levels of fibre in poultry diets are very important components for improving results regarding their physiology and nutrient utilisation, enhancing the growth performance and other important productive indices. According to Jiménez-Moreno *et al.* (2009*a*, 2009*b*) and Svihus (2011), the positive effects caused by moderate levels of fibre are directly associated with an improvement in digestibility through continuous stimulation

Table 5. Meat quality of slow-growing broilers fed diets containing *Paullinia cupana* peel meal.

Variable	*Paullinia cupana* peel meal inclusion level (%)					*P*-value	CV (%)	COR	MM	R^2
	0.00	2.50	5.00	7.50	10.00					
SW	1.91 ± 0.29b	1.98 ± 0.14b	1.99 ± 0.07b	2.05 ± 0.09ab	2.23 ± 0.12a	<0.01	4.69	0.34	$Y = 1.89 + 0.0284x$	0.85
CY	76.10 ± 4.02b	73.93 ± 1.27b	77.99 ± 2.57b	80.31 ± 1.22a	79.19 ± 1.21a	0.01	4.02	−0.18	$Y = 74.992 + 0.5024x$	0.61
FO	4.34 ± 0.44	4.56 ± 0.33	4.98 ± 0.27	4.82 ± 0.42	4.34 ± 0.28	0.08	8.97	–	–	–
LI	18.33 ± 0.94b	18.00 ± 1.63b	19.33 ± 3.37b	22.00 ± 1.80a	25.00 ± 2.58a	0.02	1.63	0.31	$Y = 17.064 + 0.6936x$	0.86
GI	42.50 ± 2.79b	44.83 ± 4.26b	47.50 ± 1.37ab	44.83 ± 5.57b	51.66 ± 3.37a	0.03	10.13	0.56	$Y = 42.6 + 0.7328x$	0.68
HE	6.22 ± 1.92c	7.50 ± 0.63b	7.16 ± 1.43b	8.00 ± 1.91b	9.50 ± 1.37a	0.05	2.86	0.51	$Y = 6.264 + 0.2824x$	0.85
BR	23.83 ± 5.79b	25.86 ± 4.68b	28.01 ± 2.27ab	30.40 ± 3.35a	31.20 ± 4.38a	<0.01	9.20	0.08	$Y = 24.004 + 0.7712x$	0.98
DR	15.31 ± 3.68b	16.46 ± 1.92b	17.13 ± 0.64b	19.05 ± 1.55b	21.07 ± 2.19a	<0.01	12.01	0.07	$Y = 14.982 + 0.5644x$	0.96
TH	15.66 ± 4.82b	16.13 ± 1.53b	18.03 ± 1.34a	19.07 ± 1.41a	20.77 ± 2.87a	<0.01	12.80	0.20	$Y = 15.3 + 0.5264x$	0.97
BA	22.23 ± 5.09a	22.21 ± 4.85a	18.10 ± 3.96b	14.02 ± 2.21c	12.50 ± 3.53c	0.03	12.24	0.09	$Y = 23.342 - 1.106x$	0.93
WI	14.44 ± 2.67a	10.82 ± 2.01b	9.79 ± 0.87b	9.31 ± 2.34b	6.99 ± 1.30c	<0.01	6.82	0.19	$Y = 13.552 - 0.6564x$	0.90
NE	8.53 ± 1.70a	8.52 ± 0.83a	8.94 ± 0.37a	8.15 ± 0.46a	7.47 ± 0.87b	<0.01	9.23	−0.01	$Y = 8.4557 + 0.1918x - 0.0291x^2$	0.88

All data represent the average of 12 replicates (broilers) per treatment.
The means within a row followed by different lowercase letters are significantly different (Tukey test at $P = 0.05$).
SW, slaughter weight (kg/bird); CY, carcass yield (%); FO, foot (g/bird); LI, liver (g/bird); GI, gizzard (g/bird); HE, heart (g/bird); BR, breast (%); DR, drumsticks (%); TH, thighs (%); BA, back (%); WI, wings (%); NE, neck (%); CV, coefficient of variation; COR, correlation coefficient between the independent variable (PCPM inclusion level) and the dependent variable analysed; MM, mathematical model adjusted according to the influence of the independent variable (PCPM inclusion level) on the dependent variable.

Table 6. Proximate composition of breast fillets from slow-growing broilers fed diets containing *Paullinia cupana* peel meal.

Variable	*Paullinia cupana* peel meal inclusion leves (%)					*P*-value	CV (%)	COR	MM	R^2
	0.00	2.50	5.00	7.50	10.00					
MO	70.48 ± 0.69c	71.20 ± 0.23b	71.15 ± 0.35b	73.04 ± 0.76a	73.65 ± 0.47a	<0.01	1.83	0.63	$Y = 70.268 + 0.3272x$	0.90
MI	1.21 ± 0.02a	1.14 ± 0.06b	1.12 ± 0.17b	1.04 ± 0.23c	1.02 ± 0.15c	<0.01	6.63	−0.79	$Y = 1.202 - 0.0192x$	0.96
FA	1.69 ± 0.11b	1.39 ± 0.15c	1.53 ± 0.18b	1.58 ± 0.13b	1.81 ± 0.23a	<0.01	10.12	0.38	$Y = 1.6526 - 0.0937x + 0.0111x^2$	0.84
PR	26.62 ± 0.59a	26.27 ± 0.15a	26.20 ± 0.18a	24.34 ± 0.28b	23.52 ± 0.36c	<0.01	5.05	−0.65	$Y = 27.016 - 0.3252x$	0.87

All data represent the average of 12 replicates (broilers) per treatment.
The means within a row followed by different lowercase letters are significantly different (Tukey test at $P < 0.05$).
MO, moisture (%); MI, minerals (%); FA, fats (%); PT, proteins (%); CV, coefficient of variation; COR, correlation coefficient between the independent variable (PCPM inclusion level) and the dependent variable analysed; MM, mathematical model adjusted according to the influence of the independent variable (PCPM inclusion level) on the dependent variable.

of the gizzard, stimulation of the small-intestine activity, and a positive effect on intestinal microbiota owing to their prebiotic action.

For instance, in a study conducted by Pushpakumara *et al.* (2017), the inclusion of palm kernel meal in broiler diets was beneficial, with improvements in feed efficiency and increased weight gain, leading the authors to recommend using up to 15% of this food in the broiler diet. Conversely, Malhado *et al.* (2022) studied different inclusion levels of barley residues in the feed of slow-growing Label Rouge broilers and found no significant ($P > 0.05$) differences in weight gain, final weight, and feed efficiency. However, they observed a significant ($P < 0.05$) difference in feed intake, with a linear increase as the inclusion of barley in the diet increased. Similarly, Costa *et al.* (2017) found that gradually increasing the inclusion of babassu flour in broiler diets resulted in birds with a higher weight and better production efficiency. However, when the inclusion reached 25%, there was a decrease in these indices.

These relations among fibre levels and their action on poultry physiology present an important challenge to the use of alternative foods in poultry diets, because many alternative foods are residues from the food-processing industry, mainly consisting of peels and seeds, which naturally have a high fibre content (Rufino *et al.* 2015; Cruz and Rufino 2017; Rufino *et al.* 2021). Depending on the alternative food being used, its fibre content can be considerably high, affecting the metabolism of other nutrients, especially proteins and soluble carbohydrates, and harming growth performance (Liu *et al.* 2018; Rufino *et al.* 2021; Cho *et al.* 2024).

When considering the positive effects of PCPM in the diet of slow-growing broilers on both growth performance and meat quality, it should also be emphasised that residues from the processing of *Paullinia cupana* may also contain substances that confer stimulating, energetic, antioxidant, antimicrobial, and chemoprophylactic properties (Marques *et al.* 2016; Yonekura *et al.* 2016). As with other alternative foods, these additional properties may improve nutrient utilisation and the physiological response of the birds (Cruz and Rufino 2017).

The results obtained from haematological parameters help reinforce these observations, because the increased levels of PCPM inclusion in the broiler diet led to a reduction in the concentration of erythrocytes and the haematocrit percentage; however, alongside there was an increase in MCH and MCHC. Literature reports, for example, that reference values for haematocrit in birds typically range from 25% to 50%; values below this limit may indicate anemia, whereas values above may suggest dehydration or polycythemia (Muneer *et al.* 2021; Al-Khalaifah *et al.* 2022). For the other variables, we also observed that in all evaluated treatments, the broilers fell within in an acceptable stable range, albeit being close to the limit (Seo *et al.* 2015; Muneer *et al.* 2021).

In the results of serum biochemical parameters, even though only the concentration of triglycerides was significantly influenced by the inclusion of PCPM in the diets of the broilers, this is an important result because the concentration of triglycerides can be an important indicator of metabolic disorders caused by feeding. In broilers, triglycerides are available in the intestinal mucosa and liver from the digestion and absorption of fatty acids, where high concentrations of these can lead to a significant reduction in growth performance (Zhou *et al.* 2020; Hu *et al.* 2021). The results of this study showed a linear reduction in triglyceride concentration with the inclusion of PCPM, which can be considered a positive aspect, because even slow-growing broilers, owing to their natural accelerated growth compared with other poultry categories, may present scenarios with elevated metabolic rates, which can be detrimental to their health and growth performance.

Moreover, it was also possible to observe the positive influence of the great growth-performance results on meat quality, with broilers fed diets with a higher inclusion level of PCPM, namely 7.5% and 10% PCPM inclusion, showing better carcass yield, higher values for liver, gizzard, and heart, as well as more breast, thigh, and drumstick yield, in addition to good content of fats. According to Malhado *et al.* (2022), good growth-performance results from the use of alternative foods generally end up being reflected in meat quality, as observed in this study, with the authors commenting that this applies to both fast-growing and slow-growing broilers. The results of Geron *et al.* (2015), Rossa *et al.* (2015), Shi *et al.* (2019) and Rufino *et al.* (2021) also supported this statement, complementing this scenario with the observation that this is directly related to the nutritional composition of the food being tested, how its inclusion can interfere with the composition of the diets, and, consequently, their utilisation by the broilers.

When comparing the results obtained in this study with those reported in the literature using other alternative feeds in broiler diets, we observed that slow-growing broilers fed diets with lower inclusion levels of PCPM (2.5–5%) showed slightly lower growth-performance and meat-quality results than did other slow-growing broilers (Dixon 2020; Rayner *et al.* 2020; Güz *et al.* 2021; Santos *et al.* 2021) and significantly lower results than did fast-growing broilers (Dixon 2020; Güz *et al.* 2021; Santos *et al.* 2021). In contrast, slow-growing broilers fed diets with higher inclusion levels of PCPM (7.5–10%) showed growth-performance and meat-quality results close to or equal to those reported in the literature for other slow-growing broilers (Dixon 2020; Rayner *et al.* 2020; Güz *et al.* 2021; Santos *et al.* 2021) and somewhat close to fast-growing broilers (Dixon 2020; Güz *et al.* 2021; Santos *et al.* 2021).

On the basis of these results, it is possible to assume that PCPM may have maintained to some extent the nutritional profile (rich in carbohydrates and lipids) and bioactive compounds (caffeine) originally contained in the *Paullinia cupana* fruit, and that these were beneficial for the growth of the broilers. Additionally, the antioxidant and fibrous compounds naturally found in the *Paullinia cupana* husk, as observed with the inclusion of other foods, may help in the intestinal health of the birds during this critical phase, further reducing the proliferation of various intestinal bacteria, pathogenic or not, through the reduction of pH and production of volatile fatty acids (Oleforuh-Okoleh *et al.* 2015).

Here, it is important to mention the peculiarities of the productive and physiological responses of the slow-growing broilers used in this study compared with fast-growing broilers, which are typically used in most studies testing alternative foods in poultry diets. The use of slow-growing broiler breeds has been suggested to decrease welfare issues, especially in tropical climate regions, which are warmer (Montoro-Dasi *et al.* 2020; van der Eijk *et al.* 2023), such as observed in this study. Previous studies have also reported that slow-growing breeds are more active, have lower levels of lameness and fewer hock and foot-pad lesions than do fast-growing breeds, in addition to their having lower mortality rates and fewer lameness issues resulting in fewer culls (Dixon 2020; Rayner *et al.* 2020; Güz *et al.* 2021).

This is especially relevant in terms of behaviour, welfare, and growth performance in a sustainable approach. de Jong *et al.* (2022) defined slower-growing broilers as growing ≤50 g/day, whereas fast-growing broilers grow ≥60 g/day. In general, slower-growing broilers are more active and exhibit improved welfare measures (Dixon 2020; Rayner *et al.* 2020; Güz *et al.* 2021; van der Eijk *et al.* 2022), although differences are not always found (de Jong *et al.* 2022). Regarding growth performance, slow-growing broilers generally have lower daily bodyweight gain, daily feed intake, and mortality rates, and can maintain greater feed efficiency than do fast-growing broilers (Güz *et al.* 2021; Torrey *et al.* 2021; Van der Eijk *et al.* 2022, 2023). Furthermore, slow-growing broilers have lower carcass yield and breast yield, and higher thigh, drumstick, and wing yields relative to carcass weight (Santos *et al.* 2021).

Conclusions

The inclusion of PCPM in the diet of slow-growing broilers positively affected growth performance, enhancing meat quality and yields of valuable cuts such as breast, drumstick, and thigh, where 10% inclusion level presented better results. Despite the increased moisture content and decreased protein contents in breast meat, the overall benefits to meat quality and bird health were significant. The study findings suggested that PCPM can be a viable alternative feed ingredient, promoting sustainable livestock management by utilising residues from the food-processing industry.

