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Active film made from *Psidium guajava* peel and starch for use in food packaging

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Abstract

The disposal of plastic film is a global problem that generates much pollution. The full use of waste from the food industry brings numerous benefits, including sustainable practices. Using films made with natural antioxidants derived from agro-industrial waste is considered an alternative to minimize these impacts. Given this context, this study aimed to develop and characterize films based on guava (*Psidium guajava*) peel flour for active food packaging. The films presented low thickness and solubility in water, proving to be a barrier to water vapor and suitable for maintaining the integrity of foods added to them. Moreover, their elasticity and resistance proved to be moderate and their moisture content is high due to the presence of large amounts of phenolic compounds from guava peel flour (320.58 ± 81.1 mg gallic acid/100 g sample), resulting in clear, slightly greenish-yellow films, which present their best effect as active antioxidant packaging to be applied in alcoholic foods (36 µmol Trolox/g), followed by use in acidic foods (17.2 µmol Trolox/g). This study demonstrated the potential for applying guava residue as a raw material for producing biodegradable films, proposing a purpose for the peel of this fruit.

Keywords: active films; flour of guava peel; antioxidant capacity; phenolic compounds.

Practical Application: Active packaging made from *Psidium guajava* waste improves food preservation via antioxidants.

1 INTRODUCTION

Guava (*Psidium guajava* L.), belonging to the Myrtaceae family, is widely cultivated in South America, Central America, and Asia. It is notable for its nutritional value, bioactive compounds, and pleasant, sweet flavor (de Faria Cardoso et al., 2023; Kumar et al., 2022). In 2022, Brazil dedicated 22,630 hectares to guava cultivation, producing 564,764 tons of fruit (IBGE, 2024). Much of this production is processed into jams and juices, with the peels and seeds becoming the primary waste. An innovative approach involves using guava peel to produce flour, which is then incorporated into biodegradable film formulations for active packaging.

When used in starch and glycerol films, flours derived from fruit and vegetables has been shown to contribute to a natural blend of lipids, proteins, carbohydrates, and fibers, enhancing the film's characteristics, including water vapor permeability and hydrophilicity (Shanbhag et al., 2023). Utilizing renewable polymers for biodegradable film and packaging production offers an eco-friendly alternative to conventional packaging made from petroleum derivatives, which decompose slowly and have significant environmental impacts.

Given this context and that no previous studies have explored the development of films using starch and guava peel flour, this study aimed to develop and characterize films made from glycerol, starch, and guava peel flour, evaluating their potential as active food packaging.

2 MATERIALS AND METHODS

2.1 Materials

This study used ripe guavas, cornstarch (Mika, Brazil), and glycerol (Synth, Brazil). All ingredients were commercially obtained from Barra do Garças (Mato Grosso, Brazil), located at 15°53'59.24"S, 52°15'24"W (318 m).

2.2 Methods

2.2.1 Guava peel flour preparation

A total of 7.5 kg of guavas were sanitized and peeled, yielding 2.25 kg of peels that were subsequently used to produce flour. The peels were dried in a forced-air circulation oven (model 82/480, Lucadema, Brazil) at 40°C for 72 h, then ground in a food processor (CUT.2.5, Metvisa, Brazil), and milled in an analytical mill (IKA-A11, IKA, Brazil) until a flour consistency was achieved. The flour was sifted through a 40-mesh sieve (Bertel, Brazil) and stored in airtight glass containers to ensure uniformity.

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2.2.2 Film preparation by casting

Films were produced via casting. A mixture containing 7 g of starch, 91 mL of distilled water, and 0.5 g of guava peel flour was heated to 80°C for 30 min with stirring (C-MAG HS7, IKA, Brazil) to gelatinize the starch. After increasing the viscosity, 1.5 mL of glycerol was added. Then, 10 mL of the solution was cast in polystyrene Petri dishes and dried in a forced-air oven (400/*ND-300, Nova Ética, Brazil) at 35°C for 24 h, followed by conditioning in desiccators with a saturated sodium bromide solution at 25°C for 48 h before film removal.

2.2.3 Thickness, moisture content, and solubility in water

Film thickness was measured using a digital micrometer (IP40, Digimess, Brazil) with a range of 0–25 mm and a resolution of 0.001 mm. The mean thickness of each film was calculated from 10 random measurements.

