Characterization of starch from different non-traditional sources and its application as coating in 'Palmer' mango fruit

Caracterização do amido de diferentes fontes não tradicionais e sua aplicação como revestimento em manga 'Palmer'

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ABSTRACT

Yam, cassava, jackfruit seed and mango seed kernel have potential for the extraction and use as starch in the food industry of starch or for the formulation of biodegradable coatings. As a biodegradable coating, starch can be applied in fruits characterized by a fast maturation, such as mango, which requires technologies to increase its shelf life. The aim of this study was to characterize starch from four non-traditional sources and to evaluate their potential as coating for 'Palmer' mango fruit. Starches used were extracted from cassava, mango seed kernel, jackfruit seed, and yam, and had their physical, optical, and chemical properties characterized for later use as coatings of 'Palmer' mango fruit. Fruits were coated with 3% cassava starch, 3.5% jackfruit seed starch, 3.5% mango seed kernel starch and 3.5% yam starch, and were compared to the control (uncoated). They were then stored at 24.4 ± 0.3 °C and 87 ± 2% RH and evaluated for 12 days. A 5x7 factorial arrangement in a completely randomized experimental design was adopted. Total starch content was higher than 70% in the four sources of starch. Starches from jackfruit and yam had higher amylose content. The four sources of starch had low water solubility and swelling power, with jackfruit seed starch having the highest values. The coating sources were effective in maintaining quality, particularly mango seed kernel starch because it reduced respiratory rate and weight loss in 27.7% and 33.8%, respectively, as well as jackfruit seed starch as it delayed fruit skin yellowing.

Index terms: Amylose; solubility; weight loss; postharvest; respiratory rate; shelf life.

RESUMO

Inhame, mandioca, semente de jaca e amêndoa da manga têm potencial para extração de amido e utilização na indústria alimentícia ou para formulação de revestimentos biodegradáveis. Como revestimento, o amido pode ser aplicado em frutas de maturação rápida, como manga, que requer tecnologias para incrementar sua vida útil. O objetivo desse trabalho foi caracterizar o amido de fontes não tradicionais e avaliar o potencial como revestimento em manga 'Palmer'. Os amidos foram extraídos de mandioca, amêndoa de manga, semente de jaca e inhame, tendo sido caracterizados para propriedades físicas, ópticas e químicas, para posterior uso como revestimentos em manga 'Palmer'. Os revestimentos utilizados foram amido de mandioca a 3%; de semente de jaca a 3,5%; de amêndoa de manga a 3,5% e de inhame a 3,5%, que foram comparados ao controle (sem revestimento). Os frutos foram armazenados a 24,4 ± 0,3 °C e 87 ± 2% de UR e avaliados por até 12 dias. O delineamento experimental foi inteiramente casualizado, em fatorial 5x7. O teor de amido total foi superior a 70% nas quatro fontes. Os amidos de semente de jaca e de inhame apresentaram maior teor de amilose. Os amidos das quatro fontes apresentaram baixa solubilidade em água e poder de inchamento, destacando-se o de semente de jaca. Os revestimentos mantiveram a qualidade dos frutos, destacando-se o amido de amêndoa de manga por reduzir a respiração e a perda de massa em 27,7% e 33,8%, respectivamente, bem como o da semente de jaca que também atrasou o amarelecimento da casca.

Termos para indexação: Amilose; solubilidade; perda de massa; pós-colheita; taxa respiratória; vida útil.

INTRODUCTION

Starch is one of the most abundant polymers in nature and the major reserve source in most plants. It is a low-cost source of energy for human nutrition and can be found in cereals, tubers, roots, seeds, and others (Baldwin; Hagenmaier; Bai, 2011).

The starch molecule is composed mainly of amylose and amylopectin. Amylose is an essentially linear macromolecule formed by D-glucose units linked by α-1,4 bonds with less than 0.1% branching (α-1,6 bonds), and contains 4 to 100 glucose units. Amylopectin is less water soluble than amylose, consisting of D-glucose units linked by α-1,4 and α-1,6 bonds, the latter being responsible for branching the molecule, which has a length of 20 to 30 units of glucose (Caballero; Finglas; Toldrá, 2015).

