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Biodegradable Films Made from Green Banana Starch for Post-Harvest Preservation of "Itália" Grapes: Sustainability, Functionality, and Innovation in Brazilian Fruit Farming

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Abstract

Films and coatings have been considered one of the technologies with the potential to increase the shelf life of food, ensuring microbiological quality, and protecting food from the influence of external factors, being a more effective system for preserving food quality and making it more attractive to consumers. The objective of this research is to develop and characterize the use of biodegradable films based on banana starch as a potential coating to increase the post-harvest life of plantains. Green bananas of the Pacovan, Prata, and Prata Anã varieties will be separated into batches and washed in running water to remove dirt and other foreign matter. They will then be immersed in a 200 ppm sodium hypochlorite solution for sanitization and manual peeling. Terra Maranhão plantains from a commercial plantation located in the municipality of Bananeiras will be harvested manually, using good agricultural practices, in the morning at the stage of commercial maturity through visual selection, by observing the light green color of the peel and yellow color of the pulp, discarding fruits that show symptoms of disease and deformity. The fruits will be transported 24 h after harvest in insulated boxes to the Post-Harvest Physiology Laboratory, where they will undergo post-harvest treatments.

Keywords: resistant starch; plantain; freeze-drying; resistance.

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

1 INTRODUCTION

Fruit farming stands out as one of the most dynamic and strategic sectors of Brazilian agribusiness, driving a high-value production chain and generating employment and income across various regions of the country. Brazil, 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 narrow commercialization window, making quality management and shelf life critical factors 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 Brazilian fruit farming. "Itália" grapes, adapted to technological production hubs such as the São Francisco Valley and regions in São Paulo and Paraná, hold significant economic importance but face considerable losses throughout the supply chain, from field to final consumer (Leão, 2021). Similarly, bananas—one of the most consumed foods in Brazil and a pillar of food security (Beling & Filter, 2017)—experience post-harvest losses of up to 30%, a concerning figure attributed to mechanical damage, uneven ripening, and especially deterioration caused by phytopathogenic microorganisms.

The conventional response to extending the shelf life of these fruits has been the use of modified atmosphere packaging, predominantly based on synthetic polymers. While effective in delaying senescence processes, these materials—derived from non-renewable sources—generate significant environmental liabilities. Their low degradation rate and accumulation in landfills and aquatic ecosystems represent a growing contradiction in the face of global sustainability demands (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

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polysaccharides, proteins, and lipids, these coatings form a thin, imperceptible layer on the fruit's surface (Lima, 2021). This semi-permeable barrier modulates gas exchange with the environment, reducing respiration rate and water loss through transpiration, while also serving as a vehicle for antimicrobial and antioxidant agents, inhibiting pathogen proliferation (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). Exploring unconventional sources of starch, such as green bananas, adds further value to this technology. Considered a low-value by-product, green bananas contain starch levels that can reach up to 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), validating the concept's effectiveness.

However, research on the application of biofilms—especially those derived from banana starch—for table grapes remains incipient. Transferring and adapting 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 export relevance. The central hypothesis of this study is that a biofilm made from green banana starch can act as an effective barrier, delaying senescence processes and protecting "Itália" grapes from deterioration, thereby increasing their shelf life.

1.1 Relevance of the work

Topic relevance: This study contributes to the advancement of sustainable post-harvest technologies by proposing biodegradable edible films made from starch extracted from green bananas of the Pacovan, Prata, and Prata Anã varieties. These films offer an eco-friendly alternative to synthetic packaging, aiming to extend the shelf life of "Itália" grapes while reducing microbial deterioration and environmental impact. The distinct nutritional and bioactive profiles of each banana cultivar enhance the functional potential of the coatings, aligning with global demands for sustainability, food safety, and innovation in agribusiness.

2 BIBLIOGRAPHIC REVIEW

2.1 Banana cultivation

Bananas, scientifically known as *Musa* spp., belong to the Musaceae family, while plantains are hybrids of *Musa acuminata* and *Musa balbisiana*. Although bananas originated in Asia, plantain diversity is greater in Africa, especially in the Central and Western regions. Their presence in Latin America likely occurred through the transatlantic slave trade (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2019).

The plant is typical of tropical climates and requires temperatures between 20 and 35 °C, high relative humidity (RH), and well-distributed rainfall for optimal growth and production (Robinson & Saúco, 2010). Although these climatic factors limit production areas, Brazil offers favorable conditions for banana cultivation across most of its territory, with few restrictions. Bananas hold social importance as an affordable energy source and are rich in minerals and vitamins. Their low acidity and soft texture make them suitable for children and the elderly (Sarmento et al., 2012). When green, they are rich in B-complex vitamins (B1, B6), vitamin C, flavonoids, beta-carotenes, and minerals such as calcium, sulfur, phosphorus, potassium, and zinc, along with high levels of resistant starch (RS) (Lima, 2021).

Brazil has a wide variety of banana cultivars. Considering consumer preferences, productivity, disease tolerance, plant size, and resistance to drought and cold, only a few cultivars have commercial agronomic potential. The most widespread cultivars in Brazil include Nanica, Nanicão, and Grande Naine (AAA group), mainly used for export, and Prata, Pacovan, Prata Anã, Maçã, Mysore, Terra, and D'Angola (AAB group). All mentioned cultivars have at least one undesirable trait, such as inadequate plant size or disease susceptibility (Donato et al., 2003).

The main banana varieties cultivated in Brazil are Prata types (Pacovan, Prata Anã, and Prata Comum), Maçã, and Cavendish. The main plantains include Terra Maranhão, D'Angola, and Terrinha (EMBRAPA, 2019). Among the most produced cultivars nationwide, Prata Anã is present in major producing regions and, along with Pacovan and Prata, accounts for over 60% of the planted banana area, especially in the Northeast.

In Brazil, only bananas of the Terra type are considered plantains, commonly known as "banana-da-terra" or "long banana," and are preferably consumed cooked, fried, baked, or as flour. These fruits can reach up to 26 cm in length and weigh up to half a kilogram, with firmer pulp than regular bananas. Most production is concentrated in the Northeast and Midwest (EMBRAPA, 2019). Brazilian production statistics do not differentiate banana types, despite important niche markets for plantains in states like Bahia and Sergipe, making it difficult to quantify their economic impact (Cordeiro & Reinhardt, 2015).

