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Development and characterization of biodegradable films based on banana starch

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Abstract

The objective of this research was to develop and characterize the use of biodegradable films based on banana starch. Green bananas of the Pacovan, Prata, and Prata Anã varieties will be separated into batches and washed in running water to remove dirt and foreign matter. They will then be immersed in a 200 ppm sodium hypochlorite solution for sanitization and manually peeled. Homogenization will be carried out in a 1% ascorbic acid solution at 5 °C, in a ratio of 0.25 kg/liter using an industrial blender with 600 W power for 2 min. The bromatological composition of the three banana varieties (Pacovan, Prata, and Anã) showed significant variations in some parameters. The contents of dry matter, organic matter, ash, crude protein, ether extract, and total carbohydrates did not differ statistically among treatments ($p > .05$), indicating uniformity in these components. Dry matter ranged from 81.80 to 82.39%, while organic matter remained constant at 98.84%. Ash and crude protein contents were similar among the varieties, with average values of 1.17 and 1.58%, respectively. The ether extract showed slight variation, with values between 0.70 and 0.74%. The analysis of the Pacovan, Prata, and Anã banana varieties revealed distinct profiles of bioactive compounds, with statistically significant variations ($p < .05$) among them. These differences highlight the specific nutritional and functional potential of each cultivar. The Prata variety showed a phenolic compound content 255% higher than Pacovan and 30% higher than Anã, indicating strong antioxidant capacity.

Keywords: antioxidant activity; bioactive compounds; climacteric fruits; shelf life extension.

Practical Application: Extends the shelf life of grapes using eco-friendly banana starch films, reducing post-harvest losses.

1 INTRODUCTION

Fruit farming stands out as one of the most dynamic and strategic sectors of Brazilian agribusiness, driving a high-value-added production chain and generating employment and income across various regions of the country. Brazil, endowed with favorable edaphoclimatic conditions, ranks among the world's largest fruit producers. However, this productive prominence contrasts with a still modest participation in the global export market (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020), a paradox largely explained by logistical challenges and post-harvest losses. The high perishability of climacteric and non-climacteric fruits imposes a restricted marketing window, making quality management and shelf life a critical factor for the sector's competitiveness (Vidal, 2021).

In this context, table grapes (*Vitis vinifera L.*), especially the «Itália» cultivar, and bananas (*Musa* spp.) exemplify both the potential and vulnerability of national fruit farming. The «Itália» grape, adapted to technological production hubs such as the São Francisco Valley and regions in São Paulo and Paraná, holds significant economic importance, but its production chain is marked by substantial losses that can occur from the field to the final consumer (Leão, 2021). Similarly, bananas, one of the most consumed foods in Brazil and a pillar of food security (Carvalho et al., 2017), face post-harvest losses that can reach 30%, an alarming rate attributed to mechanical damage, uneven ripening, and especially deterioration caused by phytopathogenic microorganisms (Caldarelli et al., 2009).

The conventional response to extending the shelf life of these fruits has been the use of modified atmosphere packaging, predominantly based on synthetic polymers. Although effective in delaying senescence processes, these materials, derived from non-renewable sources, generate significant environmental

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liabilities. Their low degradation rate and accumulation in landfills and aquatic ecosystems represent a growing contradiction in the face of global demand for sustainability (Doppalapudi et al., 2014). This issue drives the scientific community to seek innovative solutions that combine preservation efficiency with ecological responsibility.

In this scenario, biodegradable edible coatings and films emerge as one of the most promising technologies for food preservation. Formulated from natural polymers such as polysaccharides, proteins, and lipids, these coatings form a thin and imperceptible film on the fruit's surface (Lima, 2021). This semipermeable barrier modulates gas exchange with the environment, reducing respiratory rate and water loss through transpiration, while also serving as a vehicle for antimicrobial and antioxidant agents, inhibiting pathogen proliferation (Dantas et al., 2015; Ortiz et al., 2024).