References

Al-Khalaifah H, Al-Nasser A, Al-Surrayai T, Sultan H, Al-Attal D, Al-Kandari R, Al-Saleem H, Al-Holi A, Dashti F (2022) Effect of ginger powder on production performance, antioxidant status, hematological parameters, digestibility, and plasma cholesterol content in broiler chickens. *Animals* **12**, 901. doi:10.3390/ani12070901

Ali A, Ponnampalam EN, Pushpakumara G, Cottrell JJ, Suleria HAR, Dunshea FR (2021) Cinnamon: a natural feed additive for poultry health and production – a review. *Animals (Animals (Basel)* **11**, 2026. doi:10.3390/ani11072026

AOAC (2019) 'Official methods of analysis of AOAC international.' 21st edn. (Association of Official Analytical Chemists: Rockville, USA)

Aride PHR, Oliveira AM, Batista RB, Ferreira MS, Pantoja-Lima J, Ladislau DS, Castro PDS, Oliveira AT (2018) Changes on physiological parameters of tambaqui (*Colossoma macropomum*) fed with diets supplemented with Amazonian fruit camu camu (*Myrciaria dubia*). *Brazilian Journal of Biology* **78**, 360–367. doi:10.1590/1519-6984.169442

Azizi MN, Loh TC, Foo HL, Chung ELT (2021) Is palm kernel cake a suitable alternative feed ingredient for poultry?. *Animals* **11**, 338. doi:10.3390/ani11020338

Billen G, Aguilera E, Einarsson R, Garnier J, Gingrich S, Grizzetti B, Lassaletta L, Le Nöe J, Sanz-Cobena A (2021) Reshaping the European agro-food system and closing its nitrogen cycle: the potential of combining dietary change, agroecology, and circularity. *One Earth* **4**, 839–850. doi:10.1016/j.oneear.2021.05.008

Chatterjee S, Hadi AS (2006) 'Regression analysis by example.' 4th edn. (John Wiley & Sons: NJ, USA)

Cho S, Shi H, Sureshkumar S, Kim I (2024) The effects of the dietary inclusion of by-products obtained after the extraction of vitamin B2 from fermented soybean on the performance and meat quality of growing–finishing pigs. *Applied Sciences* **14**, 803. doi:10.3390/app14020803

Clement CR, dos Santos Pereira H, Vieira ICG, Homma AKO (2024) Challenges for a Brazilian Amazonian bioeconomy based on forest foods. *Trees, Forests and People* **16**, 100583. doi:10.1016/j.tfp.2024.100583

Costa APGC, Cruz FGG, Rufino JPF, Feijó JC, Melo RD, Melo LD, Damasceno JL (2017) Tucumã meal in diets for broilers on performance, carcass traits and serum biochemical profile. *Archivos de Zootecnia* **67**, 137–142. doi:10.21071/az.v67i257.3501

Cruz FGG, Rufino JPF (2017) 'Formulation and manufacture of feed (poultry, pigs and fish).' (EDUA: Manaus, Brazil) [in Portuguese]

Cruz FGG, Rufino JPF, Melo RD, Feijó JdC, Damasceno JL, Costa APGC (2016) Socio-economic profile of fowl breeding in the state of Amazonas, Brazil. *Revista em Agronegócio e Meio Ambiente* **9**, 371–391. doi:10.17765/2176-9168.2016v9n2p371-391

de Jong IC, Bos B, van Harn J, Mostert P, te Beest D (2022) Differences and variation in welfare performance of broiler flocks in three production systems. *Poultry Science* **101**, 101933. doi:10.1016/j.psj.2022.101933

Dixon LM (2020) Slow and steady wins the race: The behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed. *PlosONE* **15**, e0231006. doi:10.1371/journal.pone.0231006

Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, Marquéz JRG, Gruber B, Lafourcade B, Leitão PJ, Münkemüller T, Mcclean C, Osborne PE, Reineking B, Schröder B, Skidmore AK, Zurell D, Lautenbach S (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **36**, 27–46. doi:10.1111/j.1600-0587.2012.07348.x

Ferreira IJ, Leão DP, Nascimento OV, Cavalcanti V, Vasconcellos MC (2022) Amazon guarana (*Paullinia Cupana* var. Sorbilis): effect of consumption on physical performance – a narrative review. *European Academic Research* **X**(6), 2110–2122.

Filoche G, Pinton F (2014) Who owns guaraná? Legal strategies, development policies and agricultural practices in Brazilian Amazonia. *Journal of Agrarian Change* **14**, 380–399. doi:10.1111/joac.12035

Geron LJV, Costa FGC, Moraes KJS, Oliveira EM, Gomes R, Pereira SR, Silva AP, Cruz C, Pelicia K (2015) Consumption, performance and carcass yield of broiler chickens fed diets containing dehydrated residual cassava scrap. *Boletim da Indústria Animal* **72**, 304–310. doi:10.17523/bia.v72n4p304

Goldenfarb PB, Bowyer FP, Hall E, Brosious E (1971) Reproducibility in the hematology laboratory: the microhematocrit determination. *American Journal of Clinical Pathology* **56**, 35–39. doi:10.1093/ajcp/56.1.35

González-Alvarado JM, Jimenez-Moreno E, González-Sanchez D, Lazaro R, Mateos GG (2010) Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. *Animal Feed Science and Technology* **162**, 37–46. doi:10.1016/j.anifeedsci.2010.08.010

Güz BC, de Jong IC, Da Silva CS, Veldkamp F, Kemp B, Molenaar R, van den Brand H (2021) Effects of pen enrichment on leg health of fast and slower-growing broiler chickens. *PLoS ONE* **16**, e0254462. doi:10.1371/journal.pone.0254462

Hu X, Li X, Xiao C, Kong L, Zhu Q, Song Z (2021) Effects of dietary energy level on performance, plasma parameters, and central AMPK levels in stressed broilers. *Frontiers in Veterinary Science* **8**, 681858. doi:10.3389/fvets.2021.681858

Jiménez-Moreno E, González-Alvarado JM, de Coca-Sinova A, Lázaro R, Mateos GG (2009*a*) Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. *Animal Feed Science and Technology* **154**, 93–101. doi:10.1016/j.anifeedsci.2009.06.020

Jiménez-Moreno E, González-Alvarado JM, Lázaro R, Mateos GG (2009*b*) Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. *Poultry Science* **88**, 1925–1933. doi:10.3382/ps.2009-00193

Liu WC, Zhou SH, Kim YM, Lee SI, Pang HY, Kim IH (2018) Impacts of rapeseed meal, canola meal and their mixture substitute for soybean meal on performance of lactating sows and their offspring. *Indian Journal of Animal Research* **53**, 124–128. doi:10.18805/ijar.B-837

Logan M (2010) 'Biostatistical design and analysis using R: a practical guide.' (John Wiley & Sons: NJ, USA)

Malhado ALN, Alves JR, Lima HJD, Rosa MS (2022) Barley residue levels in the diet of Label Rouge broilers. *Revista Acadêmica: Ciência Animal* **20**, e20002. doi:10.7213/acad.2022.20002

Marques LLM, Panizzon GP, Aguiar BAA, Simionato AS, Cardozo-Filho L, Andrade G, de Oliveira AG, Guedes TA, Mello JCP (2016) Guaraná (*Paullinia cupana*) seeds: selective supercritical extraction of phenolic compounds. *Food Chemistry* **212**, 703–711. doi:10.1016/j.foodchem.2016.06.028

Mateos GG, Jiménez-Moreno E, Serrano MP, Lázaro RP (2012) Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. *Journal of Applied Poultry Research* **21**, 156–174. doi:10.3382/japr.2011-00477

Mendes AA, Patrício IS (2004) Controls, records and performance evaluation of broilers. In 'Broiler production'. (Eds AA Mendes,

IA Nääs, M Macari) pp. 323–336. (FACTA: Campinas, Brazil) [in Portuguese]
Monteiro A, Barreto-Mendes L, Fanchone A, Morgavi DP, Pedreira BC, Magalhães CAS, Abdalla AL, Eugène M (2024) Crop-livestock-forestry systems as a strategy for mitigating greenhouse gas emissions and enhancing the sustainability of forage-based livestock systems in the Amazon biome. *Science of The Total Environment* **906**, 167396. doi:10.1016/j.scitotenv.2023.167396
Montoro-Dasi L, Villagra A, de Toro M, Pérez-Gracia MT, Vega S, Marin C (2020) Fast and slow-growing management systems: characterisation of broiler caecal microbiota development throughout the growing period. *Animals* **10**, 1401. doi:10.3390/ani10081401
Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P (2017) Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security* **14**, 1–8. doi:10.1016/j.gfs.2017.01.001
Muneer M, Bilal M, Ditta A (2021) A comparative study of some hematological parameters of broiler and indigenous breeds of poultry. *SVU-International Journal of Agricultural Sciences* **3**, 189–198. doi:10.21608/svuijas.2021.99388.1146
Oleforuh-Okoleh VU, Ndofor-Foleng HM, Olorunleke SO, Uguru JO (2015) Evaluation of growth performance, haematological and serum biochemical response of broiler chickens to aqueous extract of ginger and garlic. *The Journal of Agricultural Science* **7**, 167–173. doi:10.5539/jas.v7n4p167
Oliveira DHR (2018) Alternative food for broiler chickens: an overview. *Scientific Electronic Archives* **11**, 112–117.
Pinho LS, da Silva MP, Thomazini M, Cooperstone JL, Campanella OH, da Costa Rodrigues CE, Favaro-Trindade CS (2021) Guaraná (*Paullinia cupana*) by-product as a source of bioactive compounds and as a natural antioxidant for food applications. *Journal of Food Processing and Preservation* **45**, e15854. doi:10.1111/jfpp.15854
Pushpakumara DMS, Priyankarage N, Nayananjalie WAD, Ranathunge DL, Dissanayake DMDP (2017) Effect of inclusion of palm (*Elaeis guineensis*) kernel cake in broiler chicken rations. *International Journal of Livestock Research* **7**, 103–109.
R Core Team (2021) 'R: a language and environment for statistical computing.' (R Foundation for Statistical Computing: Vienna, Austria)
Rayner AC, Newberry RC, Vas J, Mullan S (2020) Slow-growing broilers are healthier and express more behavioural indicators of positive welfare. *Scientific Reports* **10**, 15151. doi:10.1038/s41598-020-72198-x
Röös E, Bajželj B, Smith P, Patel M, Little D, Garnett T (2017) Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change* **47**, 1–12. doi:10.1016/j.gloenvcha.2017.09.001
Rosenfeld T, Pokorny B, Marcovitch J, Poschen P (2024) Local development based on non-timber forest products: evidence from a mapping of initiatives in the Brazilian Amazon since Rio 1992. *Sustainability* **16**, 6005. doi:10.3390/su16146005
Rossa LS, Malaquias MAS, Diez DC, Stahlke EVR, Stertz SC, De Macedo REF (2015) Physical chemical and nutritional profile of organic retail chicken meat. *Boletim do Centro de Pesquisa de Processamento de Alimentos* **33**, 67–78. doi:10.5380/cep.v33i2.47294
Rostagno HS, Albino LFT, Calderano AA, Hannas MI, Sakomura NK, Costa FGP, Rocha GC, Saraiva A, Abreu MLT, Genova JL, Tavernari FC (2024) 'Brazilian tables for poultry and swine: food composition and nutritional requirements.' 5th edn. (Federal University of Viçosa Press: Viçosa, Brazil) [in Portuguese]
Rufino JPF, Cruz FGG, Miller WPM, Melo RD, Feijó JdC, Chagas EOd (2015) Economical analysis of the inclusion of flour residue of tucumã (*Astrocaryum vulgare*, Mart) in the feeding of laying hens. *Revista Brasileira de Saúde e Produção Animal* **16**, 1–9. doi:10.1590/S1519-99402015000100001
Rufino JPF, Cruz FGG, Brasil RJM, Oliveira Filho PAd, Melo RD, Feijo JdC (2021) Relationship between the level and the action period of fiber in diets to laying hens. *Acta Scientiarum. Animal Sciences* **43**, e49033. doi:10.4025/actascianimsci.v43i1.49033
Sakomura NK, Rostagno HS (2016) 'Research methods in monogastric nutrition.' (Funep: Jaboticabal, SP) [in Portuguese]
Sandström V, Chrysafi A, Lamminen M, Troell M, Jalava M, Piipponen J, Siebert S, Van Hal O, Virkki V, Kummu M (2022) Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nature Food* **3**, 729–740. doi:10.1038/s43016-022-00589-6
Santana ÁL, Macedo GA (2018) Health and technological aspects of methylxanthines and polyphenols from guarana: a review. *Journal of Functional Foods* **47**, 457–468. doi:10.1016/j.jff.2018.05.048
Santos MN, Rothschild D, Widowski TM, Barbut S, Kiarie EG, Mandell I, Guerin MT, Edwards AM, Torrey S (2021) In pursuit of a better broiler: carcass traits and muscle myopathies in conventional and slower-growing strains of broiler chickens. *Poultry Science* **100**, 101309. doi:10.1016/j.psj.2021.101309
Schader C, Muller A, Scialabba NE-H, Hecht J, Isensee A, Erb K-H, Smith P, Makkar HPS, Klocke P, Leiber F, Schwegler P, Stolze M, Niggli U (2015) Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. *Journal of The Royal Society Interface* **12**, 20150891. doi:10.1098/rsif.2015.0891
Schimpl FC, da Silva JF, Gonçalves JFdC, Mazzafera P (2013) Guarana: revisiting a highly caffeinated plant from the Amazon. *Journal of Ethnopharmacology* **150**, 14–31. doi:10.1016/j.jep.2013.08.023
Seo J, Kim W, Kim J, Kim JK, Kim SC, Jang Y, Jang K, Kim K, Kim B, Park S, Park I, Kim MK, Seo KS, Kim HB, Kim IH, Seo S, Song M (2015) Effects of palm kernel expellers on growth performance, nutrient digestibility, and blood profiles of weaned pigs. *Asian-Australasian Journal of Animal Sciences (AJAS)* **28**, 987–992. doi:10.5713/ajas.14.0842
Shi H, Kim SH, Kim IH (2019) Effect of dietary inclusion of fermented sea mustard by-product on growth performance, blood profiles, and meat quality in broilers. *Journal of the Science of Food and Agriculture* **99**, 4304–4308. doi:10.1002/jsfa.9663
Sousa SA, Alves SF, de Paula JAM, Fiuza TS, Paula JR, Bara MTF (2010) Determination of tannins and methylxanthines in powdered guarana (*Paullinia cupana* Kunth, Sapindaceae) by high performance liquid chromatography. *Revista Brasileira de Farmacognosia* **20**, 866–870. doi:10.1590/S0102-695X2011005000001
Svihus B (2011) The gizzard: function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal* **67**, 207–224. doi:10.1017/S0043933911000249
Tavares-Dias M, Moraes FR (2004) 'Hematology of teleost fish.' (Villimpress: Ribeirão Preto) [in Portuguese]
Torrey S, Mohammadigheisar M, Nascimento dos Santos M, Rothschild D, Dawson LC, Liu Z, Kiarie EG, Edwards AM, Mandell I, Karrow N, Tulpan D, Widowski TM (2021) In pursuit of a better broiler: growth, efficiency, and mortality of 16 strains of broiler chickens. *Poultry Science* **100**, 100955. doi:10.1016/j.psj.2020.12.052
van der Eijk JAJ, Bakker J, Güz BC, van Krimpen MM, Molenaar R, van den Brand H, de Jong IC (2022) Providing organic macro minerals and an elevated platform improved tibia characteristics, and increased locomotion and performance of fast- and slower-growing broilers. *Poultry Science* **101**, 101973. doi:10.1016/j.psj.2022.101973
van der Eijk JAJ, van Harn J, Gunnink H, Melis S, van Riel JW, de Jong IC (2023) Fast- and slower-growing broilers respond similarly to a reduction in stocking density with regard to gait, hock burn, skin lesions, cleanliness, and performance. *Poultry Science* **102**, 102603. doi:10.1016/j.psj.2023.102603
van Hal O, de Boer IJM, Muller A, de Vries S, Erb K-H, Schader C, Gerrits WJJ, van Zanten HHE (2019) Upcycling food leftovers and grass resources through livestock: impact of livestock system and productivity. *Journal of Cleaner Production* **219**, 485–496. doi:10.1016/j.jclepro.2019.01.329
Van Kernebeek HRJ, Oosting SJ, Van Ittersum MK, Bikker P, De Boer IJM (2016) Saving land to feed a growing population: consequences for consumption of crop and livestock products. *The International Journal of Life Cycle Assessment* **21**, 677–687. doi:10.1007/s11367-015-0923-6
Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**, 3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2
Van Zanten HHE, Herrero M, Van Hal O, Röös E, Muller A, Garnett T, Gerber PJ, Schader C, De Boer IJM (2018) Defining a land boundary for sustainable livestock consumption. *Global Change Biology* **24**, 4185–4194. doi:10.1111/gcb.14321
Vastolo A, Calabrò S, Cutrignelli MI (2022) A review on the use of agro-industrial CO-products in animals' diets. *Italian Journal of Animal Science* **21**, 577–594. doi:10.1080/1828051X.2022.2039562

Wintrobe MM (1934) Relation of variations in mean corpuscular volume to number of reticulocytes in pernicious anemia: the significance of increased bone marrow activity in determining the mean size of red corpuscles. *Journal of Clinical Investigation* **13**, 669–676. doi:10.1172/JCI100613

Wu Y, Huang J, Quan S, Yang Y (2022) Light regimen on health and growth of broilers: an update review. *Poultry Science* **101**, 101545. doi:10.1016/j.psj.2021.101545

Yang K, Qing Y, Yu Q, Tang X, Chen G, Fang R, Liu H (2021) By-product feeds: current understanding and future perspectives. *Agriculture* **11**, 207. doi:10.3390/agriculture11030207

Yonekura L, Martins CA, Sampaio GR, Monteiro MP, César LAM, Mioto BM, Mori CS, Mendes TMN, Ribeiro ML, Arçari DP, Torres EAFdA (2016) Bioavailability of catechins from guaraná (*Paullinia cupana*) and its effect on antioxidant enzymes and other oxidative stress markers in healthy human subjects. *Food & Function* **7**, 2970–2978. doi:10.1039/C6FO00513F

Zhou Y, Chen Z, Lin Q, Yang Y, Hang Y, Zhou X, Wu C, Xie Z (2020) Nuciferine reduced fat deposition by controlling triglyceride and cholesterol concentration in broiler chickens. *Poultry Science* **99**, 7101–7108. doi:10.1016/j.psj.2020.09.013

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Original Article

Growth Performance and Economic Feasibility of Guarana By-products in Diets for Slow-growing Broilers[I]

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ABSTRACT

The study evaluated the inclusion of guarana by-products, guarana peel meal (GPEM), and guarana pulp meal (GPUM) in diets for slow-growing broilers to assess their impact on growth performance and economic feasibility. To evaluate the effects of guarana by-products, two experiments were conducted. In both experiments, 240 slow-growing male broilers of the Label Rouge strain were used. Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the tested product) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. GPEM, with higher fiber content, improved feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM, with higher energy content, showed optimal performance at intermediate levels (7.5%). Both by-products enhanced meat production and economic returns compared to the basal diet. The results suggest that GPEM is suitable for systems prioritizing feed efficiency and cost-effectiveness, while GPUM is better suited for phases requiring higher energy intake and weight gain. Additionally, the use of these agro-industrial residues promotes sustainability by integrating circular economy practices into poultry production. The findings highlight the potential of guarana by-products as alternative feed ingredients to improve productivity and reduce costs, particularly in regions with abundant availability of these residues.