Post-harvest losses in banana cultivation in Brazil can reach up to 42% (Reetz, 2014). Main causes include incorrect harvest timing, inadequate storage and packaging, poor transport conditions, and lack of fruit preservation technologies (Borges & Souza, 2004). Both bananas and plantains are rich in starch, but as bananas ripen, their starch is largely converted into sugars, while plantains retain starch throughout ripening. One way to minimize banana losses is to consume the fruit while still green, in the form of biomass or flour. Green banana biomass, or flour, can be used in various foods such as bread, pasta, mayonnaise, pâtés, and other products, improving nutritional quality and offering physiological benefits. Studies show that green bananas have physiological effects, such as protecting the gastric mucosa due to their high flavonoid content and significant amounts of resistant starch, acting as dietary fiber that improves intestinal transit and supports microbiota formation (Siqueira et al., 2020).

Due to its nutritional and functional potential, green bananas have been widely used, especially in the form of pulp and/or peel flour for making bread, cookies, cakes, snacks, nuggets, pasta (Castelo-Branco et al., 2017; Gomes et al., 2016; Martínez et al., 2019 ; A. A. Silva et al., 2015), and edible coatings (Singh et al., 2017). Bananas are nutritionally important fruits, being energy-rich and containing good levels of vitamin C, potassium, phosphorus, iron, and carbohydrates such as starch and sugars. Table 1 presents the main nutritional values for Prata, Prata Anã, and Pacovan bananas.

Borges (2007) found a moisture content of 7.4 g/100 g in green banana flour from the Nanicão variety, used in bakery product formulations. Moisture determination in food is crucial, as water significantly influences characteristics such as appearance, flavor, structure, and susceptibility to microbial spoilage (Brasil, 2001). According to Medeiros et al. (2010), green banana flour from the Prata cultivar showed the following chemical composition (g/100 g) for wet and dry bases: ether extract, 0.68 and 0.70; crude protein, 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/100 g, respectively. RS is one of the main chemical constituents of green bananas, accounting for 55–93% of total solids, along with fiber content reaching up to 14.5%.

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 with 11.4% moisture, 2.17% ash, 0.58% lipids, 0.45% protein, and 84.36% total carbohydrates. Green banana flour from the Nanicão variety with peel contains, on average per 100 g of product, 7.72% moisture, 4.07 g protein, 1.36 g lipids, and 73.01 g carbohydrates.

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

Table 1. Physicochemical composition of different banana varieties.

Component	Anã	Pacovan	Prata
Moisture (%)	73.8	77.7	71.9
Energy (kcal)	92.0	78.0	98.0
Protein (g)	1.4	1.2	1.3
Lipids (g)	0.1	0.1	0.2
Carbohydrates (g)	23.8	20.3	26.0
Dietary Fiber (g)	1.9	2.0	2.0
Ash (g)	0.8	0.7	0.8
Calcium (mg)	3.0	5.0	8.0
Magnesium (mg)	28.0	30.0	26.0
Manganese (mg)	0.1	0.4	0.4
Phosphorus (mg)	27.0	20.0	22.0
Iron (mg)	0.3	0.4	0.4
Sodium (mg)	Tr	1.0	Tr
Potassium (mg)	376.0	267.0	358.0
Copper (mg)	0.1	0.1	0.1
Zinc (mg)	0.2	0.1	0.1
Thiamine (mg)	Tr	0.1	Tr
Riboflavin (mg)	0.0	0.0	0.0
Pyridoxine (mg)	0.1	0.2	0.1
Niacin (mg)	Tr	Tr	Tr
Vitamin C (mg)	5.9	Tr	21.6

Tr: trace amounts. Adapted from Alves et al. (2025).

2.2 Agronomic and socioeconomic characteristics of plantains

Plantains are fruits very similar to bananas, with thicker peels and a greener appearance, and are commonly marketed as "banana-da-terra." The 'Terra Maranhão' variety stands out for its unique characteristics, combining high productivity, resistance to adverse climatic conditions, and adaptability to different cultivation systems. These traits make it a viable option for both small-scale farmers and large producers, and it is widely cultivated in Brazil and other tropical countries (Morais-Lino et al., 2008).

From an agronomic perspective, "Terra Maranhão" plantains have robust morphological features, such as vigorous pseudostems and well-developed root systems, which provide resistance to lodging and stability in sandy and clay soils. These traits give the plant a superior capacity to withstand strong winds and drought periods—essential for cultivation in semi-arid regions. Additionally, its high resistance to diseases like Black Sigatoka sets it apart from other plantain and banana varieties (Cardoso, 2022).

This variety also presents advantageous phenological traits, such as well-defined reproductive cycles and high yield per hectare. Studies indicate that "Terra Maranhão" can reach an average production of 30 tons per hectare per year, depending on the management practices employed. Such productivity is crucial to meet the growing demand for plantains in domestic and international markets, strengthening the production chain and generating rural employment (Berilli et al., 2022).

Socioeconomically, cultivating "Terra Maranhão" plantains plays an important role in food security and income generation for small farmers. Plantain production is especially significant in regions where other crops are limited by climate or soil quality. Moreover, the versatility of the fruit—consumed baked, fried, or boiled—enhances its market accessibility and demand (Morais-Lino et al., 2008).

The consumer market for plantains, particularly the "Terra Maranhão" variety, has grown significantly in recent years, driven by increased appreciation for regional and healthy foods. In addition to domestic consumption, there is a rising international demand for the fruit, where plantains are considered exotic and nutritious. This trend supports family farming and diversifies Brazilian agricultural exports (Cardoso, 2022).

Another relevant aspect is the cultural importance of "Terra Maranhão" plantains in various Brazilian communities. The fruit is widely used in traditional cuisine, serving as a central ingredient in regional dishes. This cultural connection reinforces the variety's value, promoting its conservation and encouraging sustainable farming practices that preserve biodiversity and traditional agricultural knowledge (Berilli et al., 2022).