Among polysaccharides, starch stands out as an ideal raw material due to its abundance, low cost, biodegradability, and excellent film-forming properties (Mali et al., 2010). The exploration of unconventional starch sources, such as green bananas, adds even more value to the technology. Considered a low commercial value residue or by-product, green bananas contain a starch content that can reach 27.2% (Mesquita et al., 2016), representing a sustainable and economically viable source. Previous studies have already confirmed the potential of starch-based coatings from other sources, such as cassava, to delay ripening and preserve banana quality (Costa et al., 2019; Silva et al., 2015), validating the concept's effectiveness.

However, research on the application of biofilms—especially those derived from banana starch on table grapes—is still incipient. The transfer and adaptation of this technology to the «Itália» cultivar could represent a significant advancement, offering a low-cost solution to extend shelf life, reduce the use of synthetic fungicides, and add value to a product of great importance for export. The central hypothesis of this study is that a biofilm based on green banana starch can act as an effective barrier, delaying senescence processes and protecting «Itália» grapes from deterioration, thereby increasing their shelf life. The objective of this research is to develop and characterize the use of biodegradable films based on banana starch.

1.1 Relevance of the work

The relevance of this study lies in its contribution to sustainable post-harvest technologies for fruit preservation. By utilizing starch extracted from green bananas of the Pacovan, Prata, and Anã varieties, the research proposes biodegradable edible films as an eco-friendly alternative to synthetic packaging. These films aim to extend the shelf life of «Itália» grapes, reduce microbial deterioration, and minimize environmental impact. The distinct nutritional and bioactive profiles of each banana variety enhance the functional potential of the coatings. This approach aligns with global demands for sustainability, food safety, and innovation in agribusiness, especially within the Brazilian fruit production chain.

2 MATERIAL AND METHODS

2.1 Origin, harvesting, and transport

Bananas of the Pacovan, Prata, and Prata Anã varieties will be selected from commercial plantations in the municipality of Campina Grande – PB and surrounding areas. The fruits used will be at ripening stage 1, with completely green peel, according to Von Loesecke (1949); preferably, those that do not meet the standards established for commercialization will be used. Harvesting will be done manually in the morning, following good agricultural practices. The fruits will be placed in harvest boxes and transported to the Post-Harvest Physiology Laboratory/ Universidade Federal de Campina Grande (UFCG) for starch extraction and characterization.

2.2 Starch extraction

Green bananas of the Pacovan, Prata, and Prata Anã varieties will be separated into batches and washed in running water to remove dirt and foreign matter. They will then be immersed in a 200 ppm sodium hypochlorite solution for sanitization and manually peeled. Homogenization will be carried out in a 1% ascorbic acid solution at 5 °C, in a ratio of 0.25 kg/liter using an industrial blender with 600 W power for 2 min. The material will then be passed through a 60 mesh sieve (0.250 mm) and allowed to settle for 4 h at 5 °C. After this period, the supernatant will be discarded, and the settled starch will be resuspended in distilled water, passed through a 200 mesh sieve (0.074 mm), and allowed to settle for 12 h at 5 °C. The supernatant will again be discarded, and the obtained starch will be resuspended in distilled water to form a new suspension and centrifuged at 3,000 rpm for 15 min, with the supernatant discarded sequentially. The starch suspension and settling procedures will be carried out in a refrigerated environment.

2.3 Starch drying

Starch drying will be performed using the following methods:

- Drying in an air-circulating oven at 40 °C, with weighing at different time intervals over 24 h. After this procedure, the samples will be ground using a Willey-type knife mill (macro), and the starch will be vacuum-packed and stored under refrigeration for further evaluation (Mesquita et al., 2016).
- Freeze-drying – The starch will be spread on trays and dried in a freeze dryer, model LS 3000, at −45 °C. The obtained starch will be stored in a clean, dry container under refrigeration for further evaluation (Mesquita et al., 2016).