The major sources for starch extraction are maize, wheat, potatoes, rice and cassava. There are other additional, non-traditional starch sources such as yam, jackfruit seed, and mango seed kernel. They have potential to be used in the food industry as sources of starch for the formulation of films and/or biodegradable coatings (Caballero; Finglas; Toldrá, 2015; Falade; Ayetigbo, 2015; Guimarães et al., 2017; Madruga et al., 2014; Torres-León et al., 2016).

Films and coatings prepared from starch are promising especially due to their low-cost characteristics; they are tasteless, odorless, and colorless; they have low oxygen permeability under conditions of low relative humidity; they are biodegradable; and they are edible (Bonilla et al., 2013). In addition, consumer demand for natural foods that meet high quality and safety criteria has been increasing. This has led companies and researchers to explore different ways of maintaining food quality (mainly the sensory components), freshness, and safety (Espitia et al., 2014).

The use of coatings on fruits provides benefits such as improved appearance and reduced metabolic activity. The coatings of greatest interest are those that have the advantage of non-toxicity and add antimicrobial properties (Pareek, 2016). However, the film deposited on the skin must allow adequate gas exchange between the fruit and the external ambient to avoid fermentation, which results in unpleasant off-flavors (Contreras-Oliva; Rojas-Argudo; Pérez-Gago, 2011).

Mango is a climacteric fruit with rapid ripening, requiring postharvest technologies to increase its shelf life. When harvesting is performed at the beginning of maturation, the shelf life can vary from 8 to 12 days at room temperature, depending on the cultivar. Even with their distribution to several markets, the postharvest technologies adopted are insufficient to allow extended storage periods. The use of coatings may be an alternative and some studies have been conducted for this purpose with mangoes. The primary coatings suggested are made of chitosan, carboxymethylcellulose (CMC), carnauba wax, Arabic gum, and cassava starch (Guimarães et al., 2017; Jongsri et al., 2016; Khaliq et al., 2015). In addition, alternative sources of starch may have great extraction potential, low cost and high availability. These sources should be better studied in order to generate opportunities for improving quality for various fruit production chains, including mango.

Regarding new starch sources and the need for new postharvest technologies such as coatings, the aim of this study was to characterize starch from four non-traditional sources and to evaluate their potential as coating for 'Palmer' mango fruit.

MATERIAL AND METHODS

Starch sources used in this study were cassava, mango seed kernel, jackfruit seed, and yam. 'Pernambucana' cassava and 'São Tomé' yam were purchased in the Petrolina farmers' market (Petrolina, Pernambuco State, Brazil); 'Tommy Atkins' mango seed kernels were donated by Valle Fruit Juice Company, located in Petrolina, and 'Dura' jackfruit seeds were collected in the municipality of Areia, Paraíba State, Brazil. Starches were extracted and analyzed at Embrapa Semiárido in Petrolina, Pernambuco.

Starches were obtained as follows: cassava, yam, jackfruit seeds, and mango seeds kernel were initially peeled, washed, and submerged in a 50 ppm sodium hypochlorite sanitizing solution for 10 min (Figure 1). Then, they were crushed using an industrial blender until the pulp was visually very fine. The shredded mixture was then pressed into cotton cloth fabric. Starch suspension was obtained by decantation (12 hours) at room temperature (25 ± 2 °C). The starch suspension was centrifuged twice at 16636 x g for 5 min at 25 °C. The starch product obtained was frozen for subsequent freeze-drying for 24 hours.