The management systems used in cultivating "Terra Maranhão" plantains also significantly impact productivity and sustainability. Practices such as organic fertilization, intercropping, and integrated pest management have shown promising results in reducing costs and increasing production efficiency. Furthermore, modern soil monitoring techniques can optimize water resources and minimize environmental impacts (Orozco, 2021).

The adaptability of the "Terra Maranhão" variety to different cultivation systems and its ability to thrive under adverse conditions make it a strategic ally in combating food insecurity. In low-income regions, cultivating this variety can be a viable solution to increase food availability and improve nutritional quality. Thus, plantains play a crucial role in promoting sustainable rural development (Morais-Lino et al., 2008).

The agronomic and socioeconomic characteristics of "Terra Maranhão" plantains highlight their importance in the Brazilian agricultural context. Their productivity, resilience to climate challenges, market accessibility, and cultural relevance make the variety a strategic choice for farmers and a valuable resource for sustainable development. With efficient management practices and supportive public policies, cultivating this variety can continue to strengthen Brazilian agriculture and preserve its biodiversity (Cardoso, 2022).

2.2.1 Specific needs and challenges of the "Terra Maranhão" variety

The "Terra Maranhão" variety stands out for its adaptability to different climatic and soil conditions, being widely cultivated in tropical and subtropical regions. However, its cultivation and post-harvest management face specific needs and challenges that affect productivity and fruit quality. These include the demand for efficient agronomic practices, pest and disease control, and post-harvest strategies that preserve sensory and nutritional characteristics (Morais-Lino et al., 2008).

Water demand is one of the critical aspects of cultivating "Terra Maranhão." Despite its moderate drought resistance, regular irrigation is necessary to maintain high productivity levels, especially in semi-arid regions. Implementing efficient irrigation systems, such as drip irrigation, can optimize water use and ensure a consistent supply of nutrients to the plants, promoting uniform growth and high-quality fruit formation (Cardoso, 2022).

Proper fertilization is another key factor, as "Terra Maranhão" has high nutrient requirements, especially for potassium and nitrogen, which are essential for fruit development. Nutrient deficiencies can lead to smaller fruit size and reduced yields. Balanced fertilization strategies, combined with the use of organic fertilizers, are fundamental to meeting the plant's nutritional needs without compromising cultivation sustainability (Berilli et al., 2022).

Pest and disease control is a recurring challenge in cultivating this variety, particularly in regions with high humidity, which favors pathogen development. Black Sigatoka, one of the most common banana diseases, can impair leaf development and significantly reduce productivity. Integrated pest management, including natural fungicides and cultural practices such as crop rotation, is essential to mitigate the impact of this disease (Orozco, 2021).

Post-harvest management is another specific challenge, requiring special care to avoid losses due to the rapid ripening rate of "Terra Maranhão." Techniques such as controlled refrigeration and modified atmosphere packaging are necessary to extend shelf life and preserve sensory properties. The absence of these practices can result in significant losses along the supply chain, especially in markets involving long-distance transportation (Cardoso, 2022).

The consumer market also presents challenges for "Terra Maranhão" producers, who must meet demands for fruits with high visual and sensory quality. Uniformity in fruit size and color is a key requirement for market acceptance. This demands rigorous control during cultivation and harvesting, as well as appropriate sorting and packaging practices to maintain competitiveness (Berilli et al., 2022).

Logistics is another crucial factor for the commercial success of "Terra Maranhão." Poor infrastructure in production regions can hinder efficient fruit transportation, leading to quality losses and increased operational costs. Investments in roads, refrigeration systems, and distribution centers are essential to overcome these barriers and improve the economic viability of production (Morais-Lino et al., 2008).

Access to technology and farmer training is also a specific need in cultivating this variety. Many producers rely on traditional practices, which may limit productivity and fruit quality. Training programs and technology transfer initiatives can help implement more modern and sustainable methods, promoting sector professionalization and increased profitability (Orozco, 2021).

The "Terra Maranhão" variety presents needs and challenges that require an integrated approach and tailored strategies to improve cultivation and post-harvest management. From efficient agronomic practices to investments in infrastructure and technology, a collective effort is needed to overcome these difficulties and ensure the sustainability and competitiveness of this variety in national and international markets (Cardoso, 2022).

2.3 "Itália" grape cultivar

The "Itália" grape cultivar exhibits moderate vigor and high fertility starting from the fourth bud, making it suitable for medium pruning (7–8 buds per cane). Its leaves are medium to large, five-lobed, with a narrow lyre-shaped petiolar sinus, sometimes closed, and the underside of the leaves is covered with hairs. The clusters are large, with an average weight of 600 g, cylindrical-conical, elongated, winged, and very compact, which provides good resistance to transport and storage (Leão, 2021).

The berries of the "Itália" grape are large (8–12 g), reaching over 23 mm in diameter, with a greenish-yellow color, oval shape, and fleshy consistency. The flavor is slightly muscat-like, which becomes more pronounced when harvested with total soluble solids above 16°Brix. In semi-arid tropical conditions, the phenological cycle of the "Itália" grape—from pruning to harvest—is approximately 120 days. In these regions, the average productivity is around 40 tons per hectare per year, and can reach up to 50 tons per hectare per year under optimal management conditions (Leão, 2021).

Despite its qualities, the "Itália" cultivar is sensitive to fungal diseases and berry cracking, especially if pruning occurs during the rainy season. This trait is more pronounced in the "Italia Muscat" or "Improved Italia" clone, a natural mutation identified in commercial vineyards in the sub-middle São Francisco Valley. This clone stands out for its larger berry and cluster size and a more intense muscat flavor, which gives it a higher market value compared to the common 'Itália' grape (Leão, 2021). Therefore, the production of "Itália" grapes in Brazil requires careful management and the adoption of technologies that mitigate loss risks, ensuring product quality and competitiveness in both domestic and international markets.

2.4 Waste in the grape production chain

The Brazilian viticulture sector, despite its economic and social relevance, faces significant challenges related to waste throughout the grape production chain. The high rate of post-harvest losses is a constant concern, directly impacting producers' profitability and the sustainability of the system. These losses are complex and multifactorial, resulting from the interaction of biotic and abiotic factors, as well as inadequate management practices (Hoehne & Marmitt , 2019).