INTRODUCTION

In various regions of Brazil, especially in the Amazon, logistics for inputs significantly increase the cost of feedstuffs used in the formulation and production of balanced diets (Cruz *et al.*, 2016). This scenario encourages research testing alternative feeds, especially those using agro-industrial residues to reduce feed costs, which can account for 60% to 80% of total production costs in activities such as poultry farming (Rufino *et al.*, 2015; Cruz *et al.*, 2016; Costa *et al.*, 2018a,b; Aride *et al.*, 2016, 2018, 2020; Polese *et al.*, 2022). These residues are often processed into meals and incorporated into poultry diets as nutritional supplements, while also providing competitive advantages for producers (Cruz & Rufino, 2017).

The Amazon region presents numerous native species with economic, technological, and nutritional potential, which have sparked scientific interest in various fields such as food, pharmaceuticals, cosmetics, flavorings, and essences, as well as their potential applications in animal feeding (Clement *et al.*, 2005; Oliveira *et al.*, 2010). In this context, one fruit that is produced intensively and generates a large amount of residue during the harvest season, with potential for use in animal feed, is guarana (*Paullinia cupana*) (Ferreira *et al.*, 2022). This fruit, native to the Amazon, is cultivated in several parts of Brazil and holds great economic and social importance due to its high demand from the beverage industry for the production of soft drinks and energy drinks (Espinola *et al.*, 1997; Marques *et al.*, 2016; Ferreira *et al.*, 2022).

Among the poultry farming segments that require these alternative feeds, slow-growing broiler production has stood out, particularly for small and medium producers (Machado *et al.*, 2018; Sarica *et al.*, 2020; Cruz *et al.*, 2023). These broilers exhibit greater tolerance to temperature variations and resistance to certain microorganisms (Sarica *et al.*, 2020), along with a more gradual and proportional growth rate compared to fast-growing strains (Machado *et al.*, 2018; Cruz *et al.*, 2023). However, their longer growth period can lead to higher production costs, making these strains less economically attractive for large-scale production, though they remain appealing for alternative production systems (Lusk *et al.*, 2019; Sarica *et al.*, 2020).

References to the use of guarana or its by-products in poultry diets are very scarce in the literature (Santos *et al.*, 2024). However, considering its rich nutritional properties, a high volume of production that generates residues, and its importance to Brazilian agribusiness, guarana by-products may exhibit good biological and productive potential as well as economic viability for inclusion in poultry diets (Cruz & Rufino, 2017; Costa *et al.*, 2018a,b; Santos *et al.*, 2024). Moreover, they contribute to a circular economy within these production chains (Cruz & Rufino, 2017; Oliveira, 2018; Ali *et al.*, 2021). Based on this information, the present study aimed to evaluate the growth performance and economic feasibility of slow-growing broilers fed diets containing increasing levels of guarana by-products.

MATERIALS AND METHODS

The current experiment was conducted at the Faculty of Agrarian Sciences of the Federal University of Amazonas, located in Manaus City, Amazonas State, Brazil. All experimental procedures were conducted in accordance with the guidelines of the Local Experimental Animal Care Committee and were approved by the UFAM ethics committee (protocol number 010/2022).

Acquisition and composition analysis of guarana by-products

The guarana by-products were obtained in the municipality of Maués, Amazonas, located 259 km from Manaus, the state capital. The following steps were performed to obtain guarana peel meal (GPEM): 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The peels were isolated as residues; 5) The seeds were processed for guarana extract extraction, used in the production of industrialized carbonated beverages; 6) The guarana peels were dried in a closed-circulation oven at 105°C for 24 hours; 7) The dried guarana peels were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); and 8) the final product, referred to as GPEM, was bagged and stored in a dry and ventilated location for use in the preparation of experimental diets. To obtain guarana pulp meal (GPUM), the following steps were performed: 1) Ripe guarana fruits underwent a manual harvesting process; 2) The harvested fruits were stored in baskets for approximately three days, undergoing a fermentation process; 3) The fruits were separated into seeds and peels; 4) The seeds were processed for guarana extract extraction, used in the production of industrialized carbonated beverages; 5) The residues remaining from the seed extraction were separated and dried in a closed-circulation oven at 105°C for 24 hours; 6) these dried residues were ground in a grain grinder using sieves with hole diameters similar to those used for corn (4 mm); 7) the final product, referred to as GPUM, was bagged and stored in a dry and ventilated location for use in the preparation of experimental diets.

Before conducting the experiment, the proximate composition of both GPEM and GPUM (Table 1) was determined at the Fish Technology Laboratory of UFAM. The dry matter content was determined in an oven at 105 °C following the AOAC 925.10 (2019) method. Mineral content was assessed by incineration in a muffle furnace at 550 °C, in accordance with the AOAC 923.03 (2019) method. Lipid content analysis followed the AOCS Ba 3-38 method. Total protein was determined using the Kjeldahl method, according to AOAC 920.87 (2019). Fiber content (crude fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF)) was analyzed as described by Van Soest *et al.* (1991).

Table 1 – Composition of guaraná by-products tested.

Variables	Guarana peel meal	Guarana pulp meal
Dry matter, %	89.11	83.93
Crude protein, %	18.72	12.27
Fats, %	5.36	2.41
Minerals, %	5.33	1.01
Crude Fiber, %	44.04	29.17
Neutral detergent fiber, %	61.66	40.84
Acid detergent fiber, %	39.64	26.25
Soluble carbohydrates, %	26.55	55.14
Gross energy, kcal/kg	6,495.65	5,745.42
Metabolizable energy*, kcal/kg	2,258.64	2,828.56

*Determined using the apparent metabolizable energy calculation method described by Sakomura and Rostagno (2016) and Rostagno *et al.* (2024).

Facilities, animals and experimental design

To evaluate the effects of guarana by-products on growth performance and economic viability, two experiments were conducted, one for the inclusion of GPEM, and the other for the inclusion of GPUM.

In both experiments, a poultry house with a ceiling height of 3.25 m was used, with structural adaptations to improve bird welfare. Temperature and relative humidity were monitored using a small digital weather station, recording averages of 27.6 °C and 62.3%, respectively. Throughout the experimental period, the broilers were monitored for potential signs of heat stress caused by the environment, a condition that was not observed during the entire experimental period in either experiment.

240 slow-growing male broilers of the Label Rouge strain were used in both experiments, sourced from the Hatchery Center of UFAM's Poultry Sector. Initially, 1-day-old chicks were housed in a brooder circle with wood shavings as bedding, tray feeders, and cup drinkers, at a density of 50 birds/m², with a central electric heating source, until they reached 7 days of age. Subsequently, they were allocated to their respective treatments in pens measuring 4 m² each, equipped with tubular feeders, pendulum drinkers, and wood shavings bedding on the floor. The experimental stages were divided into an initial (8–28 days) and a final (29–56 days), during which the birds had *ad libitum* access to feed and water. A lighting program suitable for slow-growing broilers was implemented (Wu *et al.*, 2022).

Table 2 – Composition of the experimental diets containing guarana peel meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	54.68	51.06	47.45	43.83	63.34	62.88	59.99	56.37	52.75
Soybean meal 46%	38.32	38.35	38.69	39.06	39.44	39.82	32.53	30.64	30.89	31.27	31.64
Guarana peel meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.82	0.81	0.80	0.79	1.02	1.02	0.76	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.80	1.81	1.82	1.83	1.55	1.58	1.59	1.60	1.61
Common salt	0.30	0.10	0.27	0.27	0.27	0.28	0.53	0.34	0.28	0.28	0.28
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.11	0.12	0.12	0.13	0.03	0.04	0.05	0.55	0.06
Soybean oil	0.00	0.27	0.64	1.37	2.09	2.82	0.50	0.50	0.96	1.19	2.41
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Nutrients	**Guarantee levels[3]**										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.76	87.66	87.56	87.46	87.89	87.66	87.49	87.39	87.29
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.18	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	4.39	5.37	6.35	7.33	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	6.15	7.52	8.89	10.26	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.95	4.83	5.71	6.60	2.84	3.66	4.55	5.44	6.32
Total lysine, %	1.21	1.21	1.21	1.21	1.22	1.22	1.06	1.01	1.01	1.01	1.01
Total methionine, %	0.45	0.45	0.45	0.46	0.46	0.47	0.35	0.35	0.35	0.35	0.36
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0.67	0.66	0.66	0.66
Total threonine, %	0.87	0.87	0.87	0.86	0.86	0.85	0.79	0.75	0.75	0.74	0.74
Total tryptophan, %	0.28	0.28	0.28	0.28	0.28	0.29	0.25	0.24	0.24	0.24	0.24

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [3] Levels analyzed and calculated on a dry matter basis.

Both experiment 1 (testing GPEM) and experiment 2 (testing GPUM) were conducted using a completely randomized design, with treatments consisting of a control diet (without the inclusion of the product being tested) and four levels of inclusion of the tested product (2.5%, 5.0%, 7.5%, and 10%) in the diets, each with four replicates of 12 birds. The experimental diets (Tables 2 and 3) were formulated based on the reference values of Rostagno *et al.* (2024), except for the GPEM and GPUM, which used values from prior compositional analyses of the product. The metabolizable energy values of these guarana by-products were determined using estimation methods described by Sakomura and Rostagno (2016) and Rostagno *et al.* (2024).

The guarana by-products were a fixed component in the diet calculations, with other feedstuffs values being adjusted based on the inclusion levels proposed in the experiments. The diets were formulated using the SuperCrac software (TD Software©, Viçosa, Brazil). The composition of these diets was analyzed to confirm their proximate composition according to the methods described by AOAC (2019), where moisture content was determined following method 925.10, mineral content according to method 923.03, lipid content analyses followed method Ba 3-38, total protein content was determined using method 920.87, and fiber content (crude fiber, NDF, and ADF) was determined according to the methods described by Van Soest *et al.* (1991).

Table 3 – Composition of the experimental diets containing guarana pulp meal.

Feedstuffs	Pre-initial (1 to 7 days)	Initial (8 to 28 days)					Final (29 to 56 days)				
		0	2.5	5	7.5	10	0	2.5	5	7.5	10
Corn 7,88%	58.07	58.07	56.27	53.17	50.10	47.00	63.34	61.57	58.49	55.40	52.31
Soybean meal 46%	38.32	38.35	35.77	35.66	35.55	35.43	32.53	30.5	30.39	30.28	30.17
Guarana pulp meal	0.00	0.00	2.50	5.00	7.50	10.00	0.00	2.50	5.00	7.50	10.00
Limestone	0.93	0.82	0.83	0.82	0.81	0.81	1.02	0.76	0.75	0.75	0.74
Dicalcium phosphate	1.79	1.79	1.82	1.84	1.85	1.87	1.55	1.58	1.60	1.61	1.63
Common salt	0.30	0.10	0.27	0.28	0.28	0.28	0.53	0.28	0.28	0.28	0.29
Vit. Min. supplement	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[1]	0.50[2]	0.50[2]	0.50[2]	0.50[2]	0.50[2]
DL-methionine 99%	0.10	0.10	0.14	0.15	0.16	0.18	0.03	0.05	0.06	0.07	0.08
Soybean oil	0.00	0.27	1.90	2.58	3.25	3.93	0.50	2.26	2.93	3.61	4.28
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Nutrients	**Guarantee levels[3]**										
Metabolizable energy, kcal/kg	3,000.00	3,100.00	3,100.00	3,100.00	3,100.00	3,100.00	3,200.00	3,200.00	3,200.00	3,200.00	3,200.00
Dry matter, %	87.88	87.88	87.86	87.67	87.58	87.50	87.89	87.76	87.59	87.42	87.35
Crude protein, %	22.50	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
Calcium, %	0.94	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus, %	0.46	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Sodium, %	0.15	0.19	0.15	0.15	0.15	0.15	0.25	0.15	0.15	0.15	0.15
Crude fiber, %	3.40	3.40	3.94	4.61	5.27	5.93	3.16	4.07	5.06	6.04	7.02
NDF, %	4.76	4.76	5.52	6.45	7.38	8.30	4.42	5.70	7.08	8.46	9.83
ADF, %	3.06	3.06	3.55	4.15	4.74	5.34	4.70	4.54	4.46	4.36	4.27
Total lysine, %	1.21	1.21	1.14	1.12	1.11	1.10	1.06	1,00	0,99	0,98	0,97
Total methionine, %	0.45	0.45	0.47	0.47	0.48	0.49	0.35	0,35	0,35	0,36	0,37
Total methionine + cystine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.68	0,66	0,66	0,66	0,66
Total threonine, %	0.87	0.87	0.82	0.81	0.80	0.79	0.79	0,75	0,73	0,72	0,71
Total tryptophan, %	0.28	0.28	0.27	0.26	0.26	0.26	0.25	0,24	0,23	0,23	0,23

[1] Vitamin/mineral supplement – starter: Content per 1 kg of diet = Folic acid 800 mg, Pantothenic acid 12,500 mg, Antioxidant 0.5 g, Biotin 40 mg, Niacin 33,600 mg, Selenium 300 mg, Vitamin A 6,700,000 IU, Vitamin B1 1,750 mg, Vitamin B12 9,600 mcg, Vitamin B2 4,800 mg, Vitamin B6 2,500 mg, Vitamin D3 1,600,000 IU, Vitamin E 14,000 mg, Vitamin K3 1,440 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [2] Vitamin/mineral supplement – finisher: Content per 1 kg of diet = Folic acid 650 mg, Pantothenic acid 10,400 mg, Antioxidant 0.5 g, Niacin 28,000 mg, Selenium 300 mg, Vitamin A 5,600,000 IU, Vitamin B1 550 mg, Vitamin B12 8,000 mcg, Vitamin B2 4,000 mg, Vitamin B6 2,080 mg, Vitamin D3 1,200,000 IU, Vitamin E 10,000 mg, Vitamin K3 1,200 mg. Mineral supplement – content per 0.5 kg = Manganese 150,000 mg, Zinc 100,000 mg, Iron 100,000 mg, Copper 16,000 mg, Iodine 1,500 mg. [3] Levels analyzed and calculated on a dry matter basis.