To characterize the major physical, optical, and chemical properties of the starches extracted, the following variables were determined:
- Morphology of starch granules: an aqueous solution containing 1 g of starch (2% w/v) was placed on a slide and observed using a Coleman N107T optical microscope

with 400x magnification, in the reflectance mode. The shape of starch granules from each source was observed and captured using Dino Capture 2.0. The 100 largest granule lengths per sample were measured. Granules were classified as small (1-10μm), medium (11-25μm), or large (> 25μm), according to Singh, McCarthy, and Singh (2006);

- Total starch content (g 100 g^{-1}): 10 g of sample with known moisture was diluted in 75 mL of distilled water and 10 mL of hydrochloric acid P.A. These samples were autoclaved at 120 °C for 20 minutes. After cooling, they were neutralized with 40% sodium hydroxide, and the solution was transferred to a 250 mL volumetric flask. The volume was completed with distilled water. Titration was then performed by Lane-Eynon, using Fehling A and B solution, with methylene blue indicator, according to the Adolfo Lutz Instituto – IAL methodology (2005);

- Determination of amylose: 100 mg of each type of starch were sampled and transferred to a 100 mL volumetric flask, with 1 mL ethyl alcohol P.A and 9 mL 1 N NaOH solution. They were then heated in a 100 °C water bath for 10 minutes, with subsequent cooling for 30 minutes. Volume was completed with distilled water. A 5 mL aliquot was taken from each sample and transferred to a 100 mL volumetric flask, in which 1 mL 1 N acetic acid and 2 mL of 2% (w/v) iodine were added, completing the volume with distilled water. The absorbance at 610 nm was measured 30 min after adding the iodine solution. Results were compared to the standard curve obtained from 40 mg of pure amylose (Sigma), according to Zavareze et al. (2009).

- Determination of amylopectin content: it was obtained by the difference between total starch and amylose contents;

- Optical properties: a Minolta CR 400 colorimeter was used to instrumentally determine the color of the different starch types, with readings using the CIELAB scale, represented by coordinates L (luminosity), chromaticity a* (negative values corresponding to green coloration and positive values representing red coloration), and chromaticity b* (negative values representing blue coloration and positive values corresponding to yellow coloration). It was used the illuminant D$_{65}$ and five readings were performed in each starch. Mean standard L, a*, and b* values were used to determine the total color difference (ΔE) using the following Equation 1:

$$\Delta E = [(L - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2]^{0.5} \qquad (1)$$

where the values of L, a*, and b* values were measured in the different types of starch. The values of L$_0$, a$_0$, and b$_0$ correspond to the white standard used (L$_0$ = 94.38; a$_0$* = -0.71; b$_0$* = 3.9) (Goyeneche et al., 2014; Pires et al., 2013).
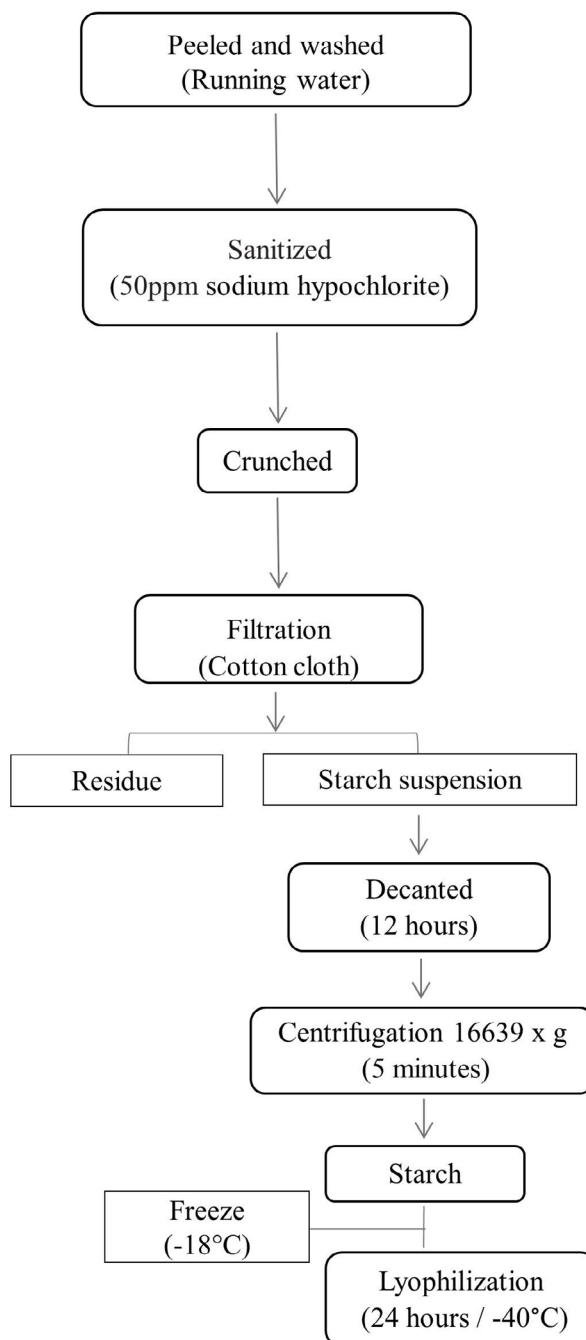
Figure 1: Diagram of the starch extraction process.