According to Hoehne and Marmitt (2019), post-harvest losses in table grapes, such as the "Itália" grape, can be attributed to several causes that occur from harvest to final consumption:

- Water Loss and Wilting: Grape clusters are highly susceptible to water loss through transpiration. Dehydration leads to darkening and drying of the stems, as well as berry wilting, compromising the fruit's appearance and texture. Maintaining adequate RH during storage and transport is crucial to minimize this loss.

- Microbial Deterioration: The development of fungi and bacteria is one of the main causes of post-harvest losses. *Botrytis cinerea* (gray mold) is a major pathogen, causing rot that spreads rapidly through clusters. Additionally, latent infections originating in the field from fungi such as *Alternaria*, *Colletotrichum*, and *Lasiodiplodia* may manifest during storage, leading to fruit deterioration.

- Mechanical Damage: Improper handling during harvest, transport, and packaging operations can cause physical damage to the berries, such as cracking, bruising, and abrasions. These damages not only reduce the fruit's visual quality but also create entry points for pathogenic microorganisms, accelerating deterioration.

- Quality Criteria and Discarding: Consumer market quality standards are increasingly strict. Fruits that do not meet aesthetic or health standards—even if minimally affected—are often discarded. In packing houses, for example, the percentage of losses due to quality criteria can be significant, exceeding losses observed in other stages of the chain.

In addition to post-harvest losses of fresh fruit, the grape processing industry also generates a substantial amount of waste. Pomace and seeds, by-products of winemaking and juice production, can represent up to 20% of the total weight of processed grapes. In Brazil, the fruit processing industry generates about 210 thousand tons of waste annually, of which only a small fraction is effectively utilized. This scenario represents a major waste of biomass rich in bioactive compounds, with potential for valorization in various applications.

Although the "Itália" grape is robust for transport and storage, it is not immune to these losses. Its sensitivity to fungal diseases and berry cracking—especially under high humidity or inadequate management—makes it vulnerable. Rainfall during the pruning period, for instance, can exacerbate these problems, resulting in significant production losses (Leão, 2021).

Reducing waste in the "Itália" grape production chain requires an integrated approach that combines good agricultural practices, post-harvest technologies, and innovative solutions for by-product utilization. Minimizing these losses is essential to increase sector efficiency and ensure the sustainability of grape production in Brazil.

Post-Harvest Preservation of Grapes

Post-harvest preservation of grapes is a fundamental pillar for the sustainability of viticulture, aiming to minimize losses and maintain fruit quality from harvest to final consumption. The implementation of appropriate technologies and storage practices is crucial to extend the shelf life of grapes, especially for table varieties such as "Itália," which are intended for fresh consumption and require high visual and sensory quality (Lima, 2021).

For effective storage, two environmental factors are of paramount importance:

- Temperature: Temperature is the most critical factor in post-harvest preservation of fruits. For table grapes, the ideal storage temperature varies slightly among cultivars but generally ranges between 0 and 2 °C. For seeded grapes like "Itália," the recommended temperature is approximately 2 °C. Temperatures below −1 °C should be avoided, as they may cause chilling injuries and even freezing of berry tissues, irreversibly compromising fruit quality. Maintaining low temperatures slows down fruit metabolism, senescence (aging), and, most importantly, the development of spoilage microorganisms (Lima, 2021).

- Relative Humidity: High RH, ranging from 90 to 95%, is essential to prevent water loss through transpiration. Dehydration is one of the main causes of grape quality depreciation, leading to berry shriveling and stem darkening and drying. Maintaining high RH in the storage environment creates a vapor pressure gradient that minimizes water loss from the fruit, preserving its turgidity and freshness (Lima, 2021).

2.5 Environmental importance of plastic waste in agriculture and the food industry

The increasing use of conventional plastics in sectors such as agriculture and the food industry has triggered a significant environmental crisis, characterized by the accumulation of non-degradable waste in terrestrial and aquatic ecosystems. Due to their durability, these materials remain in the environment for decades, contributing to pollution and causing harm to biodiversity. The adoption of biodegradable films emerges as a practical and sustainable solution capable of mitigating the environmental impacts associated with plastic waste in these sectors (Lima, 2021).

In agriculture, plastics are widely used in practices such as soil covering, greenhouses, and irrigation systems. Although these materials offer benefits in terms of productivity and efficiency, improper disposal results in fragmentation into microplastics, which contaminate the soil and harm plant health and ecosystem organisms. Biodegradable films, by decomposing into natural compounds, eliminate this problem, promoting more sustainable agriculture and reducing dependence on synthetic polymers (Vespucci et al., 2022).

In the context of the food industry, plastics are extensively used in packaging due to their barrier and durability properties. However, their environmental impact has led to increased demand for sustainable alternatives, such as biodegradable films based on biopolymers. These films, produced from starch, proteins, and other renewable materials, not only reduce plastic waste generation but also offer additional functionalities, such as antimicrobial and antioxidant barriers, which extend the shelf life of packaged foods (Cardozo, 2023).

Studies indicate that plastic waste generated by the food industry accounts for a significant portion of the garbage accumulated in landfills and oceans. Replacing these materials with biodegradable films presents dual benefits: it reduces the volume of discarded waste and minimizes the environmental impact associated with their composition. Additionally, biodegradable films have composting potential, returning to the soil as organic matter and promoting nutrient cycling (T. G. Silva et al., 2022).

The production of biodegradable films also reflects technological advances in the use of renewable resources, such as corn starch (*Zea mays* L.). These films possess physical and chemical properties that meet the demands of the food industry, providing barriers against gases and moisture, and are economically viable in regions with high corn production (Table 1). This approach strengthens the sustainability of production chains, avoiding dependence on petroleum-derived polymers (Oliveira, 2023).

Another relevant aspect is the positive social impact of replacing conventional plastics with biodegradable alternatives. The development and implementation of these technologies promote job creation in sectors such as agribusiness and bioprocessing, in addition to encouraging more sustainable agricultural practices. For example, the use of galactomannan extracted from legumes as a base for biodegradable films reinforces the connection between agriculture and innovation (Nascimento, 2019).