Experimental analysis

In both experiments, during 56 days, performance data (feed intake and weight gain) were collected from the birds for use in the economic feasibility analysis following the methodological procedures described by Costa *et al.* (2018a,b) and Rufino *et al.* (2018). At 56 days of age, after a 12-hour fasting period, 12 birds from each treatment group were randomly selected for weighing, stunning by electric shock (40 V; 50 Hz), and slaughter by cutting of the jugular vein. The carcasses were then scalded in hot water (60 °C for 62 seconds), defeathered, and eviscerated following the recommendations of Mendes & Patricio (2004).

To determine feed costs and production expenses, only the per-kilogram prices of the feedstuffs used and their updated prices in the region during the experiment were considered. The prices were as follows: corn, R$ 1.66; soybean meal, R$ 3.65; limestone, R$ 0.73; dicalcium phosphate, R$ 4.50; common salt, R$ 0.83; DL-Methionine 99%, R$ 51.00; and mineral and vitamin supplements (F1 - starter; F2 - grower; and F3 - finisher), R$ 28.35/kg (average price). The cost of GPEM and GPUM was calculated considering only transportation and handling expenses (labor), with estimated prices of R$ 0.30 and R$ 0.35 per kilogram, respectively. Fixed costs included depreciation of facilities and equipment (maintenance, water, electricity, etc.), where interest on capital remained unchanged in the short term and was considered constant across all treatments. Variable costs included only bird feed expenses and labor.

The variables were calculated based on the production of each plot. The Productive Efficiency Index (PEI) was determined using the formula:

$$PEI = \frac{DWG*VIAB*100}{FCR}$$

Where:

DWG = daily weight gain of the plot (kg)

VIAB = viability of the plot (%)

FCR = feed conversion ratio of the plot (kg/kg).

The feed cost (FC, R$), the only production cost used as an analysis variable, was determined through the acquisition of ingredients and feed preparation, estimated by the formula:

$$FC = AFI * AP$$

Where:

AFI = accumulated feed intake of the plot (kg)

AP = average price per kilogram of feed, considering both stages (R$/kg).

For total meat production (kg) and meat production per square meter (kg/m²), the carcass yield of slaughtered, scalded, defeathered, and cleaned animals was considered, as described by Costa *et al.* (2018b) and Rufino *et al.* (2018). To calculate the production cost per kilogram of meat (PCKG, R$/kg), the following formula was used:

$$PCKG = \frac{CA}{PRODKG}$$

Where:

FC = feed cost of the plot (R$)

PRODKG = meat production of the plot (kg).

To determine the production cost per square meter of meat (PCPSM, R$/m²), the following formula was used:

$$PCPSM = \frac{CA}{PRODSM}$$

Where:

FC = feed cost of the plot (R$)

PRODSM = meat production per square meter of the plot (kg/m²).

The gross revenue (REV, R$) was calculated based on the relationship between meat production and the selling price per kilogram of the product, using:

$$REV = Q * SP$$

Where:

Q = quantity of meat produced by the plot (kg)

SP = selling price per kilogram of meat produced (R$/kg).

It is important to note that the selling price per kilogram of chicken, applying a gross margin value-added calculation, was determined based on the market price in the region, fixed at R$ 8.00 per kg. Gross profit (PRO, R$) was calculated as the monetary difference between the total revenue from the estimated sale of the chickens (kilograms of chicken meat) and the discounted production cost, which derived from the feed cost, using the formula:

$$PRO = REV - FC$$

Where:

REV = gross revenue of the plot (R$)

FC = feed cost of the plot (R$).

The profitability index (PI, %), which indicates the capital available after covering costs (in this case, feed costs), was derived from the relationship between gross added value and gross revenue, using the formula:

$$PI = \left(\frac{PRO}{REV}\right) * 100$$

Where:

PRO = gross profit of the plot (R$)

REV = gross revenue of the plot (R$).

For the break-even point (BE, kg), the quantity of production required to achieve zero return, covering all costs, was considered. In this case, it represents a partial break-even point, as it reflects the production volume necessary to cover feed costs. The formula used was:

$$BE = \frac{REV}{SP}$$

Where:

REV = gross revenue of the plot (R$)

SP = selling price per kilogram of meat produced (R$/kg).

Statistical analyses

The statistical model adopted was as follows:

$$Y_{ik} = \mu + \alpha_i + \epsilon_{ik}$$

Where:

Y_{ik} = Observed value for the variable under study

μ = Overall experiment mean

α_i = Effect of GPEM or GPUM levels

ϵ_{ik} = Experimental error.

All data were analyzed using one-way ANOVA with R software (2021). Commands were executed following Logan's (2010) guidelines. Tukey's Honest Significant Difference (HSD) test was used to examine significant differences among the GPEM or GPUM levels (independent variable) for each dependent variable evaluated. Results are presented as means, and the significance level for differences was set at 0.05.

Subsequently, results for significant variables ($p<0.05$) were subjected to correlation and polynomial regression analysis to evaluate the influence of the independent variable on the dependent variables (Chatterjee & Hadi, 2006; Logan, 2010). The mathematical model, either linear ($Y = a + bx$) or quadratic ($Y = c + bx + ax^2$), was selected based on the influence of the independent variable on the dependent variable analyzed (Dormann *et al.*, 2013). R-squared values were also considered as a criterion to determine the best model (Chatterjee & Hadi, 2006; Dormann *et al.*, 2013).

RESULTS AN DISCUSSION

Experiment 1

The growth performance analysis of slow-growing broilers in the starter stage indicated a significant effect ($p<0.05$) of GPEM inclusion on feed intake and weight gain (Table 4), with the increasing inclusion of GPEM causing a linear increase in these variables; that is, the 10% inclusion level of GPEM provided higher results. However, in the final stage, feed intake and feed efficiency showed an opposite behavior, with the increasing inclusion of GPEM reducing ($p<0.05$) the broilers' feed intake, and the 10% inclusion level of GPEM providing a better feed efficiency result. In this sense, weight gain in this stage increased ($p<0.05$) linearly as the inclusion of GPEM in the diets increased.

Table 4 – Growth performance of slow-growing broilers fed diets containing increasing levels of guarana peel meal[1].

Stage	Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.5	5.00	7.5	10.00					
Starter	FI	1.43^b	1.48^b	1.69^a	1.71^a	1.74^a	<0.01	7.52	0.47	$Y = 1.44 + 0.034x$	0.96
	WG	0.87^b	0.94^b	0.98^{ab}	1.01^a	1.06^a	<0.01	2.33	0.42	$Y = 0.882 + 0.018x$	0.94
	FE	1.64	1.57	1.72	1.69	1.64	0.10	8.28	-	-	-
Final	FI	2.95^a	3.01^a	2.98a	3.01^a	2.63^b	0.05	12.64	-0.08	$Y = 2.9269 + 0.0681x - 0.0094x^2$	0.95
	WG	1.03^b	1.04^b	1.01^b	1.03^b	1.16^a	0.05	10.69	0.20	$Y = 1.004 + 0.01x$	0.92
	FE	2.86^a	2.89^a	2.95^a	2.92^a	2.27^b	0.05	4.59	-0.36	$Y = 2.8049 + 0.1197x - 0.0166x^2$	0.93
General	FI	4.38	4.49	4.67	4.72	4.37	0.09	5.35	-	-	-
	WG	1.90^b	1.98^b	1.99^b	2.04^{ab}	2.22^a	<0.01	4.69	0.29	$Y = 1.886 + 0.028x$	0.89
	FE	2.31^a	2.27^a	2.35^a	2.31^a	1.97^b	<0.01	4.58	-0.34	$y = 2.262 + 0.058x - 0.0083x^2$	0.91

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg). [3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

When observing the cumulative growth performance, it was found that the inclusion of GPEM did not significantly affect ($p>0.05$) the cumulative feed intake in the entire evaluated period. However, the cumulative results of weight gain and feed efficiency showed that these variables were significantly influenced ($p<0.05$) by the inclusion of GPEM, with weight gain increasing linearly, and feed efficiency improving as the levels of GPEM in the diets increased, that is, the 10% inclusion level of GPEM led to better cumulative weight gain and feed efficiency results.

The inclusion of GPEM positively impacted most growth performance variables, notably producing heavier broilers with improved feed efficiency. This result is particularly significant given that GPEM contains a considerable amount of fiber, which increased the dietary fiber levels from 4% to 7%. Despite this increase in fiber contents, broiler performance was not adversely affected by the progressive inclusion of GPEM. Fiber in poultry diets has traditionally posed challenges for researchers and industry, as the avian gastrointestinal tract exhibits limited enzymatic activity for fiber digestion, particularly in broilers, potentially restricting nutrient utilization (Azizi *et al.*, 2021). Nonetheless, studies by González-Alvarado *et al.* (2010), Mateos *et al.* (2012), Rufino *et al.* (2021) and Santos *et al.* (2024) suggest that moderate fiber levels in poultry diets play a crucial role in enhancing physiological responses, nutrient utilization, and overall growth performance. Jiménez-Moreno *et al.* (2009a,b) and Svihus (2011) further emphasized that the beneficial effects of moderate fiber levels are linked to improved digestibility through continuous gizzard stimulation, enhanced small intestine activity, and a positive impact on intestinal microbiota due to the prebiotic effects of fiber.

In this sense, Pushpakumara *et al.* (2017) found that including up to 15% palm kernel meal in broiler diets improved feed efficiency and weight gain. Malhado *et al.* (2022) reported no significant effects (p>0.05) on weight gain, final weight, or feed efficiency when using barley residues in slow-growing broilers but noted a linear increase (p<0.05) in feed intake with higher barley levels. Similarly, Costa *et al.* (2018a) observed improved weight and production efficiency with tucumã meal inclusion, though levels above 25% negatively affected these indices.

The high fiber content in many alternative feeds derived from food processing residues can challenge nutrient metabolism and growth performance (Rufino *et al.*, 2015; Cruz & Rufino, 2017; Liu *et al.*, 2018; Rufino *et al.*, 2021; Cho *et al.*, 2024). However, residues from guarana processing like GPEM may provide additional benefits due to bioactive compounds with antioxidant, antimicrobial, and stimulating properties, potentially enhancing nutrient utilization and physiological responses (Marques *et al.*, 2016; Yonekura *et al.*, 2016; Cruz & Rufino, 2017).

According to the economic analysis on the performance of slow-growing broilers fed diets containing GPEM (Table 5), no significant difference (p>0.05) was observed among the treatments for the breakeven point variable. However, all other variables were significantly affected by the inclusion of GPEM.

Table 5 – Economic analysis of the performance of slow-growing broilers fed diets containing increasing levels of guarana peel meal[1].

Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.5	5.00	7.5	10.00					
PRE-INI, R$/kg	3.09	3.11	3.14	3.18	3.21	-	-	-	-	-
PRE-FIN, R$/kg	2.97	2.90	2.91	2.94	2.97	-	-	-	-	-
PEI	169.91^{b}	204.82^{a}	204.74^{a}	207.05^{a}	208.47^{a}	<0.01	6.19	0.76	$Y = 173.9 + 10.556x - 0.7382x^2$	0.86
FC, R$	132.95^{b}	135.05^{b}	141.61^{a}	144.86^{a}	135.71^{b}	0.03	5.45	0.48	$Y = 131.28 + 3.5629x - 0.295x^2$	0.71
PRODKG, kg	22.92^{c}	23.76^{b}	23.88^{b}	24.60^{b}	26.76^{a}	<0.01	7.23	0.92	$Y = 22.68 + 0.3408x$	0.85
PCKG, R$/kg	5.80^{a}	5.68^{b}	5.93^{a}	5.89^{a}	5.07^{c}	0.03	8.24	-0.56	$Y = 5.6826 + 0.1431x - 0.0193x^2$	0.73
PRODSM, kg/m²	5.73^{c}	5.94^{b}	5.97^{b}	6.15^{a}	6.69^{a}	<0.01	7.23	0.92	$Y = 5.67 + 0.0852x$	0.85
PCPSM, R$/m²	33.24^{b}	33.76^{b}	35.40^{a}	36.21^{a}	33.93^{b}	0.03	5.45	0.48	$Y = 32.823 + 0.8881x - 0.0735x^2$	0.71
REV, R$	160.44^{c}	166.32^{c}	167.16^{c}	172.20^{b}	187.32^{a}	<0.01	7.23	0.92	$Y = 158.76 + 2.3856x$	0,85
PRO, R$	27.49^{b}	31.27^{b}	25.55^{b}	27.34^{b}	51.61^{a}	0.01	5.25	0.64	$Y = 30.717 - 3.7693x + 0.5542x^2$	0.78
PI,	17.13^{b}	18.80^{b}	15.28^{b}	15.88^{b}	27.55^{a}	0,03	4,86	0.56	$Y = 18.79 - 2.0398x + 0.2757x^2$	0.73
BE, kg	18.99	19.29	20.23	20.69	19.39	0.51	5.45	-	-	-

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point. [3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPEM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana peel meal levels) on the dependent variable.

In the variables of productive efficiency, total production of chicken meat in kilograms, and meat production per square meter, all broilers fed diets containing GPEM showed better results, with a gradual improvement in efficiency as the inclusion level of this alternative product increased. These findings align with results obtained by Costa *et al.* (2018a, b), who reported improved broiler productivity when including increasing levels of tucumã residue flour in their diets.

As mentioned above, the use of alternative foods in broiler diets often presents challenges related to the balance between their composition and the effects on bird productivity. Many of these feeds are by-products of the food processing industry, often comprising peels and seeds, which naturally contain high fiber levels (Cruz & Rufino, 2017; Rufino *et al.*, 2021). However, depending on the specific feed used, its fiber content may vary and can be outweighed by other nutrients of nutritional interest, such as proteins and soluble carbohydrates, which affect feed efficiency and, consequently, productivity (Rufino *et al.*, 2021; Rufino *et al.*, 2023).

These results of productive indexes directly influence economic variables, such as feed cost, production cost per kilogram, and production cost per square meter, which were higher in several treatments that included GPEM. According to Rufino *et al.* (2015), higher inclusion levels of alternative foods can result in fluctuations in the production volume required to cover feed costs, affecting production costs either by increasing them, as seen in this study, or lowering them as compensation for using cheaper ingredients.

Feed cost represents a significant component of production expenses, and the use of agricultural residues in diets can impact these costs by replacing or reducing conventional ingredients (Nogueira *et al.*, 2014; Cruz & Rufino, 2017). Economic analyses of alternative foods for poultry show that factors such as procurement logistics, production volume, and price fluctuations are crucial in deciding whether to use alternative ingredients (Silva *et al.*, 2009; Rufino *et al.*, 2015; Melo *et al.*, 2017; Costa *et al.*, 2018a,b; Batalha *et al.*, 2019). These parameters confirm the economic viability of alternative feeds, which is closely tied to performance results (Pelizer *et al.*, 2007; Costa *et al.*, 2009).