Moisture content was determined using the gravimetric method according to Baur and Ensminger (1977). Samples were cut into discs (2 cm in diameter), weighed, and dried at 105°C to a constant weight, and the moisture content was calculated.

The solubility of films in water was determined using the method proposed by Gontard et al. (1992). The 2-cm-wide films were weighed and immersed in 50 mL of distilled water for 24 h at 25°C, and the system was agitated every 8 h. Subsequently, the insoluble material was filtered, dried at 105°C for 24 h, and reweighed.

2.2.4 Water vapor permeability and moisture absorption

The analysis of water vapor permeability followed the ASTM E96 method (ASTM, 2005). Samples were placed in permeation cells (internal diameter: 63 mm; height: 25 mm) containing silica (0% relative humidity [RH]) and were weighed before being positioned in a desiccator with distilled water (100% RH). This test, conducted at 25°C, involved measuring the mass gain at 12-h intervals until a constant weight was achieved. Prior to characterization, all films were conditioned at 5°C and 50% RH for 48 h.

Water absorption was assessed by drying the films at 70 °C for approximately 15 h. Post-drying, films were stored in desiccators for the experiment's duration. Weighing occurred on an analytical balance before films underwent immersion in water at room temperature for predetermined durations. Upon completion of each time interval—1, 3, 5, 7, 10, 15, and 20 min—the films were removed, dried, and weighed. This process was replicated for all samples across the mentioned immersion periods (Ribeiro Sanches et al., 2021b).

2.2.5 Instrumental color analysis and mechanical properties

Color properties were measured using a colorimeter (MiniScan EZ Hunterlab, USA) that had been previously calibrated. The instrument utilized provided black-and-white standards. For analysis, the samples were placed in a 2.5-inch glass sample cup featuring a 1.25-inch port insert, utilizing D65 illuminant and a 10° viewing angle. Six measurements were recorded across different quadrants of each sample. The CIELab scale was employed to measure the following parameters: L* (luminosity), a* (red–green chromaticity coordinate), b* (yellow–blue chromaticity coordinate), h* (hue angle), and C* (color intensity). This method follows the protocol outlined by Ribeiro Sanches et al. (2021a).

The mechanical properties of the films were evaluated using a universal testing machine (model WDW3OE), following the ASTM D882-02 standard method (ASTM, 2002) at a test speed of 1 mm/s. Each sample's mechanical properties were determined based on the average of five measurements. Film samples were cut into 5-mm-wide and 2.2-mm-long strips and conditioned at 25°C and 50% RH for 48 h before testing.

2.2.6 Total phenolic compounds and the release of antioxidants into food simulants

Total phenolic compounds were quantified using the Folin–Ciocalteu spectrophotometric method, as described by Singleton et al. (1999). Initially, 0.1 g of the film was mixed with 10 mL of methanol in a beaker and homogenized using an ultra-turrax for 1 min. The supernatant was then treated with 2.5 mL of a 1:10 diluted Folin–Ciocalteu reagent in water. After a 5-min interval, 2.0 mL of 7.5% (w/v) Na_2CO_3 was added. Two hours later, absorbance at 760 nm was recorded. A calibration curve was prepared using gallic acid as a standard, and results were presented in milligrams of gallic acid equivalents per 100 grams of the sample (mg GAE/100 g).

Three simulant extracts were prepared to mimic different food environments: one representing fatty foods (ethanol:water, 95:5, v/v), another for acidic foods (citric acid:water, 3:97, v/v), and the last one for alcoholic foods (ethanol:water, 10:90, v/v), following the methodology of Re et al. (1999). The ABTS radical was produced by mixing ABTS (7 mmol/L) with potassium persulfate (2.45 mmol/L), allowing the reaction to proceed for 12–16 h at room temperature in darkness. The resulting radical was then diluted with ethanol to achieve an absorbance of 0.7 (± 0.02) at 734 nm. For the assays, 3 mL of the diluted ABTS radical and 30 μL of the extract were combined and incubated for 25 min at 30°C in the dark, and the absorbance was measured at 734 nm. The antioxidant capacity of the samples was assessed using a calibration curve based on Trolox (20–2,500 μmol/L).