Physicochemical Evaluations

Plant samples were stored in freezers at −10 °C at the Food and Animal Nutrition Laboratory (LANA) of INSA. After this procedure, the samples were thawed, weighed, placed in bags, and pre-dried in an air-circulating oven, model MA035 from

MARCONI, a national company, for 72 h at 55 °C. The samples were ground in a Willey-type knife mill, brand De Leo, model EDB-5, manufactured in Brazil, with a 2-mm sieve, placed in plastic containers, and stored in freezers at –10 °C for laboratory determinations. Procedures were carried out to determine air-dried sample (ASA), oven-dried sample (ASE) and dry matter (DM), mineral matter (MM), crude protein (CP), and ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF) of the plant species, following the methodologies: (Inct – Ca G-001/1), (Inct – Ca G-003/1), (Inct – Ca M-001/1), (Inct – Ca N-001/1), (Inct – Ca G-005/1), (Inct – Ca F-001/1), and (Inct – Ca F-003/1), respectively (Detmann et al., 2012). For NDF determination, adaptations such as the use of alpha-amylase and 8 molar urea were applied (Melo et al., 2006). The organic matter (OM) content was obtained by the difference between organic and MM. For the estimation of non-fibrous carbohydrates (NFC) and total carbohydrates (TCHO), the following equations proposed by Mertens (1997) and Sniffen et al. (1992) were used: NFC = 100 – (%NDF + %CP + %EE + %MM) and TCHO = 100 – (%CP + %EE + %MM).

2.4 Bioactive compounds

The analysis of bioactive compounds and physicochemical parameters was performed according to methodologies previously described in the scientific literature. Total phenolic compounds were determined using the Folin–Ciocalteu method, with gallic acid as the standard. Samples were extracted with methanol and read in a spectrophotometer at 765 nm, according to Cavalcante et al. (2024).

Total chlorophyll, chlorophyll A, and chlorophyll B were quantified by extraction with 80% acetone, followed by spectrophotometric readings at 645 and 663 nm, according to Lichtenthaler and Wellburn (1983). Total carotenoids were extracted with acetone and quantified by spectrophotometry at 470 nm, following the methodology described by Rodriguez-Amaya (2001).

Total flavonoids were determined by complexation with aluminum chloride ($AlCl_3$), with readings at 420 nm, using quercetin as the standard (Shraim et al., 2021). Total anthocyanins were quantified using the pH differential method, with buffers at pH 1.0 and 4.5, and readings at 520 and 700 nm, according to Giusti & Wrolstad (2001). Total sugars were determined by the colorimetric method of DuBois et al. (1956), using phenol and sulfuric acid, with spectrophotometric reading at 490 nm. pH was measured directly using a calibrated potentiometer, according to Association of Official Analytical Chemists standards (AOAC, 2019).

Titratable acidity was determined by titration with 0.1 N NaOH solution, using phenolphthalein as an indicator. Results were expressed as citric acid equivalent, according to AOAC Official Method 942.15. Soluble solids content (°Brix) was obtained by direct refractometry, according to AOAC Official Method 932.14. Vitamin C (ascorbic acid) was quantified by titration with 2,6-dichlorophenolindophenol solution, according to AOAC Official Method 967.21. In specific cases, spectrophotometric reading at 520 nm was used, according to Hoehne and Marmitt (2019).

2.5 Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA). The physicochemical evaluation and bioactive compounds of the starch were compared using Tukey's test ($p < .05$) in relation to the banana variety, with the aid of PROC GLM from SAS OnDemand (SAS Intitute, 2025). The physicochemical composition of the «Itália» grape was analyzed using a 4 x 3 factorial design, consisting of four storage times (0, 7, 14, and 21 days) and three types of biodegradable film (Pacovan, Prata, and Anã banana starch).

3 RESULTS

The bromatological composition of the three banana varieties (Pacovan, Prata, and Anã) showed significant variations in some parameters. The contents of DM, OM, ash, CP, EE, and TCHO did not differ statistically among treatments ($p > .05$), indicating uniformity in these components. DM ranged from 81.80 to 82.39%, while OM remained constant at 98.84%. Ash and CP contents were similar among the varieties, with average values of 1.17 and 1.58%, respectively. The EE showed slight variation, with values between 0.70 and 0.74% (Table 1).

On the other hand, statistically significant differences were observed for NDF, ADF, and NFC. NDF was highest in the Anã variety (5.78%), followed by Prata (4.49%) and Pacovan (3.13%), with $p = .0004$. ADF also showed significant differences ($p =$

Table 1. Physicochemical evaluation of starch from Pacovan, Prata, and Prata Anã bananas.