- Solubility and Swelling Power: a sample of 1 g starch was dispersed in 40 mL water in falcon tubes, stirred for 1 minute in a vortex mixer, and heated in water bath for 30 min, stirring every 10 min in four different temperatures, at 60, 70, 80, and 90 °C. The tubes were centrifuged for 10 min at 8320 x g. The supernatant was collected using a syringe and dried in a dryer at 105 °C for 24 h to determine weight of soluble starch (M1). Tubes containing swollen starch granules (M2) were weighed (Leach; McCowen; Schoch, 1959). Solubility and swelling power were calculated according to the following Equations 2 and 3:

$$\text{Solubility (g 100 g}^{-1}) = (\text{Soluble starch mass/Initial starch mass}) *100 \quad (2)$$

$$\text{Swelling Power (g 100 g}^{-1}) = [(\text{Swollen starch mass/Initial starch mass}) - \text{Soluble Starch Mass}] \times 100 \quad (3)$$

- Freeze-thaw stability (syneresis): determined according to the method proposed by Charoenrein et al. (2011), with 5% starch suspension heated at 95 °C for 30 minutes in controlled water bath. Then, the tubes were rapidly cooled in an ice-water bath and 20 g of the gel obtained was transferred to hermetically sealed falcon tubes and underwent successive freezing cycles at -18 °C and thawing in a thermal bath at 30 °C for 90 min, followed by centrifugation at 8320 x g for 10 min. The gel supernatant was weighed to express the percentage of liquid separated by total sample mass.

Chemical and optical evaluations were performed with five replicates, and data were submitted to an analysis of variance (ANOVA) using the F test (p≤0.05) and applying Tukey's test (p≤0.05) to compare mean values. The other variables were performed with four replicates, each one in triplicate, and the results were presented by their mean values and standard deviations.

After characterization, biodegradable coatings made from different types of starch were prepared to be applied to 'Palmer' mango fruit. Preliminary trials using different concentrations of starch (2-4%) and glycerol (1-4%) determined the suitable formulation for each one. The criteria adopted for the choice of concentrations for starch and glycerol were the reduction of the respiratory rate and the reduction of weight loss as well as the delay in color evolution of mango fruit.