In terms of gross income, gross profit, and profitability index, higher inclusion levels of GPEM yielded better results, demonstrating a positive economic impact. Despite apparent increases in production costs, productivity improvements effectively compensated for these, leading to favorable economic outcomes. According to Furtado *et al.* (2011), Rufino *et al.* (2015), Cruz & Rufino (2017), and Brelaz *et al.* (2021), including alternative foods in poultry diets can offer positive effects by utilizing regional agro-industrial by-products unsuitable for human consumption, reducing production costs without compromising bird performance, or enhancing productivity to offset costs. These impacts are especially significant for small and medium-scale poultry operations.

Conducting an economic and financial feasibility analysis of investments is essential, as it estimates and analyzes financial performance perspectives based on production outcomes (Rufino *et al.*, 2018). If alternative feeds fail to achieve comparable productive and economic results to conventional feeds, they must be excluded from feed formulations or reconsidered for use under different conditions (Rufino *et al.*, 2015).

According to Cruz & Rufino (2017), an alternative feed must meet four essential criteria to validate its use in animal production diets: (1) Proven biological composition with potential for use without anti-nutritional factors; (2) Accessible logistics, sufficient production volume, and year-round availability; (3) Cost similar to or lower than conventional feeds; and (4) A positive impact on productivity, comparable to or exceeding that of conventional diets. These criteria ensure effective technical decisions regarding the use of alternative feeds in poultry diets (Melo *et al.*, 2017; Rufino *et al.*, 2021; Rufino *et al.*, 2023).

Experiment 2

The growth performance analysis (Table 6) of slow-growing broilers in the starter stage showed that increasing GPUM levels significantly ($p<0.05$) influenced feed intake and weight gain, with 7.5% GPUM inclusion yielding higher results for these parameters. Regarding feed efficiency, GPUM inclusion had a positive effect, as all slow-growing broilers fed diets containing GPUM demonstrated better feed efficiency than those fed the basal diet, with 5% GPUM inclusion providing the best results for feed efficiency. Similarly, in the final stage, slow-growing broilers fed diets with 7.5% GPUM inclusion exhibited higher ($p<0.05$) feed intake. However, in this stage, broilers fed diets with 2.5% GPUM inclusion achieved better feed efficiency. Cumulatively, all slow-growing broilers fed diets containing GPUM showed higher ($p<0.05$) feed intake and weight gain compared to those fed the basal diet, with 7.5% inclusion providing optimal results. Feed efficiency during this period exhibited significant ($p<0.05$) improvement up to 7.5% inclusion, beyond which no further improvements were observed.

When comparing the results of experiment 2 (GPUM) with those obtained in experiment 1 (GPEM), it stands out that GPUM promoted higher feed intake across all stages, especially at the 7.5% inclusion level, whereas GPEM showed a reduction in consumption during the final stage. This reduction may be associated with the higher fiber content, which, although potentially limiting intake, stimulates gizzard function and enhances nutrient digestibility (Sacranie *et al.*, 2012; Jiménez-Moreno *et al.*, 2019; Santos *et al.*, 2024). In terms of weight gain, both guarana by-products had positive impacts, but the effect of GPEM was linear and more pronounced at higher inclusion levels (10%), while GPUM showed optimal results at 7.5%, suggesting that its nutritional profile effectively supports growth at moderate inclusion levels. Regarding feed efficiency, GPEM showed significant improvements across all stages, with the best cumulative performance at 10% inclusion, whereas GPUM achieved peak efficiency at moderate inclusion levels (5%-7.5%).

These observed differences can be primarily attributed to the fiber profile of each by-product. The higher fiber content in GPEM may have stimulated increased gizzard activity, promoting more efficient digestibility and consequently better feed efficiency, as reported in studies highlighting the benefits of moderate fiber levels in poultry diets (Sacranie *et al.*, 2012; Abdollahi *et al.*, 2019; Jiménez-Moreno *et al.*, 2019; Santos *et al.*, 2024). In contrast, GPUM, with its lower fiber content and higher metabolizable energy (2,828.56 kcal/kg for GPUM versus 2,258.64 kcal/kg for GPEM), favored more consistent feed intake and higher weight gains, which aligns with findings from other studies using agricultural by-products with moderate fiber levels (Jiménez-Moreno *et al.*, 2009; Costa *et al.*, 2018b; Oliveira, 2018; Rufino *et al.*, 2024).

Table 6 – Growth performance of slow-growing broilers fed diets containing increasing levels of guarana pulp meal[1].

Stage	Variables[2]	Guarana peel meal levels, %					*p*-value[3]	CV[4], %	COR[5]	MM[6]	R^2
		0.00	2.5	5.00	7.5	10.00					
Starter	FI	1.30[c]	1.51[b]	1.52[b]	1.63[a]	1.50[b]	0.04	10.72	0.47	$Y = 1.3051 + 0.0871x - 0.0066x^2$	0.89
	WG	0.50[c]	0.75[b]	0.78[ab]	0.82[a]	0.74[b]	<0.01	8.31	0.60	$Y = 0.5151 + 0.0963x - 0.0074x^2$	0.95
	FE	2.61[a]	1.99[b]	1.94[b]	2.00[b]	2.02[b]	<0.01	14.93	-0.53	$Y = 2.5446 - 0.2057x + 0.0159x^2$	0.87
Final	FI	2.83[b]	2.95[b]	3.10[a]	3.16[a]	3.04[ab]	<0.01	5.17	0.59	$Y = 2.8086 + 0.0903x - 0.0065x^2$	0.93
	WG	1.13	1.20	1.19	1.19	1.05	0.10	8.34	-	-	-
	FE	2.49[c]	2.45[c]	2.59[b]	2.65[b]	2.90[a]	0.02	8.62	0.65	$Y = 2.412 + 0.0408x$	0.82
General	FI	4.13[c]	4.46[b]	4.63[b]	4.80[a]	4.55[b]	<0.01	6.44	0.57	$Y = 4.1123 + 0.1798x - 0.0133x^2$	0.95
	WG	1.64[c]	1.96[a]	1.98[a]	2.01[a]	1.80[b]	<0.01	9.42	0.30	$Y = 1.654 + 0.1348x - 0.012x^2$	0.95
	FE	2.52[a]	2.27[c]	2.33[b]	2.38[b]	2.53[a]	<0.01	5.67	0.13	$Y = 2.276 + 0.2908x - 0.0488x^2$	0.82

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] FI = Feed intake (kg/bird). WG = Weight gain (kg/bird). FE = Feed efficiency (kg/kg). [3] The means followed by lowercase letters in the lines differ using the Tukey test ($p<0.05$). not significant = $p>0.05$. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

These results reinforce important insights reported in the literature, which suggest that the impact of fiber in poultry diets depends not only on its quantity, but also on its composition and interaction with other nutrients (Sanchez *et al.*, 2021; Tejeda & Kim, 2021; Santos *et al.*, 2024). Previous studies indicate that insoluble fibers, such as those in GPEM, may be more effective at stimulating gastrointestinal motility and improving digestibility in slow-growing broilers, whereas soluble fibers, present in smaller proportions in GPUM, tend to have a lesser effect on gastrointestinal function (Mateos *et al.*, 2012; Sanchez *et al.*, 2021; Tejeda & Kim, 2021; Machado *et al.*, 2022).

Thus, the cumulative effects observed in both experiments underscore the importance of energy balance and nutrient profile when choosing a guarana by-product for the diet of slow-growing broilers. Overall, while GPEM demonstrated a greater ability to sustain performance throughout the production cycle, GPUM exhibited superior performance during the early and intermediate stages. This difference could have significant practical implications depending on the production system's objectives. In systems prioritizing feed efficiency and cost reduction, GPEM emerges as a more advantageous choice (Willems *et al.*, 2013; Zampiga *et al.*, 2021). Conversely, GPUM may be better suited for systems aiming to maximize feed intake and weight gain during critical growth periods, particularly in nutritional strategies focused on accelerating initial growth (Willems *et al.*, 2013; Prakash *et al.*, 2020; Zampiga *et al.*, 2021).

In the results of the economic analysis (Table 7), all variables evaluated in experiment 2 were statistically significant ($p<0.05$). Overall, the economic results from experiment 2 showed interesting differences compared to those observed in experiment 1, reflecting the distinct nutritional characteristics of the guarana by-products evaluated. Increasing levels of GPUM inclusion resulted in a proportional rise in feed cost, reaching the highest value at the 7.5% inclusion level. This was also reflected in the cost per kilogram of meat produced, which significantly increased at higher inclusion levels. These results contrast with those of experiment 1, where GPEM demonstrated greater stability in production costs, even at higher inclusion levels. As mentioned above, this difference can be partly attributed to the positive effects of GPEM's insoluble fibers, which optimized digestibility and offset costs through superior feed efficiency (Sacranie *et al.*, 2012; Abdollahi *et al.*, 2019; Jiménez-Moreno *et al.*, 2019).

In terms of meat production and gross revenue, both by-products showed positive gains compared to the control, but with distinct patterns. GPUM inclusion led to higher meat production and gross revenue at intermediate levels, from 2.5% to 7.5%, reflecting its higher soluble carbohydrate content and metabolizable energy, which favored short-term productive performance (Jiménez-Moreno *et al*., 2009; Costa *et al*., 2018b; Oliveira, 2018; Rufino *et al*., 2024). In contrast, GPEM exhibited consistent increases in meat production and revenue across all inclusion levels.

Gross profit and profitability index indicators also highlighted important economic differences between the two by-products. GPUM showed better economic performance at intermediate levels, but its viability was compromised at extreme levels, particularly at 10% inclusion, where additional costs were not offset by increased production. This contrasts sharply with GPEM results, which maintained consistent economic outcomes across the entire range of inclusion levels, with the best results observed at 10%. This reflects GPEM's ability to sustain stable productive and economic performance throughout the production cycle.

In general, the key point in the contrast observed in the economic results of both experiments lies in the relationship between the nutritional profiles and the economic costs of the products and their productive responses. Although the higher fiber content of GPEM may limit feed intake at certain times, it also promotes more efficient nutrient utilization, offsetting the additional costs associated with diet formulation (Mateos *et al*., 2012; Melo *et al*., 2017; Lusk *et al*., 2019). Conversely, GPUM, with its lower fiber content and higher energy density, is more sensitive to higher inclusion levels, as energy saturation can lead to reduced feed efficiency, directly affecting economic viability (Sacranie *et al*., 2012; Oliveira, 2018; Abdollahi *et al*., 2019).

Table 7 – Economic analysis of the performance of slow-growing broilers fed diets containing guarana pulp meal.[1]

Variables[2]	Guarana peel meal levels, %					p-value[3]	CV[4], %	COR[5]	MM[6]	R^2
	0.00	2.5	5.00	7.5	10.00					
PRE-INI, R$/kg	3,16	3,18	3,20	3,24	3,25	-	-	-	-	-
PRE-FIN, R$/kg	3,04	3,06	3,08	3,10	3,12	-	-	-	-	-
PEI	186.55^{b}	214.01^{a}	187.38^{b}	184.17^{b}	164.62^{c}	0.02	12.12	-0.47	$Y = 192 + 5.1206x - 0.8069x^2$	0.72
FC, R$	153.96^{c}	167.25^{bc}	174.60^{b}	182.84^{a}	173.69^{b}	<0.01	7.06	0.66	$Y = 153.17 + 7.2294x - 0.5027x^2$	0.95
PRODKG, kg	19.70^{c}	23.59^{a}	23.85^{a}	24.22^{a}	21.65^{b}	<0.01	9.42	0.30	$Y = 19.866 + 1.6452x - 0.1464x^2$	0.95
PCKG, R$/kg	7.82^{ab}	7.08^{c}	7.32^{bc}	7.56^{b}	8.04^{a}	<0.01	5.87	0.29	$Y = 7.7286 - 0.2421x + 0.0279x^2$	0.87
PRODSM, kg/m²	4.92^{c}	5.89^{a}	5.96^{a}	6.05^{a}	5.41^{b}	<0.01	9.42	0.30	$Y = 4.9609 + 0.4113x - 0.0366x^2$	0.95
PCPSM, R$/m²	38.49^{c}	41.81^{bc}	43.65^{b}	45.70^{a}	43.42^{b}	<0.01	7.06	0.66	$Y = 38.294 + 1.806x - 0.1256x^2$	0.95
REV, R$	162.78^{c}	188.76^{a}	190.82^{a}	193.78^{a}	173.20^{b}	0.01	9.12	0.22	$Y = 163.52 + 11.574x - 1.0539x^2$	0.96
PRO, R$	8.81^{b}	21.50^{a}	16.21^{ab}	10.94^{b}	-0.48^{c}	0.03	9.51	-0.39	$Y = 10.338 + 4.343x - 0.5509x^2$	0.91
PI,	4.92^{b}	11.38^{a}	8.46^{a}	5.47^{b}	-0.57^{c}	0.02	9.75	-0.42	$Y = 5.7286 + 2.1895x - 0.2865x^2$	0.92
BE, kg	19.24^{c}	20.90^{bc}	21.82^{b}	22.85^{a}	21.71^{b}	<0.01	7.06	0.66	$Y = 19.142 + 0.903x - 0.0627x^2$	0.95

[1] All data represent the average of 48 replicates (broilers) per treatment. [2] PRE-INI = Price of initial diets. PRE-FIN = Price of final diets. PEI = Productive Efficiency Index; FC = Feed Cost; PRODKG = Total Meat Production (kg); PCKG = Production Cost per kg; PRODMQ = Meat Production per m²; PCPSM = Production Cost per m²; REV = Gross Revenue; PRO = Gross Profit; PI = Profitability Index; BE = Break-even point. [3] The means followed by lowercase letters in the lines differ using the Tukey test (p<0.05). not significant = p>0.05. [4] CV = Coefficient of variation. [5] COR = correlation coefficient between the independent variable (GPUM levels) and the dependent variable analyzed. [6] MM = Mathematical model adjusted according to the influence of the independent variable (Guarana pulp meal levels) on the dependent variable.

Additionally, the difference in profitability results also reflects the composition of the by-products. GPUM, with a lower protein content (12.27%) and mineral content (1.01%), lacks some structural benefits provided by GPEM, such as greater metabolic stability and support for intestinal microbiota development (Jiménez-Moreno *et al*., 2019; Sanchez *et al*., 2021; Tejeda & Kim, 2021). This may explain why GPUM's profitability is more affected at extreme inclusion levels, while GPEM maintains positive results due to the broader support provided by its nutritional profile. It is also important to highlight that both options contribute to a more sustainable approach to poultry production, promoting the use of agro-industrial residues and potentially reducing indirect costs (Rufino *et al*., 2015; Costa *et al*., 2018b; Batalha *et al*., 2019; Brelaz *et al*., 2019).

CONCLUSION

he inclusion of guarana by-products (GPEM and GPUM) in diets for slow-growing broilers has proven to be a viable alternative to enhance growth performance and economic feasibility, promoting the sustainable use of agro-industrial residues. GPEM, despite its higher fiber content, delivered better results in feed efficiency and weight gain at higher inclusion levels (up to 10%), while GPUM was more efficient at intermediate levels (7.5%). Both by-products contributed to greater meat production and economic returns compared to the basal diet, with positive impacts varying according to inclusion levels. The results highlight the importance of considering the specific goals of the production system when selecting the most suitable by-product. The use of GPEM is recommended for systems prioritizing feed efficiency and cost-effectiveness, while GPUM appears to be more appropriate for phases that require higher energy intake and weight gain.