Variable (%)	Type of banana			SEM	p-value
	Pacovan	Prata	Prata anã		
Dry matter	81.80	82.32	82.39	0.24	.1530
Organic matter	98.84	98.84	98.84	0.005	.6495
Ash	1.17	1.16	1.17	0.005	.6495
Crude protein	1.58	1.57	1.58	0.07	.9963
Ethereal extract	0.70	0.73	0.74	0.01	.2617
Fiber in neutral detergent	3.13c	4.49b	5.78a	0.11	.0004
Fiber in acid detergente	1.14b	1.22[a]	1.26a	0.008	.0092
Non-fibrous carbohydrates	93.44a	92.06b	90.75c	0.05	< .0001
Total carbohydrates	96.57	96.55	96.53	0.07	.8585

SEM: tandard error of the mean; Different letters in the line differ from each other by the Tukey's test.

.0092), being higher in the Anã (1.26%) and Prata (1.22%) varieties compared to Pacovan (1.14%). NFC levels were highest in Pacovan (93.44%), followed by Prata (92.06%) and Anã (90.75%), with a highly significant difference ($p < .0001$) (Table 1).

The analysis of the Pacovan, Prata, and Anã banana varieties revealed distinct profiles of bioactive compounds, with statistically significant variations ($p < 0.05$) among them (Table 2). These differences highlight the specific nutritional and functional potential of each cultivar. The Prata variety showed a phenolic compound content 255% higher than Pacovan and 30% higher than Anã, indicating strong antioxidant capacity.

In contrast, Pacovan and Prata presented similar levels of total chlorophyll, both more than 560% higher than Anã, which may be related to the ripening stage or specific physiological characteristics. The Anã variety stood out for its higher levels of chlorophylls A and B (up to 56% higher), carotenoids (170% higher than Prata), anthocyanins (almost 90% higher than Pacovan), and vitamin C (about 9% higher than the others).

Regarding physicochemical characteristics, the more acidic pH and higher titratable acidity of Prata suggest a more intense flavor and greater preservation potential. The °Brix was also 130% higher in this variety compared to Pacovan, indicating a higher sugar concentration and more advanced ripening.

4 DISCUSSION

The bananas showed an average value of 82.17% DM, 98.84% OM, 1.17% ash, 1.58% CP, 0.72% EE, and 96.55% TCHO. The protein content is similar to that reported by Unicamp (2013) for Prata Anã bananas (1.4%), while the carbohydrate levels in the fruit were much higher than those found in that study.

Pires et al. (2014) observed that green banana pulp contained 0.6 ash, 2.4% fiber, 0.32% lipids, 1.45% protein, and 70.3% initial moisture. They also characterized banana flour, which showed 11.4% moisture, 2.17% ash, 0.58% lipids, 0.45% protein, and 84.36% TCHO. Green banana flour from the Nanicão variety with peel contains, on average per 100g of the product, 7.72% moisture, 4.07g protein, 1.36g lipids, and 73.01g carbohydrates (Borges et al., 2009).

According to Juarez-Garcia et al. (2006), green banana flour from the Terra variety contains 7.1% moisture, 4.7% ash, 2.7% lipids, 3.3% protein, 14.5% dietary fiber, and 73.4% total starch. Moraes Neto et al. (1998) found lower average values of 3.3g/100g protein in green banana flour (Musa sapientum) from the Prata variety using solar drying.

Borges (2014) found a moisture value of 7.4g/100g for green banana flour from the same Nanicão variety, used in bakery product formulations. Moisture determination in food is highly important, as water significantly influences characteristics such as appearance, flavor, structure, and susceptibility to microbial spoilage (Brasil, 2001).

When flour has an ash content between 0.66 and 1.35%, it is considered common. To be classified as whole flour, it must have a maximum ash content of 2.0%, all values on a dry basis (Brasil, 2001). Pessoa (2009) observed ash content in banana peel flour of 1.50% for Prata, 1.87% for Pacovan, and 1.58% for Prata Anã. Andrade et al. (2017) produced green Prata banana flour using both peel and pulp and found protein content of 3.0% and ash content of 2.2%.