The use of plant proteins, such as soy protein isolate, has also gained prominence in the formulation of biodegradable films. These materials offer good mechanical resistance and barrier properties and are biodegradable under natural conditions. The application of proteins in encapsulating films, such as in the case of *Bacillus megaterium*, demonstrates the multifunctional potential of these materials, expanding their relevance across various industrial sectors (Soares et al., 2016).

The integration of biodegradable films into agriculture and the food industry is not merely an alternative practice but a significant advancement in addressing the global environmental crisis. This transition requires a joint effort among researchers, producers, and policymakers to create a favorable environment for innovation and the adoption of these technologies. Encouraging the production of regional biopolymers and implementing regulations that limit the use of conventional plastics are essential steps in this process (Lima, 2021).

Biodegradable films offer a viable and sustainable solution to the challenges posed by plastic waste in agriculture and the food industry. Their ecological and functional properties, combined with the potential for integration into sustainable practices, make these materials indispensable for a transition toward a circular economy. Expanding the use of biodegradable films is a strategic step toward reducing environmental impact and promoting responsible practices in sectors crucial to human development (Vespucci et al., 2022).

2.6 Contributions of biodegradable films to sustainability

Biodegradable films represent a promising alternative to address the environmental challenges caused by the excessive use of conventional plastics. Their production from renewable sources such as starch, proteins, and polysaccharides significantly contributes to reducing dependence on fossil fuels. Moreover, these materials have the ability to decompose under natural conditions, reducing waste accumulation in landfills and ecosystems, reinforcing their role as allies in promoting sustainability (Lima, 2021).

The use of biodegradable films in food and agricultural packaging also supports the transition to a circular economy. Being compostable, these materials can be integrated into the soil’s nutrient cycle, promoting fertility and reducing the need for chemical inputs. This benefit is particularly relevant in agricultural contexts, where plastic waste often causes serious soil contamination and productivity loss (Vespucci et al., 2022).

Another positive impact of biodegradable films is the reduction of greenhouse gas emissions associated with their production and disposal. While synthetic plastics generate significant emissions throughout their life cycle, the biopolymers used in biodegradable films have a lower carbon footprint, especially when sourced locally and from renewable materials such as corn, cassava, and soy. This feature helps mitigate climate change and aligns industrial production with the Sustainable Development Goals (Cardozo, 2023).

Advances in the formulation of biodegradable films have expanded their functionality and applicability, enabling their use across diverse sectors. Materials enriched with antimicrobial and antioxidant compounds have shown effective results in food preservation, reducing waste and extending product shelf life. This functionality not only improves supply chain efficiency but also meets consumer demand for more natural and sustainable solutions (T. G. Silva et al., 2022).

The production of biodegradable films also brings social benefits by enhancing the value of local production chains. Using raw materials such as corn or cassava starch stimulates regional agriculture, generates income for small producers, and strengthens local economies. Furthermore, the development of these technologies encourages job creation in research, innovation, and manufacturing sectors, contributing to sustainable economic development (Oliveira, 2023).

In the industrial sphere, biodegradable films foster innovation and technological diversification, driving the development of materials with unique properties. The application of biopolymers such as galactomannan and plant proteins demonstrates the potential of these materials to replace conventional plastics without compromising functional performance. This transition to more sustainable materials reflects the industry's commitment to environmentally responsible and socially conscious practices (Nascimento, 2019).

The adoption of biodegradable films also promotes environmental awareness among consumers and companies. The growing demand for sustainably packaged products reinforces the need for more responsible practices throughout the production and consumption chain. This cultural shift is essential for building a market that prioritizes sustainability, encouraging the reduction of global environmental impact (Soares et al., 2016).

Although the production cost of biodegradable films is still higher than that of conventional plastics, the environmental and social benefits outweigh the initial economic barriers. Public policies that support the production and use of these materials—such as tax incentives and environmental regulations—can increase large-scale adoption, making biodegradable films an accessible and viable solution for various sectors (Lima, 2021).

Biodegradable films offer significant contributions to sustainability by reducing plastic pollution, promoting regenerative agricultural practices, lowering carbon emissions, and stimulating technological innovation. By integrating these materials into production chains, society takes an important step toward a more sustainable future, where the circular economy and environmental responsibility play central roles in global development (Vespucci et al., 2022).

2.7 Starch-based biofilm

The final product of the photosynthetic process is starch, and its formation occurs due to the combined activity of several enzymes, both in photosynthetically active organelles—where starch serves as a temporary reserve—and in the amyloplasts of storage organs (Geigenberger, 2011). Starch is a polysaccharide primarily composed of amylose (20–30%) and amylopectin (70–80%). Amylose is water-insoluble, which makes starch insoluble, while amylopectin is soluble, allowing starch to swell in aqueous phases and form suspensions that can be used to produce biodegradable films.

RS is physiologically defined as the sum of starch and its degradation products that are not digested in the small intestine of healthy individuals. Thus, this starch fraction behaves similarly to dietary fiber (Ramos et al., 2009). RS is a natural polymer derived from various sources, including unripe bananas, and can be obtained through biomass production processes. Its effectiveness lies in its specific nature, which inhibits the action of gastrointestinal hydrolytic enzymes, allowing it to reach the intestine, where it is fermented by the endogenous intestinal microbiota, acting as a prebiotic (Saad, 2006).

Unfortunately, there are significant limitations to the development of starch-based films, as they exhibit poor tensile properties and high water vapor permeability compared to conventional petroleum-derived films. These characteristics are due to their hydrophilic nature and sensitivity to moisture content, a factor that is difficult to control. However, the possibility of transforming native starch into a thermoplastic material with satisfactory properties has been improved in recent years (Silva, 2016).

RS is one of the main components of green bananas and has characteristics similar to insoluble fibers (prebiotics), such as the ability to increase fecal bulk, stimulate better intestinal function, and help prevent constipation (Navarro et al., 2012). Due to the high amount of RS present in green banana biomass, its use in the development of new products is considered beneficial and of interest for preventing intestinal diseases, as it can be fermented by intestinal bacteria that secrete short-chain fatty acids and essential vitamins that stimulate their growth (Pereira, 2007).