2.3 Statistical analyses

All experiments were performed in triplicate, and data were expressed as mean ± standard deviation. The Grubbs test was employed to identify outliers, while the Shapiro–Wilk test checked data normality. Comparisons between means were made using the Kruskal–Wallis test, followed by analyses of variance (ANOVAs) with Tukey's post-hoc test, considering a 5% significance level.

3 RESULTS AND DISCUSSION

3.1 Thickness, moisture content, and solubility in water

The films were thin, with an average thickness of 0.23 ± 0.04 mm, and this thinness can be attributed to the low glycerol concentration (approximately 1%). As Díaz et al. (2019) reported, a film's small thickness indicates a dense structure characterized by increased polymer–polymer interactions and a reduced ability of glycerol to bind water molecules.

The moisture content in the films was recorded at 15 ± 1.27 g/100 g. This high moisture content is due to the FCG's phenolic compounds, which increase free hydroxyl groups, aiding water incorporation during film formation. These values are slightly higher than those found in starch films with jaboticaba peel flour, which varied at 6.40–12.78% (Ribeiro Sanches et al., 2021b). This variation underscores the relationship between a film's moisture content and composition, specifically the levels of hydrophilic components such as proteins and fibers and glycerol's hygroscopicity.

The films exhibited a water solubility of 20.17 ± 8.23%, indicating low solubility, which benefits the maintenance of film integrity in food packaging applications. Hiremani et al. (2020) highlighted that low water solubility is vital for packaging high-moisture products, significantly affecting the shelf life of the goods.

3.2 Water vapor permeability and moisture absorption

The guava film's low water vapor permeability of 0.14 g mm $m^2 h^{-1} kPa^{-1}$ suggests it is a good barrier against water vapor, suitable for storing hygroscopic products. Braga et al. (2018) reported that the soluble pectin content increases with fruit ripening while protopectins decrease. Similarly, Jorge et al. (2023) found that pectins can improve the film structure's homogeneity, rigidity, and uniformity, resulting in more tortuous paths along the polymer matrix, hindering the diffusion of water vapor through the film and consequently reducing its water vapor permeability.

The guava film's moisture absorption varied at 54–58%, indicating hydrophilic behavior with no significant change over 20 min of analysis (Figure 1). This hydrophilicity is likely due to the heat treatment process, which not only removes water molecules but might also encourage cross-link formation between polymer molecules in the film, namely starch and pectin (Lalnunthari et al., 2019).

3.3 Instrumental color analysis and mechanical properties

The color parameters of the guava film and its visual appearance are shown in Figure 2.

The films were uniform, lacking brittle areas or bubbles, although guava peel fibers were visible within the matrix. These films had considerable luminosity (L* = 87.5 ± 1.1), demonstrating a clear color perception. They exhibited low hue (h = 3.52 ± 1.8) and color intensity (C = -0.37 ± 0.06), leaning toward a greenish-yellow coloration, attributed to carotenoids, chlorophyll, and phenolic compounds.

The analysis of the mechanical properties indicated that the film made from guava peel flour demonstrated moderate elasticity and nonlinear behavior, elongating at a break value of 26%. The film's tensile strength was measured at 2.57 MPa, suggesting similarities between this film and the one developed by Rodrigues et al. (2021) from jackfruit (*Artocarpus heterophyllus*) starch, which had a tensile strength of 6.64 MPa and an elongation at break of 26.79%. The authors noted that increased starch concentration, particularly amylose-rich starch, enhances tensile strength.

3.4 Total phenolic compounds and antioxidant capacity

The guava peel flour film contained a significant amount of total phenolic compounds (320.58 ± 81.1 mg gallic acid/100 g of sample), indicating the utility of guava peel as an active packaging material due to its high phenolic content, including vanillic acid, ellagic acid, and various other phenolic acids and flavonoids (Danielski & Shahidi, 2023).

The antioxidant capacity of the films was assessed by analyzing the release of antioxidants in food simulants using the ABTS radical, and the results for the three simulants used are shown in Table 1.