Sá et al. (2021) reported that green Prata banana flour had 4.19% ash and 5.40% protein. Bezerra et al. (2013), in a previous study with Cavendish bananas, reported protein content of 4.33g/100g, ash of 2.72g/100g, fiber of 15.52g/100g, and starch of 68.42g/100g. This variation in values can be explained by the wide variety of banana cultivars found in Brazil, as well as different planting conditions.

According to Medeiros et al. (2010), green banana flour from the Prata cultivar showed the following chemical composition in g/100g for wet and dry basis: EE, 0.68 and 0.70; CP, 4.50 and 4.73; crude fiber, 1.01 and 1.17; ash, 2.59 and 2.68; carbohydrates, 87.92 and 90.72; starch, 72.72 and 75.20; and caloric value, 373.00 and 385.30 kcal/100g, respectively. Among the main chemical constituents of green banana is resistant starch, which may account for 55–93% of total solids, along with fiber levels that can reach up to 14.5%.

Table 2. Average and standard deviation of the bioactives of three banana varieties.

Bioactives	**Unit of measurement**	**Type of banana**		
		Pacovan	**Prata**	**Prata anã**
Phenolic compounds	mg gallic acid equivalent/100 g	232.29 ± 0.17c	826.42 ± 0.7a	637.89 ± 0.3b
Total chlorophyll	µg/g fresh matter	3913.86 ± 0.5a	3899.00 ± 0.0a	587.02 ± 2.2b
Chlorophyll A	µg/g fresh matter	1.50 ± 0.0b	1.50 ± 0.0b	2.10 ± 0.0a
Chlorophyll B	µg/g fresh matter	2.38 ± 0.0b	2.30 ± 0.0b	3.60 ± 0.0a
Carotenoids	mg/100g fresh matter	0.03 ± 0.3c	0.05 ± 0.0b	0.08 ± 0.0a
Flavonoids	mg catechin equivalent/100g	0.80 ± 0.0c	1.80 ± 0.0a	1.60 ± 0.0b
Anthocyanins	mg cyanidin-3-glycoside/100g	0.09 ± 0.0c	0.14 ± 0.0b	0.17 ± 0.0a
Total sugars	g/100g fresh matter	1.92 ± 0.1b	4.01 ± 0.1a	1.70 ± 0.0b
pH	-	3.13 ± 0.02a	3.03 ± 0.0c	3.08 ± 0.05ab
Titratable acidity	g citric acid/100 g	0.57 ± 0.01c	0.94 ± 0.01a	0.92 ± 0.0b
° Brix (soluble solids)	°Brix (total soluble solids)	0.20 ± 0.05c	0.46 ± 0.5a	0.30 ± 0.0b
Vitamin C	mg ascorbic acid/100g	33.30 ± 0.02b	33.30 ± 0.05b	36.23 ± 0.05a

Different letters in the line differ from each other by the Tukey's test.

The Prata variety showed a phenolic compound content 255% higher than Pacovan and 30% higher than Prata Anã, indicating strong antioxidant capacity. This group of compounds is known for neutralizing free radicals and preventing chronic diseases (Sousa et al., 2011). Additionally, Prata also had the highest levels of flavonoids and total sugars, traits associated with palatability and anti-inflammatory effects.

In contrast, Pacovan and Prata had similar levels of total chlorophyll, both more than 560% higher than Prata Anã, which may be related to the ripening stage or specific physiological traits. Although chlorophyll is more commonly associated with photosynthesis in leaves, its presence in fruits may affect coloration and protection against radiation (Sabino et al., 2014).

Prata Anã stood out for its higher levels of chlorophylls A and B (up to 56% higher), carotenoids (170% higher than Prata), anthocyanins (almost 90% higher than Pacovan), and vitamin C (about 9% higher than the others). These compounds are linked to benefits such as vision protection, immune support, reduction of oxidative damage, and anti-inflammatory properties (Borges et al., 2012; Sabino et al., 2014). This high concentration reinforces the functional appeal of Prata Anã for nutritional formulations aimed at health promotion.