Starch is used in the food, cosmetics, pharmaceutical, paper, textile, and petroleum industries and has also been used as a thermoplastic material in packaging production. According to Mali et al. (2010), although starch has interesting properties, films made exclusively from starch are not very flexible and tend to be brittle. Therefore, the introduction of additives into polymer matrices is necessary.

Green banana flour and starch contain variable levels of amylose (23–35%), depending on the variety (Mesquita et al., 2016), and a higher proportion of amylopectin, which has a different structure compared to corn or potato amylopectin (Zhang & Hamaker, 2012). This is a unique starch in terms of functionality, with potential applications as a thickener and stabilizer in systems requiring viscosity (Zhang & Hamaker, 2012). It shows heat resistance, low retrogradation tendency, and minimal syneresis compared to other starchy sources—an important factor in developing products that need to be stored under refrigeration (Fontes et al., 2017).

The use of starch-based coatings is a new technology based on the formation of biodegradable plastic from thermoplastic starch, which has desirable characteristics for food packaging, including low cost, high efficiency, thin thickness, and the ability to carry antimicrobial and antioxidant compounds (Krotcha & Mulder-Johnston, 1997).

Environmental pollution caused by the uncontrolled disposal of synthetic polymer plastic films is a major global issue. To minimize this problem, biofilms can be used, and starch is one of the materials that can be employed in their formulation, being biodegradable when released into the environment (Henrique et al., 2008). A biofilm is a thin film prepared from biological materials that acts as a barrier to external elements and, consequently, can protect the packaged product from physical and biological damage and extend its shelf life.

Brazilian viticulture has experienced significant growth in recent decades, driven by the diversification of cultivars and expansion into new production regions. Among table grape varieties, the "Itália" grape (*Vitis vinifera* L.) stands out for its economic and social importance, being widely cultivated in various regions of the country, such as the sub-middle São Francisco Valley, Paraná, and São Paulo (Leão, 2021). However, the grape production chain—from harvest to final consumption—is susceptible to considerable losses that affect producers' profitability and product availability in the market (Hoehne & Mamitt, 2019).

These losses are multifactorial, ranging from mechanical damage during handling and transport to deterioration caused by microorganisms and moisture loss. Post-harvest preservation thus becomes a crucial challenge for the wine industry, requiring the implementation of technologies and practices that extend grape shelf life and minimize waste (Lima, 2021).

In this context, the development and application of edible biofilms emerge as an innovative and sustainable solution. Biofilms are thin, transparent coatings applied to the surface of fruits that act as protective barriers, controlling gas exchange, reducing moisture loss, and inhibiting the growth of spoilage microorganisms (Ortiz et al., 2024). This literature review aims to address the main aspects related to the production of "Itália" grapes in Brazil, the causes and impacts of waste in the production chain, storage and preservation technologies and practices, and the potential use of biofilms to protect and extend the shelf life and transportability of grapes, contributing to the sustainability and efficiency of the Brazilian viticulture sector.

The "Itália" grape (*Vitis vinifera* L.), also known as "Pirovano 65," is a table grape cultivar of great importance to Brazilian viticulture. Its introduction into the country and adaptation to different climatic and soil conditions have made it one of the most cultivated varieties, especially in regions with semi-arid tropical climates, such as the sub-middle São Francisco Valley, and in temperate areas such as Marialva (PR) and the regions of Jundiaí, São Miguel Arcanjo, and Jales (SP) (Leão, 2021).

2.8 Economic implications of using biofilms

The application of biofilms in the production chain of "Itália" grapes presents several economic implications that can positively impact producers' profitability and the sector's sustainability. The main economic advantage lies in the reduction of post-harvest losses, which are among the greatest challenges in viticulture. By extending the shelf life of grapes, biofilms minimize fruit waste caused by deterioration, wilting, and mechanical damage, resulting in a greater volume of marketable product and, consequently, increased revenue for producers (Ortiz et al., 2024).

In addition to directly reducing losses, the extended shelf life and transportability provided by biofilms allow grapes to reach more distant markets, expanding commercialization opportunities and access to consumers who demand fresh, high-quality products. This can lead to an increase in the market value of "Itália" grapes, especially during off-season periods or in regions with limited supply (Ortiz et al., 2024).

Another relevant economic aspect is the potential reduction in the need for post-harvest chemical treatments, such as the use of sulfur dioxide (SO_2). Although SO_2 is effective in controlling fungi, its use may raise concerns about residues and affect consumer perception. Biofilms with incorporated antimicrobial agents can offer a more natural and safer alternative, adding value to the product and meeting the growing demand for minimally processed and chemical-free foods (Ortiz et al., 2024).

However, implementing biofilm technology also involves costs. Research and development of effective formulations, acquisition of application equipment, and workforce training are initial investments that must be considered. Cost-benefit analysis is crucial to determine the economic feasibility of large-scale adoption. Studies indicate that, in some cases, cassava starch may be a low-cost option for biofilm formulation, making the technology more accessible (Matheus et al., 2023).

In summary, the use of biofilms in the "Itália" grape production chain has the potential to generate significant economic benefits through loss reduction, market expansion, and product value enhancement. Optimizing formulations and application methods, along with careful cost-benefit analysis, will be essential to drive the adoption of this technology and strengthen the economic sustainability of Brazilian viticulture.

3 CONCLUSIONS

This review highlights the potential of biodegradable films made from banana starch as a sustainable alternative for post-harvest preservation of 'Itália' grapes. The high perishability of this cultivar, combined with significant losses throughout the production chain, reinforces the need for technologies that combine efficiency, food safety, and environmental responsibility.

The use of starch extracted from green banana varieties such as Pacovan, Prata, and Prata Anã offers nutritional and functional advantages, while also contributing to the utilization of agricultural by-products. The Terra Maranhão variety, in turn, stands out for its adaptability and socioeconomic relevance, making it a promising source of raw material for the development of biofilms.

The application of these edible coatings can reduce the use of synthetic fungicides, extend the shelf life of fruits, and add value to national production, especially in tropical and semi-arid regions. Furthermore, it promotes the appreciation of regional cultivars and strengthens family farming, aligning with global demands for innovation, sustainability, and waste reduction.