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AUTHOR CONTRIBUTIONS

The experimental plan and design were conceived, planned, and developed by A.N.A. Santos, J.P.F., Rufino and A.T. Oliveira. The primary research draft was written by A.N.A. Santos, C.C. Guimarães, J.P.F. Rufino and A.T. Oliveira. A.N.A. Santos, M.F.S. Gomes, J.M. Mendes, J.L. Silva Junior, F.A.L. Chaves and M.A.F. Mendonça prepared materials and methods, collected data and performed laboratory analysis. J.P.F. Rufino and A.T. Oliveira performed statistical analysis and result interpretation. The manuscript was reviewed and edited by all the authors. The ultimate manuscript was read and approved by all the authors.

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DATA AVAILABILITY STATEMENT

The data of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare no competing interests.

REFERENCES

Abdollahi MR, Zaefarian F, Hunt H, *et al.* Wheat particle size, insoluble fibre sources and whole wheat feeding influence gizzard musculature and nutrient utilisation to different extents in broiler chickens. Journal of Animal Physiology and Animal Nutrition 2019;103:146–11. https://doi.org/10.1111/jpn.13019

Ali A, Ponnampalam EN, Pushpakumara G, *et al.* Cinnamon: a natural feed additive for poultry health and production - a review. Animals (Basel) 2021;11:2026. http://doi.org/10.3390/ani11072026

AOAC - Association of Official Agricultural Chemists. Official methods of analysis of AOAC international. 21st ed. Rockville: AOAC; 2019.

Aride PHR, Oliveira AM, Ferreira MS, *et al.* Growth and hematological responses of tambaqui, Colossoma macropomum fed different levels of rice, Oryza spp.. Brazilian Journal of Biology 2020;81:1-7. https://doi.org/10.1590/1519-6984.232560

Aride PHR, Oliveira AM, Baptista RB, *et al.* Changes on physiological parameters of tambaqui (Colossoma macropomum) fed with diets supplemented with Amazonian fruit Camu camu (Myrciaria dubia). Brazilian Journal of Biology 2018;78:360-7. https://doi.org/10.1590/1519-6984.169442

Aride PHR, Oliveira AT, Oliveira AM, *et al.* Growth and hematological responses of tambaqui fed different amounts of cassava (Manihot esculenta). Arquivo Brasileiro de Medicina Veterinária e Zootecnia 2016;68:1697-704. https://doi.org/10.1590/1678-4162-8704

Azizi MN, Loh TC, Foo HL, *et al.* Is palm kernel cake a suitable alternative feed ingredient for poultry? Animals (Basel) 2021;11:338. https://doi.org/10.3390/ani11020338

Batalha OS, Alfaia SS, Cruz FGG, *et al.* Análise econômica da farinha de silagem ácida de resíduos de piracucu em rações de poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2019;12:363-75. https://doi.org/10.17765/2176-9168.2019v12n2p363-375

Brelaz KCBTR, Cruz FGG, Rufino JPF, *et al.* Viabilidade econômica do óleo do resíduo de pescado na alimentação de poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2021;14:e007618. https://doi.org/10.17765/2176-9168.2021v14n1e007618

Chatterjee S, Hadi AS. Regression analysis by example. 4th ed. New Jersey: John Wiley & Sons; 2006.

Cho S, Shi H, Sureshkumar S, *et al.* The effects of the dietary inclusion of by-products obtained after the extraction of vitamin B2 from fermented soybean on the performance and meat quality of growing–finishing pigs. Applied Sciences 2024;14:803. https://doi.org/10.3390/app14020803

Clement CR, Lleras PE, van Leeuwen J. O potencial das palmeiras tropicais do Brasil: acertos e fracassos das últimas décadas. Agrociencias 2005;9(1/2):67-71. Available from: http://www.alice.cnptia.embrapa.br/alice/handle/doc/678989

Costa FGP, Goulart CC, Costa JS, *et al.* Desempenho, qualidade de ovos e análise econômica da produção de poedeiras semipesadas alimentadas com diferentes níveis de raspa de mandioca. Acta Scientiarum. Animal Sciences 2009;31(1):13-8. https://doi.org/10.4025/actascianimsci.v31i1.457

Costa APGC, Cruz FGG, Rufino JPF, *et al.* Tucumã meal in diets for broilers on performance, carcass traits and serum biochemical profile. Archivos de Zootecnia 2018a;67:137-42. https://doi.org/10.21071/az.v67i257.3501

Costa APGC, Cruz FGG, Rufino JPF, *et al.* Viabilidade econômica da farinha do resíduo de tucumã na alimentação de frangos de corte. Agropecuária Técnica (UFPB) 2018b;38(4):225-33. https://doi.org/10.25066/agrotec.v38i4.28894

Cruz FGG, Rufino JPF, Melo RD, *et al.* Perfil socioeconômico da avicultura no setor primário do Estado do Amazonas, Brasil. Revista em Agronegócio e Meio Ambiente 2016;9(2):371-91. https://doi.org/10.17765/2176-9168.2016v9n2p371-391

Cruz FGG, Rufino JPF. Formulação e fabricação de rações (Aves, Suínos e Peixes). Manaus: EDUA; 2017.

Cruz FL, Carvalho FP, Marçal JO, *et al.* Fatty acid profile of slow-growing broilers supplemented with biocomplexed minerals. Ciência Rural 2023;53(5):e20210525. https://doi.org/10.1590/0103-8478cr20210525

Dormann CF, Elith J, Bacher S, *et al.* Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 2013;36:27-46. https://doi.org/10.1111/j.1600-0587.2012.07348.x

Espinola EB, Dias RF, Mattei R, *et al.* Pharmacological activity of Guaraná (*Paullinia cupana* Mart) in laboratory animals. Journal of Ethnopharmacology 1997;55:223-9. https://doi.org/10.1016/s0378-8741(96)01506-1

Ferreira FAM, Ferreira BB, Bragança VAN, *et al.* Guaraná (*Paullinia cupana* Kunth), marapuama (Ptychopetalum olacoides Benth.), gentian (Gentiana lutea L.), quassia (Quassia amara L.) and their properties: a brief review. Research, Society and Development 2022;11(2). https://doi.org/10.33448/rsd-v11i2.24592

Furtado DA, Carvalho Junior SB, Lima ISP, *et al.* Desempenho e características de carcaça de aves caipiras alimentadas com feno de erva-sal (Atriplex nummularia lindl.). Revista Caatinga 2011;24:182-91.

González-Alvarado JM, Jimenez-Moreno E, González-Sanchez D, *et al.* Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. Animal Feed Science and Technology 2010;162:37-46. https://doi.org/10.1016/j.anifeedsci.2010.08.010

Jiménez-Moreno E, González-Alvarado JM, Coca-Sinova A, *et al.* Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. Animal Feed Science and Technology 2009;154:93-101. https://doi.org/10.1016/j.anifeedsci.2009.06.020

Jiménez-Moreno E, González-Alvarado JM, Lázaro R, *et al.* Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. Poultry Science 2009;88:1925-33. https://doi.org/10.3382/ps.2009-00193

Jiménez-Moreno E, González-Alvarado JM, de Coca-Sinova A, *et al.* Insoluble fiber sources in mash or pellets diets for young broilers. 2. Effects on gastrointestinal tract development and nutrient digestibility. Poultry Science 2019;98(6):2531–47. https://doi.org/10.3382/ps/pey599

Liu CW, Zhou HS, Kim MY, *et al.* Impacts of rapeseed meal, canola meal and their mixture substitute for soybean meal on performance of lactating sows and their offspring. Indian Journal of Animal Research 2018;53:124-8. https://doi.org/10.18805/ijar.B-837

Logan M. Biostatistical design and analysis using R: a practical guide. New Jersey: John Wiley & Sons; 2010.

Lusk JL, Thompson NM, Weimer SL. The cost and market impacts of slow-growth broilers. Journal of Agricultural and Resource Economics 2019;44(3):536-50. https://doi.org/10.22004/ag.econ.292330

Machado NJB, Lima CAR, Brasil RJM, *et al.* Digestible threonine for slow-growing broilers: performance, carcass characteristics, intestinal mucin, and duodenal morphometry. Revista Brasileira de Zootecnia 2018;47:e20170193. https://doi.org/10.1590/rbz4720170193

Machado ALN, Alves JR, Lima HJD, *et al.* Barley residue levels in the diet of Label Rouge broilers. Revista Acadêmica Ciência Animal 2022;20:e20002. https://doi.org/10.7213/acad.2022.20002

Marques LLM, Panizzon GP, Aguiar BAA, *et al.* Guaraná (*Paullinia cupana*) seeds: Selective supercritical extraction of phenolic compounds. Food Chemistry 2016;212:703-11. https://doi.org/10.1016/j.foodchem.2016.06.028

Mateos GG, Jiménez-Moreno E, Serrano MP, *et al.* Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of Applied Poultry Research 2012;21:156-74. https://doi.org/10.3382/japr.2011-00477

Melo RD, Cruz FGG, Feijó JC, *et al.* Viabilidade econômica da farinha de cará na alimentação de poedeiras comerciais leves. Revista Brasileira de Saúde e Produção Animal 2017;18(2):221-30. https://doi.org/10.1590/S1519-99402017000200001

Mendes AA, Patrício IS. Controles, registros e avaliação do desempenho de frangos de corte. In: Mendes AA, Nääs IA, Macari M. Produção de frangos de corte. Campinas: FACTA; 2004.

Nogueira MA, Cruz FGG, Tanaka ES, *et al.* Suplementação de óleo de dendê (Elaeis guineensis Jaquim) na alimentação de poedeiras leves em clima tropical. Revista Acadêmica Ciência Animal 2014;12(2):103-111.

Oliveira PR, Costa CA, Bem GF, *et al.* Effects of an extract obtained from fruits of Euterpe oleracea Mart. in the components of metabolic syndrome induced in C57BL/6J mice fed a high-fat diet. Journal of Cardiovascular Pharmacology 2010;56(15):619-26. https://doi.org/10.1097/fjc.0b013e3181f78da4

Oliveira DHR. Alternative food for broiler chickens: an overview. Scientific Electronic Archives 2018;11:112-7. https://doi.org/10.36560/1152018691

Pelizer LH, Pontieri MH, Moraes IO. Utilização de resíduos agroindustriais em processos biotecnológicos como perspectiva de redução de impacto ambiental. Journal of Technology Management & Innovation 2007;2(1):118-27. Available from: https://www.jotmi.org/index.php/GT/article/view/art41

Prakash A, Saxena VK, Singh MK. Genetic analysis of residual feed intake, feed conversion ratio and related growth parameters in broiler chicken: a review. World's Poultry Science Journal 2020;76(2):304–17. https://doi.org/10.1080/00439339.2020.1735978

Polese MF, Polese MF, Radael MC, *et al.* Zootechnical parameters of Corn feed particle size in performance, digestibility and rate of passage in juvenile tambaqui Colossoma macropomum. Brazilian Journal of Biology 2022;82:1-13. https://doi.org/10.1590/1519-6984.232612

Pushpakumara DMS, Priyankarage N, Nayananjalie WAD, *et al.* Effect of inclusion of palm (Elaeis guineenses) kernel cake in broiler chicken rations. International Journal of Livestock Research 2017;7:103-9. http://doi.org/10.5455/ijlr.20170201053413

Rostagno HS, Albino LFT, Calderano AA, *et al.* Tabelas brasileiras para aves e suínos: composição dos alimentos e exigências nutricionais. 5th ed. Viçosa: Editora da Universidade Federal de Viçosa; 2024.

Rufino JPF, Cruz FGG, Miller WPM, *et al.* Análise econômica da inclusão de farinha do resíduo de tucumã (Astrocaryum vulgare, Mart) na alimentação de poedeiras comerciais. Revista Brasileira de Saúde e Produção Animal 2015;16(1):1-9. https://doi.org/10.1590/S1519-99402015000100001

Rufino JPF, Cruz FGG, Feijó JC, *et al.* Análise econômica de patos submetidos a diferentes planos nutricionais fásicos e densidades de alojamento. Revista em Agronegócio e Meio Ambiente 2018;11(3):767-81. https://doi.org/10.17765/2176-9168.2018v11n3p767-781

Rufino JPF, Cruz FGG, Brasil RJM, *et al.* Relationship between the level and the action period of fiber in diets to laying hens. Acta Scientiarum.

Animal Sciences 2021;43:e49033. https://doi.org/10.4025/actascianimsci.v43i1.49033

Rufino JPF, Cruz FGG, Oliveira Filho PA, *et al.* Farelo de açaí (Euterpe precatoria) como alimento alternativo em dietas para poedeiras comerciais leves. Revista em Agronegócio e Meio Ambiente 2023;16:e11466. https://doi.org/10.17765/2176-9168.2023v16n4e11466

Sacranie A, Svihus B, Denstadli V, *et al.* The effect of insoluble fiber and intermittent feeding on gizzard development, gut motility, and performance of broiler chickens. Poultry Science 2012;91(3):693–700. https://doi.org/10.3382/ps.2011-01790

Sakomura NK, Rostagno HS. Métodos de pesquisa em nutrição de monogástricos. Jaboticabal: Funep; 2016.

Sanchez J, Barbut S, Patterson R, *et al.* Impact of fiber on growth, plasma, gastrointestinal and excreta attributes in broiler chickens and turkey poults fed corn- or wheat-based diets with or without multienzyme supplement. Poultry Science 2021;100(8):101219. https://doi.org/10.1016/j.psj.2021

Santos ANA, Rufino JPF, Viana AL, *et al.* *Paullinia cupana* peel meal on the growth performance, meat quality, and haematological and serum biochemical parameters of slow-growing broilers. Animal Production Science 2024;64:AN24137. https://doi.org/10.1071/AN24137

Sarica M, Yamak U, Boz M, *et al.* Performance of fast, medium and slow growing broilers in indoor and free-range production systems. South African Journal of Animal Science 2020;49:1127-38. https://doi.org/10.4314/sajas.v49i6.16

Silva EP, Rabello CBV, Dutra Júnior WM, *et al.* Análise econômica da inclusão dos resíduos de goiaba e tomate na ração de poedeiras comerciais. Revista Brasileira de Saúde e Produção Animal 2009;10(4):774-85.