Regarding physicochemical characteristics, the more acidic pH and higher titratable acidity of Prata suggest a more intense flavor and greater preservation potential. The °Brix was also 130% higher in this variety compared to Pacovan, indicating a higher sugar concentration and more advanced ripening—factors that directly influence fruit acceptance (Sousa et al., 2011).

Therefore, the results reveal that Prata has high sweetness and antioxidant potential, making it suitable for direct consumption; Prata Anã presents a more complete functional profile, with emphasis on health-promoting bioactive compounds; and Pacovan, despite having lower levels in several parameters, shows agronomic potential, as evidenced by its high total chlorophyll content.

These particularities can guide the use of different varieties in the food industry, whether for producing purées, flours, nutritional bars, or juices, and contribute to strategies for diversifying and adding value to bananas in the regional market.

5 CONCLUSIONS

The application of biodegradable films made from starch of different banana varieties significantly influenced the physicochemical preservation of «Itália» grapes during shelf life. Films produced with starch from Prata and Anã bananas showed greater effectiveness in maintaining soluble solids and moisture, contributing to the preservation of the fruits' sensory and nutritional quality. On the other hand, Pacovan starch stood out for its retention of vitamin C at more advanced storage stages, although it showed greater loss of sugars and moisture.

REFERENCES

Association of Official Analytical Chemists. (2019). *Official methods of analysis of AOAC International* (21st ed.). AOAC.

Andrade, B. A., Silva, A. P., Oliveira, M. R., & Costa, M. G. (2017). Produção de farinha de banana verde (Musa spp.) para aplicação em pão de trigo integral. *Brazilian Journal of Food Technology*, *21*, Article e2016103. https://doi.org/10.1590/1981-6723.10316

Bezerra, C. V., Amante, E. R., Oliveira, D. C., Rodrigues, A. M. C., & Silva, L. H. M. (2013). Green banana (Musa cavendishii) flour obtained in spouted bed – Effect of drying on physico-chemical, functional and morphological characteristics of the starch. *Industrial Crops and Products*, *41*, 241–249. https://doi.org/10.1016/j.indcrop.2012.04.035

Borges, A. M. (2014). *Caracterização e estabilidade de pré-misturas para bolos à base de farinha de banana verde* [Master's thesis, Universidade Federal de Lavras]. Repositório UFLA. https://repositorio.ufla.br/handle/1/2806

Borges, A. M., Pereira, J., & Lucena, E. M. P. (2009). Caracterização da farinha de banana verde. *Ciência e Tecnologia de Alimentos*, *29*(2), 333–339. https://doi.org/10.1590/S0101-20612009000200015

Borges, C. V., Ramlov, F., Kuhnen, S., Maraschin, M., Amorim, E. P., & Ledo, C. A. S. (2012). *Carotenoides pró-vitamina A em frutos de bananeira*. Embrapa Mandioca e Fruticultura. http://www.alice.cnptia.embrapa.br/alice/handle/doc/943504

Brasil. (2001). *Resolução RDC N°12, de 2 de janeiro de 2001.* Aprova o Regulamento Técnico sobre os padrões microbiológicos para alimentos. Ministério da Saúde. https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2001/res0012_02_01_2001.html

Caldarelli, C. A., Nakamura, C. Y., Okano, W. E., & Ercolin, T. M. (2009, July 26–30). *Logística do mamão formosa: uma análise de modalidade de transporte* [Paper presentation]. 47º Congresso da Sociedade Brasileira de Economia, Administração e Sociologi Rural, Porto Alegre, RS, Brasil.

Carvalho, C., Kist, B. B., Santos, K. E., & Filter, C. F. (2017). *Anuário Brasileiro da Fruticultura*. Editora Gazeta. https://wp.ufpel.edu.br/fruticultura/files/2017/05/PDF-Fruticultura_2017.pdf

Cavalcante, M. A., Borges, W. L., & Souza, T. M. (2024). Compostos fenólicos a partir de vegetais: uma revisão sobre os métodos de quantificação e avaliação das propriedades antioxidante e antimicrobiana. *Peer Review*, *6*(10), 66–89. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1170248/1/ART-2024-93-Compostos-fenolicos-a-partir-de-vegetais.pdf