Therefore, the integration of agronomic knowledge, post-harvest technologies, and the use of natural resources represents a promising path for the advancement of Brazilian fruit farming, with positive impacts on competitiveness, public health, and environmental preservation.

REFERENCES

Alves, A., Menezes, B., Alves, C., Granja, J., Nascimento, V., & Assis, R. (2025). Análise físico-química e composição centesimal da banana verde e banana madura. *Holos Environment*, *25*(1), 1–10. https://doi.org/10.14295/holos.v25i1.12516

Beling, R. R., & Filter, C. F. (Eds.). (2017). *Anuário Brasileiro da Fruticultura 2017*. Editora Gazeta.

Berilli, S. S., Pazinato, M .F., Pirovani, C. H. D., Torrezani, S. P., Pereira, L. L., & Berilli, A. P. C. G. (2022). Aplicação de biofertilizante dirigido ao cacho do plátano Terra Maranhão para ganho de produtividade. *Revista Brasileira de Fruticultura*, *44*(1), Article e-964. https://doi.org/10.1590/0100-29452022964

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. L., & Souza, L. S. (2004). Exigências edafoclimáticas. In A. L. Borges & L. S. Souza (Eds.), *O cultivo da bananeira* (pp. 132–145). Embrapa Mandioca e Fruticultura.

Borges, A. M. (2007). *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

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.

Cardoso, G. V. (2022). *Avaliação e caracterização de genótipos de bananeira dos subgrupos Gros-Michel, Cavendish e Terra* [Doctoral thesis, Universidade Federal do Espírito Santo]. Repositório UFES. http://repositorio.ufes.br/handle/10/15767

Cardozo, M. H. A. L. (2023). A engenharia de bioprocessos na promoção da sustentabilidade: uma análise das produções recentes. *Prospectus*, *2*(1). https://doi.org/10.29327/sustentare-wipis-2023-311985

Castelo-Branco, V. N., Guimarães, J. N., Souza, L., Guedes, M. R., Silva, P. M., Ferrão, L. L., Miyahira, R. F., Guimarães, R. R., Freitas, S. M. L., Reis, M. C., & Zago, L. (2017). The use of green banana (Musa balbisiana) pulp and peel flour as an ingredient for tagliatelle pasta. *Brazilian Journal of Food Technology*, *20*, Article e2016119. https://doi.org/10.1590/1981-6723.11916

Cordeiro, Z. J. M., & Reinhardt, D. H. R. C. (2015). *Pesquisa com banana no Brasil: uma análise retrospectiva com visão de futuro* [Paper presentation]. III Congresso Latinoamericano y del Caribe de Plátanos y Bananos, Corupá, SC, Brazil. http://www.alice.cnptia.embrapa.br/alice/handle/doc/1024121

Costa, M. S., Costa, J. D. S., Gomes, J. P., Figueiredo 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

Donato, S. L. R., Silva, S. O., Passos, A. R., Lima Neto, F. P., & Lima, M. B. (2003). Avaliação de variedades e híbridos de bananeira sob irrigação. *Revista Brasileira de Fruticultura*, *25*(2), 348–351.

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

Empresa Brasileira de Pesquisa Agropecuária. (2019, 2 de fevereiro). *Registradas as primeiras variedades de banana-da-terra do Brasil*. https://www.embrapa.br/busca-de-noticias/-/noticia/41393172/registradas-as-primeiras-variedades-de-banana-da-terra-do-brasil

Fontes, S. M., Cavalcanti, M. T., Candeia, R. A., & Almeida, E. L. (2017). Characterization and study of functional properties of banana starch green variety of Mysore (Musa AAB - Mysore). *Food Science and Technology*, *37*(2), 224–231. https://doi.org/10.1590/1678-457X.18916

Geigenberger, P. (2011). Regulation of starch biosynthesis in response to a fluctuating environment. *Plant Physiology*, *155*(4), 1566–1577. https://doi.org/10.1104/pp.110.170399

Gomes, A. A. B., Ferreira, M. E., & Pimentel, T. C. (2016). Bread with flour obtained from green banana with its peel as partial substitute for wheat flour: physical, chemical and microbiological characteristics and acceptance. *International Food Research Journal*, *23*(5), 2214–2222.

Henrique, C. M., Cereda, M. P., & Sarmento, S. B. S. (2008). Características físicas de filmes biodegradáveis produzidos a partir de amidos modificados de mandioca. *Ciência e Tecnologia de Alimentos*, *28*(1), 231–240. https://doi.org/10.1590/S0101-20612008000100033

Hoehne, L., & Marmitt, L. G. (2019). Métodos para 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). *Levantamento sistemático da produção agrícola*. IBGE. https://ftp.ibge.gov.br/Producao_Agricola/Levantamento_Sistematico_da_Producao_Agricola_%5Bmensal%5D/Fasciculo_Indicadores_IBGE/2020/estProdAgri_202011.pdf

Krochta, J. M., & Mulder-Johnston, C. (1997). Edible and biodegradable polymer films: challenges and opportunities. *Food Technology*, *51*(2), 61–74.

Leão, P. C. S. (2021, 8 de dezembro). *Uva de Mesa: Itália*. Embrapa. 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

Lima, M. A. C. (2021, 8 de dezembro). *Uva de Mesa: Armazenamento*. Embrapa. 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). Filmes de amido: produção, propriedades e potencial de utilização. *Semina: Ciências Agrárias*, *31*(1), 137–156.