Svihus B. The gizzard: function, influence of diet structure and effects on nutrient availability. World's Poultry Science Journal 2011;67:207-24. https://doi.org/10.1017/S0043933911000249

Tejeda OJ, Kim WK. Effects of fiber type, particle size, and inclusion level on the growth performance, digestive organ growth, intestinal morphology, intestinal viscosity, and gene expression of broilers. Poultry Science 2021;100(10):101397. https://doi.org/10.1016/j.psj.2021.101397

Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 1991;74:3583-97. https://doi.org/10.3168/jds.s0022-0302(91)78551-2

Willems OW, Miller SP, Wood BJ. Aspects of selection for feed efficiency in meat producing poultry. World's Poultry Science Journal 2013;69(1):77–88. https://doi.org/10.1017/S004393391300007X

Wu Y, Huang J, Quan S, *et al.* Light regimen on health and growth of broilers: an update review. Poultry Science 2022;101:101545. https://doi.org/10.1016/j.psj.2021.101545

Yonekura L, Martins CA, Sampaio GR, *et al.* Bioavailability of catechins from guaraná (*Paullinia cupana*) and its effect on antioxidant enzymes and other oxidative stress markers in healthy human subjects. Food & Function 2016;7:2970-8. https://doi.org/10.1039/c6fo00513f

Zampiga M, Calini F, Sirri F. Importance of feed efficiency for sustainable intensification of chicken meat production: implications and role for amino acids, feed enzymes and organic trace minerals. World's Poultry Science Journal 2021;77(3):639–59. https://doi.org/10.1080/00439339.2021.1959277

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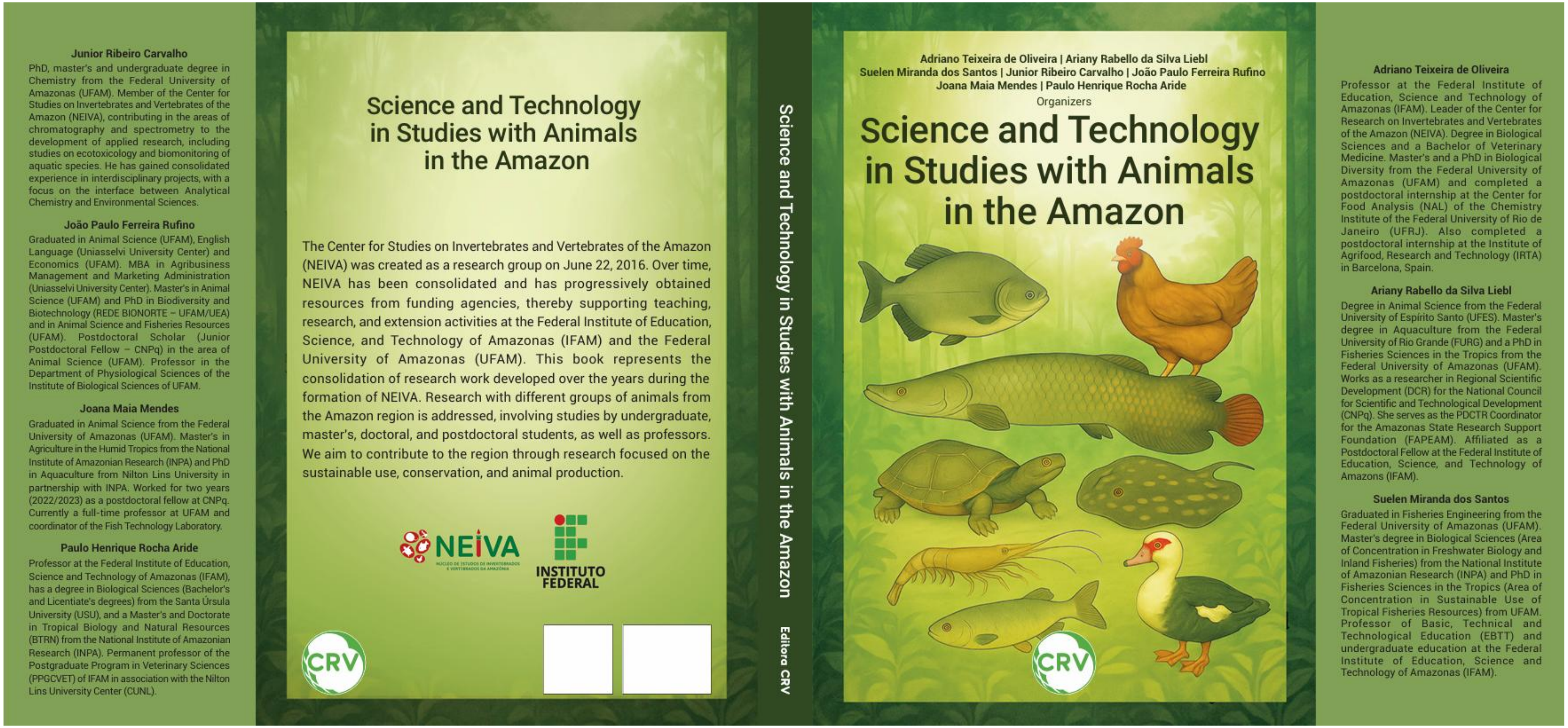

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The production of slow-growing broilers in alternative systems represents only 3% of the Brazilian poultry market, with great growth potential (Del Castilho et al., 2013; Albino et al., 2014). This is not a large-scale practice (Almeida et al., 2013), being closely linked to family farming due to the low required investment, simple management, use of family labor, generation of supplemental income, and the provision of high-quality protein at a low cost (Cruz et al., 2013).

In this context, family farming plays an essential role in food security by preserving traditional knowledge in food production and managing natural resources sustainably. Furthermore, this production model fosters the local economy (FAO, 2014) and contributes to retaining the population in rural areas (Cruz et al., 2013). It generates income for small producers, provides inputs for other crops, utilizes waste from agricultural crops, fruits, and vegetables, and serves consumers who value the origin of the products they consume (Cielo et al., 2019).

The main advantages of this system include easy management and low need for advanced technologies. However, it is crucial that producers adopt basic practices, from animal welfare to food safety, at the end of the chain (Santos et al., 2020). In Brazil, alternative systems of poultry farming began with the regulation of caipira poultry farming through Circular Letter No. 007/99 from the Division of Industrial Operations of the Department of Inspection of Animal-Origin Products, Ministry of Agriculture and Supply (Brazil, 1999).

In these alternative production models, the operation can be either intensive or extensive, without limitations regarding the breeds used (Chagas, 2010). It is divided into two main categories: "backyard free-range" characterized by extensive and minimally technician farming, aimed at self-consumption, with low productivity, lack of reproductive control, and entirely farm-based production cycles, and "commercial free-range", which involves semi-intensive farming with greater specialization and technification, using improved breeds for higher productivity in these systems, with a focus on medium-scale commercialization (Albuquerque; Reis, 2022).

Brief history of domestic poultry

Archaeological studies show that the first domestic poultry (*Gallus gallus domesticus*) appeared in Asia, specifically in China, around 5,400 B.C. (Hirst, 2019). The domestication of these birds began around 3,200

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B.C., with two main purposes: for ornamentation and cockfighting. Birds that did not meet these uses were slaughtered for consumption. In the 16th century, cockfighting became popular in Europe, and breeders became very demanding regarding the strength and aggressiveness of the birds. With the banning of cockfighting in the 19th century, Europeans sought new ways to value these birds, leading to exhibitions that awarded the most attractive birds in terms of plumage, size, and the shape of combs and wattles. This period marked the beginning of the interest in exploiting these birds and, eventually, the development of poultry production (Gessulli, 1999).

Redneck birds, originating from various parts of the world, were introduced to Brazil during the period of discovery (Embrapa, 2007). These birds were raised freely around houses and fed primarily on food scraps and insects (Barbosa et al., 2007; Chagas, 2010). For centuries, these birds played a significant role in Brazilian rural culture, accompanying the evolution of the Brazilian population (Tavares; Ribeiro, 2007; Santana et al., 2020).

Genetically, domestic poultry originated from four distinct genealogical branches: American, Mediterranean, English, and Asian (Englert, 1998). They descend from up to four main species of wild fowl (Jungle Fowl): *Gallus sonnerati* (Grey Jungle Fowl), *Gallus gallus* (Red Jungle Fowl), *Gallus lafayettei* (Ceylon Jungle Fowl), and *Gallus varius* (Green Jungle Fowl) (Moiseyeva et al., 2003).

Phylogenetic research indicates that the Red Jungle Fowl, originating from Southeast Asia, appears to be the closest ancestral species to modern poultry (Tixier-Boichard et al., 2011). Through various crossbreeding, including inbreeding, current poultry maintain similarities with the main ancestral breeds, reflected in their plumage, build and abilities (Barbosa, 2007).

In Brazil, native poultry breeds are limited to small groups in backyard farms. This scenario is primarily the result of the replacement of these breeds by specialized industrial breeds, which occurred during the expansion of industrial poultry farming in the country, especially from the 1970s onwards (Moiseyeva et al., 2003; Barbosa et al., 2007; Tavares; Ribeiro, 2007). Redneck breeds are known for their slow growth, being slaughtered at around two to six months, and when directed for laying, producing about 180 eggs per cycle (Figueiredo et al., 2008). They also stand out for their high adaptability to different regions and climates of Brazil and being less susceptible to diseases (Carvalho et al., 2020).

Main breeds or strains

Before addressing the main redneck breeds or strains, it is essential to clarify the difference between breeds and strains, with strains referring to the result of crossbreeding between two breeds or varieties. Redneck strains are known for their hardiness and for having higher productivity rates compared to traditional redneck breeds. However, they grow slower than commercial strains (Figueiredo et al., 2008). On the other hand, redneck breeds were developed to better adapt to redneck rearing systems, aiming to increase production and offer consumers products with specific characteristics in terms of taste and meat quality (Galvão Junior et al., 2010).

For an entrepreneur in the poultry sector, the main concern when starting the business is to choose the breed or strain that best suits the type of poultry farming they wish to implement. This choice is not simple, as there are many options, each with its own advantages and disadvantages. The decision should consider the available infrastructure, financial resources, available labor, the type of marketing of products and by-products, and, eventually, the option of subsistence farming (Embrapa, 2007).

The main redneck or colonial breeds, as described by Cavalcanti (2019), are:

- **Gigante Negro de Jersey (Jersey Black Giant)**

The breed developed in New Jersey around the 1800s was created to meet the high demand for heavy chickens for broiler production destined for the New York market. There are two varieties of this breed, black and white, which are primarily used for meat. These birds are large, have a serrated comb and yellow skin, and produce brown-shelled eggs. The meat tends to have dark pigmentation due to the pigments in the legs that spread to the meat. The plumage is black, and the skin is yellow, with dual-purpose suitability for meat and eggs. It is the heaviest American breed, but it has some depreciation due to the dark pigmentation in the skin. Adult males weigh an average of 5.902 kg, and females 4.540 kg. The hens produce about 180 eggs in the first laying cycle, with an average weight of 60g.

- **Rhode Island Red**

Originating from the United States, the Rhode Island Red is a medium-sized breed producing meat and eggs. These birds have bright red plumage, a wide, long, deep body, and a medium-sized serrated comb. The body is robust, with brown plumage and black feathers on the tail, neck, and wings. Recently, this variety has been widely used to produce sexable hybrids based on color. The presence of a white or light spot on the wings of male chicks and its absence in female chicks allows for the identification of sexes with an accuracy rate of 80–90% right after hatching. Additionally, by crossing a rooster of this breed (genetically "gold" or non-barred) with hens that are genetically "silver" or barred, it is possible to distinguish the sex of the chicks by the color of their down. Many commercial laying hybrids result from crossbreeding between Rhode Island Red and Barred Plymouth Rock, producing many brown-shelled eggs.

- **New Hampshire**

The New Hampshire breed, also of American origin, is known for its hardiness and light brown plumage. This breed, which has yellow skin and produces brown-shelled eggs, was initially bred for broiler production but was later used in crossbreeding with other meat breeds. Currently, few breeders are still focused on this breed. New Hampshire played an important role in developing modern broiler hybrids due to its ability to produce many eggs with a high hatch rate. Similar to Rhode Island Red, the presence of a white or light spot on the wings of male chicks and its absence in females allows for sex identification with 80–90% accuracy right after hatching. When fully grown, males weigh an average of 3.632 kg and females 2.951 kg. The hens produce an average of 220 eggs in the first laying cycle, weighing 55g.

- **Plymouth Rock Barred**

The birds of this variety have feathers with white and black crossbars, giving them a gray appearance. The barred gene, which is sex-linked, influences the dosage of melanin, resulting in visual differences between males and females. Additionally, the black pigmentation on the females' toes ends abruptly, leaving the tip of each toe yellow. In contrast, the males have more irregular white spots on their heads and a less contrasting transition in the black color of their feet. These color pattern differences between the sexes vary among the breed's lines, requiring adjustments for accurate chick sexing. With the growing preference for white-shelled eggs, the popularity of this breed has declined. It is currently more commonly used as a female line in crossbreeding with Rhode Island Red roosters to produce autosexing chicks that, when grown, produce brown-shelled eggs. This type of crossbreeding has increased the breed's popularity.

- **Sussex**

Sussex is an English breed predominantly dual-purpose. It has a serrated comb, white skin, and brown-shelled eggs. The varieties include speckled, red, and white (light), with Light Sussex being the most popular. This breed is a good meat producer. In some European countries, white-skinned chickens are preferred. When fully grown, males weigh an average of 4.086 kg and females 3.178 kg. The hens produce an average of 180 eggs in the first laying cycle, weighing 55g.

- **Orpington**

Developed in England in the 1880s, the Orpington breed serves dual purposes (meat and eggs). It comes in black, yellow, white and blue varieties. These birds have a serrated comb, white skin, and brown-shelled eggs. When fully grown, males weigh an average of 4.540 kg and females 3.632 kg. The hens produce an average of 160 brown-shelled eggs, with an average weight of 55g.

- **Cornish**

The Cornish is an English meat breed with red, black, yellow and white varieties. It has a pea comb and yellow skin and produces brown-shelled eggs. It has a body structure different from other breeds, with shorter legs and a muscular chest. The meat production capabilities are highly valued in this breed, and it is commonly used in crossbreeding with hens of breeds such as Plymouth Rock Barred, Plymouth Rock White, New Hampshire, and hybrid lines. However, it produces few eggs, which are small in size and have low hatchability. When fully grown, males weigh an average of 4.086 kg and females 3.178 kg. The hens produce an average of 80 eggs in the first laying cycle, weighing 50g.

For the production of redneck broilers, the following lines are available on the market:

- **Caipira Pescoço Pelado (Naked neck redneck)**

This strain consists of hardy, easy-to-manage birds with red plumage and bare necks. The colors of the birds can vary between red, white, black, or brindle. They are ready for slaughter between 60 and 70 days of age, and the hens reach sexual maturity between 22 and 25 weeks, producing about 150 to 180 eggs per year. The egg production is relatively low, indicating that this line mainly focuses on meat production. Desired targets: weight of 1.90 kg at 63 days of age, with a feed consumption of 4.42 kg.

- **Caipira Pesadão (Heavy redneck)**

A rustic bird with red plumage and black tail feathers. It has proven productive efficiency and is well-received for sale at local markets. It offers excellent feed conversion and great meat yield after slaughter. The line is known for its good cut yield and weight gain, reaching up to 2.4 kg in around 56-68 days. It has good acceptability, adaptability to environmental conditions, and hardiness. Birds can achieve weights exceeding 4 kg.

- **Caipira Pesadão Misto Label Rouge (Mixed Label Rouge heavy redneck)**

This slow-growing bird is raised exclusively for slaughter, which can occur at 49 days with a weight of 2.00 kg, or at 63 days with a weight of 2.76 kg, consuming 4.10 kg and 6.46 kg of feed, respectively. Fed with balanced feed for broilers and raised outdoors, this line maintains the traditional characteristics of redneck chicken, producing firm and flavorful meat similar to the taste of game meat.

- **Caipira Pesadão Paraíso Pedrês (Paraíso Pedrês heavy caipira)**

Developed through crossbreeding various rustic breeds, this bird can reach 2.00 kg in 50 days or 2.35 kg in 56 days, consuming 4.28 kg and 5.43 kg of feed, respectively.

- **Caipira Colonial EMBRAPA 041 (EMBRAPA 041 colonial redneck)**

These yellow-colored birds are produced from crossbreeding dual-purpose (mixed) breeds. They can be slaughtered at 2.055 kg at 77 days or 2.445 kg at 91 days, consuming 6.202 kg and 7.89 kg of feed, respectively.