Costa, M. S., Costa, J. D. S., Gomes, J. P., Figueirêdo Neto, A., Andrade, R. O., & Lima, G. S. (2019). Preservation of bananas coated with cassava starch and pectin. *Revista Agrarian*, *12*(46), 542–549. https://doi.org/10.30612/agrarian.v12i46.8499

Dantas, E. A., Silva, F. L. H., & Costa, M. G. (2015). Caracterização e avaliação das propriedades antioxidantes de filmes biodegradáveis incorporados com polpas de frutas tropicais. *Ciência Rural*, *45*(1), 142–148. https://doi.org/10.1590/0103-8478cr20131342

Detmann, E., Souza, M. A., Valadares Filho, S. C., Queiroz, A. C., Berchielli, T. T., Saliba, E. O. S., Cabral, L. S., Pina, D. S., & Azevedo, J. A. G. (2012). *Métodos para análise de alimentos*. Suprema.

Doppalapudi, S., Jain, A., Khan, W., & Domb, A. J. (2014). Biodegradable polymers—an overview. *Polymers for Advanced Technologies*, *25*(5), 427–435. https://doi.org/10.1002/pat.3305

DuBois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, *28*(3), 350–356. https://doi.org/10.1021/ac60111a017

Giusti, M. M., & Wrolstad, R. E. (2001). Characterization and measurement of anthocyanins by UV-visible spectroscopy. In R. E. Wrolstad (Ed.), *Current protocols in food analytical chemistry* (pp. F1.2.1–F1.2.13). Wiley. https://doi.org/10.1002/0471142913.faf0102s00

Hoehne, L., & Marmitt, L. G. (2019). Métodos para a determinação de vitamina C em diferentes amostras. *Revista Destaques Acadêmicos*, *11*(4), 36–55. http://doi.org/10.22410/issn.2176-3070.v11i4a2019.2280

Instituto Brasileiro de Geografia e Estatística. (2020). *Produção agrícola municipal: culturas temporárias e permanentes*. IBGE. Retrieved November 29, 2025 from https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=766

Juarez-Garcia, E., Agama-Acevedo, E., Sáyago-Ayerdi, S. G., Rodríguez-Ambríz, S. L., & Bello-Pérez, L. A. (2006). Composition, digestibility and application in breadmaking of banana flour. *Plant Foods for Human Nutrition*, *61*(3), 131–137. https://doi.org/10.1007/s11130-006-0020-x

Leão, P. C. S. (2021). *Uva de Mesa: Itália*. Embrapa Semiárido. https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/uva-de-mesa/pre-producao/caracteristicas-da-especie-e-relacoes-com-o-ambiente/cultivares/uvas-finas-de-mesa-com-sementes/italia

Lichtenthaler, H. K., & Wellburn, A. R. (1983). Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochemical Society Transactions*, *11*(5), 591–592. https://doi.org/10.1042/bst0110591

Lima, M. A. C. (2021). *Uva de Mesa: Armazenamento*. Embrapa Semiárido. https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/uva-de-mesa/pos-producao/operacoes-pos-colheita/armazenamento

Mali, S., Grossmann, M. V. E., & Yamashita, F. (2010). Starch films: production, properties and potential of utilization. *Semina: Ciências Agrárias*, *31*(1), 137–156. https://doi.org/10.5433/1679-0359.2010v31n1p137

Medeiros, M. J., Oliveira, P. A. A. C., Souza, J. M. L., Silva, R. F., & Souza, M. L. (2010). Composição química de misturas de farinhas de banana verde com castanha-do-Brasil. *Revista do Instituto Adolfo Lutz*, *69*(3), 396–402.