Martínez, P., Peña, F., Bello-Pérez, L. A., Núñez-Santiago, C., Yee-Madeira, H., & Velezmoro, C. (2019). Physicochemical, functional and morphological characterization of starches isolated from three native potatoes of the Andean region. *Food Chemistry: X*, *2*, Article 100030. https://doi.org/10.1016/j.fochx.2019.100030

Matheus, J. R. V., Farias, P. M., Satoriva, J. M., Andrade, C. J., & Fai, A. E. C. (2023). Cassava starch films for food packaging: Trends over the last decade and future research. *International Journal of Biological Macromolecules*, *225*, 658–672. https://doi.org/10.1016/j.ijbiomac.2022.11.129

Medeiros, M. J., Oliveira, P. 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 Instituto Adolfo Lutz*, *69*(3), 396–402. https://doi.org/10.53393/rial.2010.v69.32642

Mesquita, C. B., Leonel, M., Franco, C. M. L., Leonel, S. L., 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

Morais-Lino, L. S., Santos-Serejo, J. A., Silva, S. O., Santana, J. R. F., & Kobayashi, A. K. (2008). Cell suspension culture and plant regeneration of a Brazilian plantain, cultivar Terra. *Pesquisa Agropecuária Brasileira*, *43*(10), 1325–1330. https://doi.org/10.1590/S0100-204X2008001000010

Nascimento, J. F. (2019). *Influência do processo da fabricação de propriedades de filmes biodegradáveis à base de galactomanana* [Master's thesis, Universidade Federal da Paraíba]. Repositório UFPB. https://repositorio.ufpb.br/jspui/handle/123456789/20121

Navarro, S. D., Mauro, M. O., & Oliveira, R. J. (2012). O prebiótico amido resistente e suas propriedades funcionais. *Revista Terra & Cultura: Cadernos de Ensino e Pesquisa*, *28*(54), 45–50.

Oliveira, V. C. F. (2023). *Desenvolvimento de filme biodegradável a partir de amido de milho Zea mays L* [Bachelor's thesis, Instituto Federal Goiano] Repositório IFG. https://repositorio.ifg.edu.br/handle/prefix/1667

Orozco, G. A. M. (2021). *Produção de filmes de amido extraído de banana prata verde (Musa sapientum) modificados com plasma DBD em múltiplas etapas* [Master's dissertation, Universidade Federal do Ceará]. Repositório UFC. https://repositorio.ufc.br/handle/riufc/60001

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://revista.ecogestaobrasil.net/v11n28/v11n28a30a.html

Pereira, K. D. (2007). Amido resistente, a última geração no controle de energia e digestão saudável. *Ciência e Tecnologia de Alimentos*, *27*(Suppl. 1), 88–92. https://doi.org/10.1590/S0101-20612007000500016

Pires, V. C. F., Silva, F. L. H., & Souza, R. M. S. (2014). Parâmetros da secagem da banana pacovan e caracterização físico-química da farinha de banana verde. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, *9*(1), 197–209. https://doi.org/10.18378/rvads.v9i1.2577

Ramos, D. P., Leonel, M., & Leonel, S. (2009). Amido resistente em farinhas de banana verde. *Alimentos e Nutrição*, *20*(3), 479–484.

Reetz, E. R. (Ed.). (2014). *Anuário Brasileiro da Fruticultura 2014*. Editora Gazeta.

Robinson, J. C., & Saúco, V. G. (2010). *Bananas and Plantains*. CABI.

Sá, A. A., Gonçalves, M. I. A., Vasconcelos, T. R., Mendes, M. L. M., & Messias, C. M. B. O. (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

Saad, S. M. I. (2006). Probióticos e prebióticos: o estado da arte. *Revista Brasileira de Ciências Farmacêuticas*, *42*(1), 1–16. https://doi.org/10.1590/S1516-93322006000100002

Sarmento, J. D. A., Morais, P. L. D., Almeida, M. L. B., Silva, G. G., Sarmento, D. H. A., & Batalha, S. A. (2012). Qualidade pós-colheita de banana submetida ao cultivo orgânico e convencional. *Revista Brasileira de Produtos Agroindustriais*, *14*(1), 85–93.

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/10.1590/0103-8478cr20140332

Silva, A. M. (2016). *Filmes biodegradáveis de amido contendo compostos ativos encapsulados e nanopartículas: uma revisão* [Undergraduate thesis, Universidade Federal do Rio Grande do Sul]. Repositório Digital UFRGS. http://hdl.handle.net/10183/151218

Silva, T. G., Guerra, I. C., Mesquita, J. A., Hernandes, T., & Takeuchi, K. P. (2022). Desenvolvimento de soluções filmogênicas para a produção de filmes biodegradáveis, comestíveis e com atividade antioxidante: revisão sistemática. *Research, Society and Development*, *11*(7), Article e59511730139. https://doi.org/10.33448/rsd-v11i7.30139

Singh, T. P., Chauhan, G., Agrawal, R. K., Mendiratta, S. K., Kumar, S., Talukder, S., & Singh, P. (2017). Development and process optimization of biodegradable films based on banana (Musa sp.) flour. *Journal of Animal Research*, *7*(4), 733–740. https://doi.org/10.5958/2277-940X.2017.00112.7

Siqueira, L. V., Paetzold, M. G., & Farinña, L. O. (2020, November 9–12). *Desenvolvimento e caracterização de biofilmes à base de biomassa de banana verde* [Paper presentation]. Anais do 8° COSIMP – Congresso de Ciências Farmacêuticas do Mercosul (Online), Brazil. https://www.even3.com.br/anais/8cosimp/287622-desenvolvimento-e-caracterizacao-de-biofilmes-a-base-de-biomassa-de-banana-verde/

Soares, D. S. B., Silva, E. A. N., & Oliveira, T. M. (2016). Aplicação de filmes biodegradáveis de proteínas do soro de leite. *Revista de Agricultura Neotropical*, *3*(3), 1–5. https://doi.org/10.32404/rean.v3i3.1196

Vespucci, I. L., Nunes, M. P. C., Campos, A. J., Soares Júnior, M. S., & Caliari, M. (2022). Filmes biodegradáveis à base de amido para aplicação em pequenas produções de frutas. *Brazilian Journal of Development*, *8*(2), 14413–14427. https://doi.org/10.34117/bjdv8n2-390

Vidal, M. F. (2021). *Produção comercial de frutas na área de atuação do BNB* (Caderno Setorial ETENE, Nº 168). Banco do Nordeste. https://www.bnb.gov.br/s482-dspace/bitstream/123456789/822/1/2021_CDS_168.pdf

Zhang, P., & Hamaker, B. R. (2012). Banana starch structure and digestibility. *Carbohydrate Polymers*, *87*(2), 1552–1558. https://doi.org/10.1016/j.carbpol.2011.09.053