Production systems

According to Melo and Voltolini (2019), the rearing systems for these birds include intensive, free-range (or extensive), and semi-extensive (partially free-range or part of the rearing cycle). The region's extensive and semi-extensive systems are the most commonly used for rearing adapted chickens. In the intensive system, the birds are kept in total confinement in closed barns, which is more typical of other regions and larger-scale productions, making it financially unfeasible for family farmers, especially due to local climatic conditions. In family farming, extensive and semi-extensive systems are preferred, where various materials can be used for building fences and poultry facilities, as long as they meet the minimum requirements for proper rearing of the birds.

In Brazil, the legislation for alternative poultry production, free-range, capoeira, or colonial production, is based on Normative Instruction No. 007, dated May 17, 1999 (Brasil 1999), which guides producers who wish to regulate alternative poultry production. According to this norm, some measures must be followed: the producer should not use animal-derived ingredients in the feed, the stocking density should be 7 birds/m^2 in the covered area and at least 1m^2 for 4 or 5 birds in the pasture area. Additionally, the birds must stay in the rearing environment for at least 85 days before slaughter. Organic poultry production must follow Law No. 10.831, published in December 2003, regulated by Decree No. 6.323 of December 27, 2007 (Brasil, 2007).

Within the free-range style poultry rearing systems, we can find the following designations:

- **Green chicken system:** The term "green chicken" generally refers to chickens raised sustainably and ecologically, with an emphasis on animal welfare and environmentally responsible production. These chickens are fed with antibiotic-free and hormone-free feed, often raised outdoors, which allows for more natural and healthy growth. The goal is to offer a high-quality product with better taste and nutritional value while minimizing environmental impact and promoting more sustainable agricultural practices. Green chicken is an increasingly popular choice among consumers concerned with health and sustainability.
- **Free-range system:** The free-range or colonial poultry rearing system is a traditional method that favors rearing in conditions closer to the natural environment. The birds are kept free-range, with access to pasture and natural foods such as insects and grains, supplemented by balanced feed. This system is characterized by simpler and less intensive management, allowing the birds to exhibit natural behaviors, contributing to animal welfare. The result is meat with a distinctive flavor, appreciated texture, and quality, and it is a practice that values local culture and sustainability, often associated with organic production and environmental respect.
- **Organic system:** In the organic production system, the use of antibiotics and growth promoters is prohibited. The diet consists exclusively of grains and vegetables grown organically, meaning without the use of chemical pesticides and fertilizers. For commercialization, the products must have certification from the Ministry of Agriculture, Livestock, and Supply (Mapa) and accreditation from the National Institute of Metrology, Standardization, and Industrial Quality (Inmetro), ensuring that the production process follows organic production standards (Mapa, 2008). To obtain certification, producers must hire a certifying agency approved by Mapa and accredited by Inmetro, characterizing the Certification by Audit System.

There are two more accessible ways for small producers to obtain organic certification:

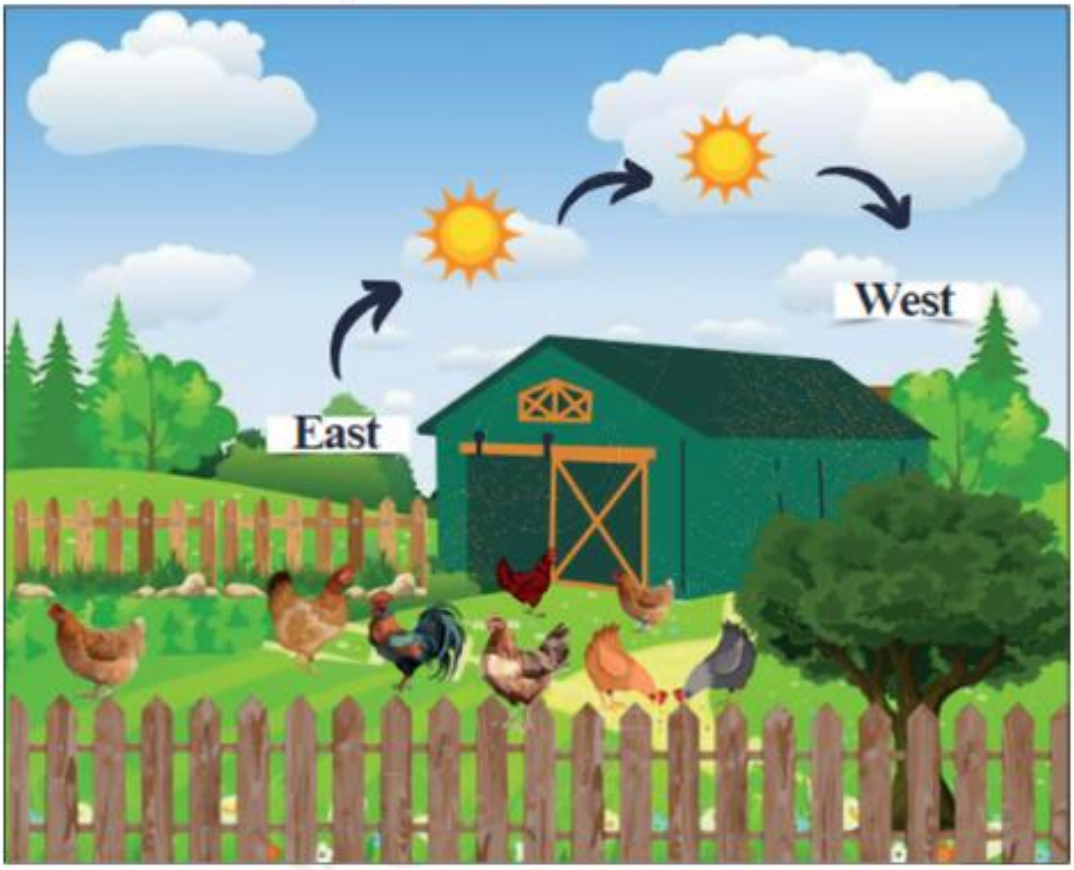
a) **Participatory Guarantee System (SPG):** This system involves collective production, where groups or associations register with MAPA and commit to producing organically, with commercialization restricted to fairs.
b) **Social Control of Direct Sales:** Aimed at family farming, where certification is not mandatory if the producer is associated with a social organization registered with an official inspection body.

General management

To practice poultry farming (Figure 1), the producer needs to invest in appropriate infrastructure to facilitate chicken rearing. According to Barbosa et al. (2007), Chagas (2010), and Raimundo et al. (2018), this involves:

a) **Facilities:** When birds are kept free-range, various problems may arise, but proper facilities can mitigate them. With them, the producer can better control hygiene and sanitation, prevent diseases, protect the birds from predators, and ensure good egg production, all essential factors for successful rearing.
b) **Site selection:** It is recommended that the chicken coop be built close to the producer's house. The site should be dry, well-ventilated, and with minimal slope to avoid water puddles. It is important for the area to have vegetation, such as brushwood, and preferably trees for shading. This vegetation will be a favorable habitat for insects and worms, which will serve as a supplementary protein source for the birds. The ideal orientation for the poultry house is east-west. This way, the sun crosses the building through the highest part of the roof, avoiding an increase in internal temperature during the warmer periods of the year.
c) **Fencing:** To better control the flock, a fence around the chicken coop, with the area depending on the number of birds, is necessary. Inside the fenced area, there should be space for fruit trees or other trees that provide shade and bird protection. Ideally, there should be two separate pens to allow rotation of the birds, facilitate management and periodic cleaning of the unused coop, and allow vegetation to rest.

Figure 1 – Correct orientation for constructing the poultry house in a fenced environment.



d) **Perches:** Perches, where the birds sleep, should be built securely and without risks of injuring the birds' feet, preferably at the back of the coop, which is more isolated. Perch rows should be spaced about 40 cm apart. The height of the perches can vary between 40 and 60 cm from the floor, with a width of 5 cm and a height of 2 cm.

e) **Nests:** It is recommended that nests be made of wood and measure 30 cm in width, height, and depth. They should be placed on wooden stands 50 cm above the floor, with a perch 10 cm from the nest entrance to facilitate bird access. Each nest should accommodate a maximum of four hens and be located in the darker parts of the coop to prevent the birds from staying in the nest when not laying eggs.

f) **Nest bedding:** Corn straw, wood shavings, or dry grass can be used to cover the nests as long as proper hygiene and sanitation are maintained.

g) **Feeders:** Feeders can be made from galvanized sheet metal or PVC pipes four to six inches in diameter, cut longitudinally with end barriers. Alternatively, they can be made from wood, with dimensions of 10 cm in height and 15 cm in width.

h) **Drinkers:** Drinkers can be made like the feeders, using galvanized sheet metal or PVC pipes four to six inches in diameter, cut longitudinally with end barriers. Any other waterproof material can also be used.

i) **Feeding:** The feed should be balanced to meet the birds' nutritional needs. Other types of food can be replaced, depending on the property's availability. It is crucial to follow each step of the poultry management process in family farms to ensure good control of growth and health in the coop, thus achieving the desired results.

REFERENCES

ALBINO, L. F. T.; CARVALHO, B. R.; MAIA, R. C.; BARROS, V. R. S. M. **Galinhas Poedeiras**: Criação e Alimentação. Viçosa, Minas Gerais: Aprenda Fácil, 2014.

ALBUQUERQUE, M. F.; REIS, E. M. B. Viabilidade econômica na produção de frango de corte de crescimento lento em Rio Branco/Acre. **Ciência Animal**, v. 32, n. 4, p. 20-28, 2022.

ALMEIDA, E. C. J.; CARNEIRO, P. L. S.; WENCESLAU, A. A.; FARIAS FILHO, R. V.; MALHADO, C. H. M. Características de carcaça de galinha naturalizada Peloco comparada a linhagens de frango caipira. **Pesquisa Agropecuária Brasileira**, v. 48, n. 11, p. 1517-1523, 2013. DOI: https://doi.org/10.1590/S0100-204X2013001100013

ARAÚJO, W. A. G.; ALBINO, L. F. T.; SAKOMURA, N. K.; PAULINO, P. V. R.; CAMPOS, A. M. Meat quality in "in door" and "out door" production systems of poultry and swine. **Open Journal of Animal Sciences**, v. 1, n. 3, p. 75-88, 2013. DOI: https://doi.org/10.4236/ojas. 2011.13010

BARBOSA, F. J. V.; NASCIMENTO, M. P. S. B.; DINIZ, F. M.; NASCIMENTO, H. T. S.; ARAÚJO NETO, R. B. **Sistema alternativo de criação de galinhas caipiras**. Sistema de Produção. [*S. l.*]: Embrapa, Meio Norte, 2007.

BRASIL. Decreto nº 6.323, de 27 de dezembro de 2007. Regulamenta a Lei nº 10.831, de 23 de dezembro de 2003, que dispõe sobre a agricultura orgânica, e dá outras providências. **Diário Oficial da União**: seção 1, Poder Executivo, Brasília, DF, p. 2, dez. 2007.

BRASIL. Instrução Normativa nº 7, de 17 de maio de 1999. Estabelece as normas de produção, tipificação, processamento, envase, distribuição, identificação e de certificação da qualidade para os produtos orgânicos de origem vegetal e animal. **Diário Oficial da União**: seção 1, Poder Executivo, Brasília, DF, p. 11, 19 maio 1999.

CARVALHO, D. A.; SARMENTO, J. L. R.; ALMEIDA, M. J. Conservação uso e melhoramento de galinhas caipiras. Ponta Grossa, PR: Atena, 2020.

CAVALCANTI, F. A. V. R. **Avicultura caipira**. Natal, RN: Sebrae, 2019.

CHAGAS, J. P. **Galinha Caipira Moderna**: orientações para criação em Porto Velho – RO. Porto Velho: Emater, 2010.

CIELO, I.; ROCHA JÚNIOR, W.; CANEVESI, F. Importância socioeconômica da integração avícola para os produtores da mesorregião oeste do Paraná. **Desenvolvimento em Questão**, v. 17, n 49, p. 329-347, 2019.

CRUZ, F. G. G.; CHAGAS, E. O.; BOTELHO, T. R. P. Avicultura familiar como alternativa de desenvolvimento sustentável em comunidades ribeirinhas do Amazonas. **Interações**, Campo Grande, v. 14, n. 2, p. 197-202, 2013.

DEL CASTILHO, C. C.; SANTOS, T. T.; RODRIGUES, C. A. F.; TORRES FILHO, R. A. Efeitos do sexo e genótipo no desempenho e características de produção de frangos de corte ao ar livre. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 65, n. 5, p. 1483-1490, 2013. DOI: https://doi.org/10.1590/S0102-09352013000500029

DELGADO, G. C.; BERGAMASCO, S. M. P. P. **Agricultura familiar brasileira**: desafios e perspectivas de futuro. [*S. l.*], 2017. Avaliable in: https://www.cfn.org.br/wp-content/uploads/2017/10/Agricultura_Familiar.pdf. Accessed in: 27 jul. 2024.

EMBRAPA – EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Criação de galinhas caipiras**. Brasília, DF: Embrapa Meio Norte, Embrapa Informação Tecnológica, 2007.

ENGLERT, S. I. **Avicultura**: tudo sobre raças, manejo, alimentação e sanidade. Guaíba: Agropecuária, 1998.

FAO – FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. **Ano Internacional da Agricultura Familiar**. Organização das Nações Unidas para a Alimentação e a Agricultura. ONU, 2014. Avaliable in: http://www.fao.org/brasil. Accessed in: 27 jul. 2024.

FIGUEIREDO, E. A. P.; SCHMIDT, G. S.; LEDUR M. C.; ÁVILA, V. S. **Raças e linhagens comerciais de galinhas**. Brasília, DF: Embrapa – Parque de Estação Biológica, 2008.

GALVÃO JUNIOR, G. B.; BENTO, E. F.; SOUZA, A F. **Sistema alternativo de produção de aves** (Cartilha). Panguaçu: IFRN/RN, 2010.

GESSULLI, O. P. **Avicultura Alternativa**: sistema "ecologicamente correto" que busca o bem estar animal e a qualidade do produto final. Porto Feliz: OPG Editores, 1999.

HIRST, K. K. The Domestication History of Chickens (Gallus domesticus). [*S. l.*], 2019. Avaliable in: https://www.thoughtco.com/the-domestication-history-of-chickens-170653. Accessed in: 27 jun. 2024.

MAPA – MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO. **Aves**. Brasília, 2008. Avaliable in: http://www.agricultura.gov.br/animal/especies/aves. Accessed in: 27 jul. 2024.

MELO, R. F.; VOLTOLINI, T. V. **Agricultura familiar dependente de chuva no Semiárido**. Petrolina, PE: Embrapa Semiárido, 2019.

MOISEYEVA, I. G.; ROMANOV, M. N.; NIKIFOROV, A. A.; SEVASTYANOVA, A. A.; SEMYENOVA, S. K. Evolutionary relationships of Red Jungle Fowl and chicken breeds. **Genetics Selection and Evoltion**, v. 35, p. 403, 2003. DOI: https://doi.org/10.1186/1297-9686-35-5-403

RAIMUNDO, E. K. M.; EVANGELISTA, G. M.; PAULINO, R. D.; BELTRÃO, L. G. C.; BARBOSA, L. B.; SILVA, J. R. Exploração da avicultura caipira em regime de economia solidária: uma análise dos problemas e condicionantes ambientais da produção em uma cooperativa da Paraíba. **Cadernos de Agroecologia**, v. 13, n. 1, p. 7-12, 2018.