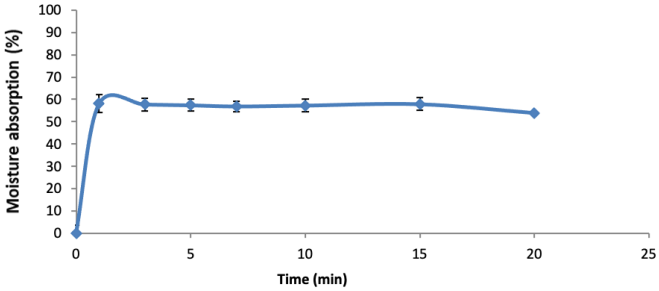

Figure 1. Moisture absorption of the guava film.

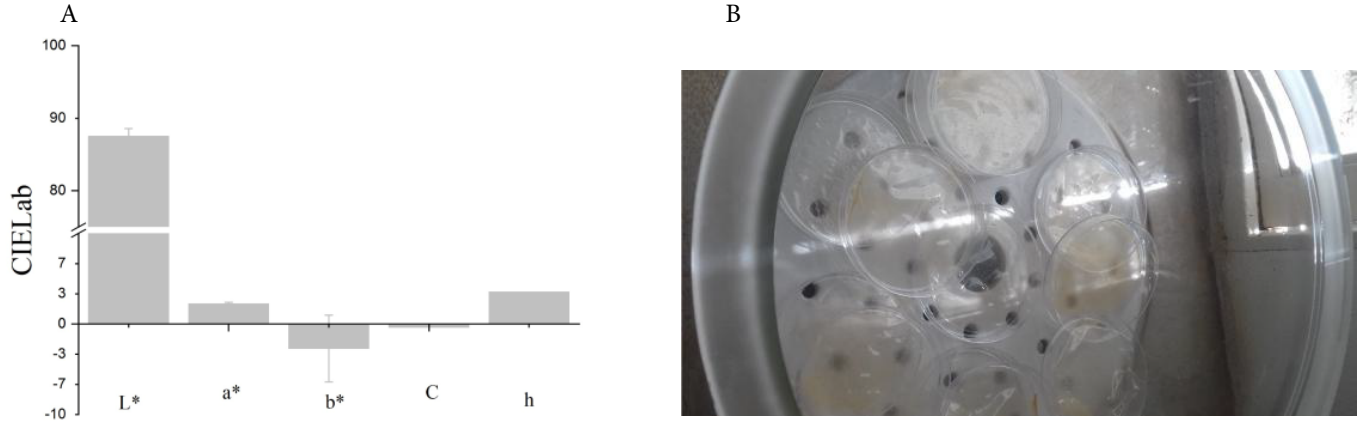

Figure 2. Color parameters (a) and visual appearance (b) of guava films.

Table 1. Analysis of antioxidant release from the guava film in food simulants using the ABTS method.

Food simulant	Concentration (μmol Trolox/g of sample)
Alcoholic	36.0 ± 2.5^{a}
Acidic	17.2 ± 0.1^{b}
Greasy	8.2 ± 0.9^{c}

*Means followed by different letters show a significant difference using Tukey's test ($p < 0.05$).

Phenolic compounds in food simulants are released in two phases. The initial phase is intense and associated with the diffusion of surface phenolic compounds of the film. The subsequent phase is slower, corresponding to the compounds within the film (Benlloch-Tinoco et al., 2025). Films containing guava flour exhibited the highest antioxidant capacity with an alcoholic food simulant (ethanol:water, 10:90), a highly polar simulant. This finding supports analysis results showing the film's affinity for water.

According to Brasil's RDC 51 of 2010 (Brasil, 2010), this simulant is suitable for alcoholic beverages, alcoholic concentrates, and fruits and vegetables processed in an alcoholic medium.

The acidic simulant, the most polar of the three evaluated, was second in antioxidant capacity. Its high polarity hindered the efficient release of phenolic compounds like quercetin, which are more active in less polar solvents (Vinhal et al., 2020).

4 CONCLUSIONS

The films are thin, moderately elastic, and possess tensile strength, with low solubility in water, making them effective water vapor barriers and capable of maintaining integrity when storing food products. The high phenolic compound content in guava peel flour contributes to a clear film with a light greenish-yellow hue and optimal antioxidant capacity. This makes it suitable for alcoholic foods—such as alcoholic beverages, alcoholic concentrates, and fruits and vegetables processed in an alcoholic environment—or acidic foods.

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