Melo, A. A. S., Silva, J. H., & Oliveira, A. S. (2006). Desempenho leiteiro de vacas alimentadas com caroço de algodão em dieta à base de palma forrageira. *Pesquisa Agropecuária Brasileira*, *41*(7), 1165–1171. https://doi.org/10.1590/S0100-204X2006000700013

Mertens, D. R. (1997). Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science*, *80*, 1463–1481. https://doi.org/10.3168/jds.S0022-0302(97)76075-2

Mesquita, C. B., Leonel, M., Franco, C. M. L., Leonel, S., Garcia, E L., & Santos, T. P. R. (2016). Characterization of banana starches obtained from cultivars grown in Brazil. *International Journal of Biological Macromolecules*, *89*, 632–639. https://doi.org/10.1016/j.ijbiomac.2016.05.040

Moraes Neto, J. M. A., Cirne, L. E. M. R., Pedroza, J. P., & Silva, M. G. (1998). Componentes químicos da farinha de banana (Musa sp.) obtida por meio de secagem natural. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *2*(3), 316–318. https://doi.org/10.1590/1807-1929/agriambi.v2n3p316-318

Ortiz, T. A., Veloso, D. A., Brogiato, H. L., & Reis, L. C. (2024). Biofilmes: tecnologia na conservação de frutas em prol da segurança alimentar, sustentabilidade ambiental e viabilidade econômica. *Revista Brasileira de Gestão Ambiental e Sustentabilidade*, *11*(28), 961–973. https://doi.org/10.21438/rbgas(2024)112830

Pessoa, T. R. B. (2009). *Avaliação do processo de obtenção de farinha da casca de banana (Musa sapientum) das variedades Prata, Pacovan e Maçã* [Master's thesis, Universidade Federal da Paraíba]. Repositório UFPB. https://repositorio.ufpb.br/jspui/handle/tede/4061

Pires, V. C. F., Silva, F. L. H., & Souza, R. M. S. (2014). Parâmetros de secagem da banana pacovan e caracterização físico-química da farinha de banana verde. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, *9*(1), 197–209.

Rodriguez-Amaya, D. B. (2001). *A guide to carotenoid analysis in foods*. ILSI Press.

Sá, A. A., Silva, M. C., Oliveira, A. P., & Costa, M. G. (2021). Avaliação físico-química e nutricional de farinhas de banana verde com casca elaboradas a partir de variedades distintas. *Brazilian Journal of Food Technology*, *24*, Article e2020020. https://doi.org/10.1590/1981-6723.02020

Sabino, L. B. S., Silva, M. I. M. J., & Borges, A. M. (2014, October 3–7). *Quantificação de bioativos presentes na polpa liofilizada da banana (Musa paradisíaca)* [Paper presentation]. 54º Congresso Brasileiro de Química, Natal, RN, Brazil. https://www.abq.org.br/cbq/2014/trabalhos/10/4590-18733.html

SAS Institute. (2025). *SAS OnDemand for Academics: PROC GLM procedure* [Computer software]. SAS Institute Inc. https://www.sas.com/

Shraim, A. M., Ahmed, T. A., Rahman, M. M., & Hijji, Y. M. (2021). Determination of total flavonoid content by aluminum chloride assay: A critical evaluation. *LWT*, *150*, Article 111932. https://doi.org/10.1016/j.lwt.2021.111932

Silva, A. A., Barbosa Junior, J. L., & Barbosa, M. I. M. J. (2015). Farinha de banana verde como ingrediente funcional em produtos alimentícios. *Ciência Rural*, *45*(12), 2252–2258. https://doi.org/10.1590/0103-8478cr20140908

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. G., & Russell, J. B. (1992). A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *Journal of Animal Science*, *70*(11), 3562–3577. https://doi.org/10.2527/1992.70113562x

Sousa, M. S. B., Vieira, L. M., & Lima, A. (2011). Fenólicos totais e capacidade antioxidante in vitro de resíduos de polpas de frutas tropicais. *Brazilian Journal of Food Technology*, *14*(3), 202–210. https://doi.org/10.4260/BJFT2011140300024

Universidade Estadual de Campinas. (2013). *TBCA: Tabela Brasileira de Composição de Alimentos*. UNICAMP. https://www.tbca.net.br

Vidal, M. F. (2021, June). *Produção comercial de frutas na área de atuação do BNB*. Escritório Técnico de Estudos Econômicos do Nordeste. https://www.bnb.gov.br/s482-dspace/bitstream/123456789/822/1/2021_CDS_168.pdf

Von Loesecke, H. W. (1949). *Bananas: Chemistry, physiology, and technology*. Interscience Publishers.