'Palmer' mango fruits were harvested in October 2017 in the production area of AM Export, located in Petrolina, Pernambuco State, Brazil, at maturity stage 2, which is characterized by a light green skin coloration. The fruits were transported to the Postharvest Physiology Laboratory of Embrapa Semiárido, where they were washed to remove excess lime from fruit surface. They were then sanitized in chlorinated water at 200 ppm for 10 minutes, as mentioned by Azerêdo et al. (2016). Subsequently, they were dried in ambient temperature for the application of the following coatings: 3% cassava starch; 3.5% jackfruit seed starch; 3.5% mango seed kernel starch, 3.5% yam starch, and control (uncoated). The following was added to all treatments except for the control: 1% glycerol, 0.3% Tween 80, and 0.3% sunflower oil. The inclusion of glycerol and Tween 80 aimed to improve adhesion on surface of the fruit while sunflower oil aimed to improve the brightness of the fruits (Amariz et al., 2010; Rodrigues et al., 2018). After drying, fruits were stored at 24.4 ± 0.3 °C at 87 ± 2% RH for evaluations at 0, 2, 3, 5, 7, 9, 10, and 12 days.

Fruits were evaluated for: weight loss (%), obtained by the percentage difference in fruit weight at both harvest and evaluation dates; respiratory activity (mol kg^{-1} h^{-1}), performed using O_2 and CO_2 analyzer Witt PA 7.0 after the fruits were kept for 10 minutes in a hermetically sealed container; and color determination on the green region of the skin using a Minolta CR 400 colorimeter, with the CIELAB reading scale, represented by the coordinates Luminosity (L), Chroma (C), and Hue angle (°H).

A 5 x 7 factorial arrangement in a randomized experimental design (coating x storage time) was adopted, with four replicates, consisting of four fruits each. Data were subjected to an analysis of variance using the F test (p≤0.05). When there was a significant effect of the factor storage time and/or interaction with the factor coating, a polynomial regression analysis was applied, adopting up to third-degree equations and determination coefficients higher than 70% for a more reliable response and safe conclusions. When only coatings had a significant effect, Tukey´s test (p≤0.05) was used to compare mean values.

RESULTS AND DISCUSSION

Physical, optical, and chemical characteristics of starches extracted from different sources

The morphology of starch granules from jackfruit seed, cassava, mango seed kernel and yam was observed by optical microscopy (Figure 2). Starches from yam and mango seed kernel were characterized as having a more rounded or oval structure with many oblong granules. Cassava starch was slightly rounded with a tendency towards forming straight corners, while jackfruit starch structure ranged from irregular to polygonal. Granule size was observed to vary according to botanical origin

(Martins; Gutkoski; Martins, 2018). Yam starch had the largest granules, with mean values of 35.08±5.22 µm, which is considered large according to the classification proposed by Singh, McCarthy and Singh (2006). Mango seed kernel and cassava starches, with mean values of 19.01±2.43 µm and 13.54±2.2 µm, respectively, were classified as medium sized, following the same criteria. Jackfruit seed starch had the lowest mean granule value 7.32±1.45 µm, and was considered small, according to the same authors. These observations corroborate others studies that evaluated starch granule sizes from the same sources. Yam, mango seed kernel and cassava starches granules of 18-35 µm (Zou et al., 2020), 12-30 µm (Nawab et al., 2016) and 12-20 µm (Luchese et al., 2018), respectively, were reported. Madruga et al. (2014), studying two jackfruit cultivars, mentioned mean values of 6-11 µm of jackfruit seed starch.

According to Falade and Ayetigbo (2015), granule size is an important attribute in particle interaction, homogenization in food products and in the formulation of biodegradable films and coatings. The smaller the particle, the higher the amount per unit mass and the higher the potential for homogeneity.

Cassava and mango seed kernel starches had the highest total starch content, 89.29 and 88.42%, respectively, statistically differing from the others sources evaluated (Table 1). The four starch types met the minimum specifications required by the Brazilian legislation for commercial starches to be used in the food industry (Brazil, 1978), which is a minimum of 70% total starch.

The lowest amylopectin content and, consequently, the highest amylose content were observed in jackfruit seed and yam starches (Table 1). These values are in accordance with those reported in other studies (Huang et al., 2016; Zhu, 2016). Thus, jackfruit seed and yam starches would be expected to have the best coating potential due to their amylose concentration, given its importance in the formation of coatings. However, other characteristics that render a raw material to be suitable as coating should also be observed.
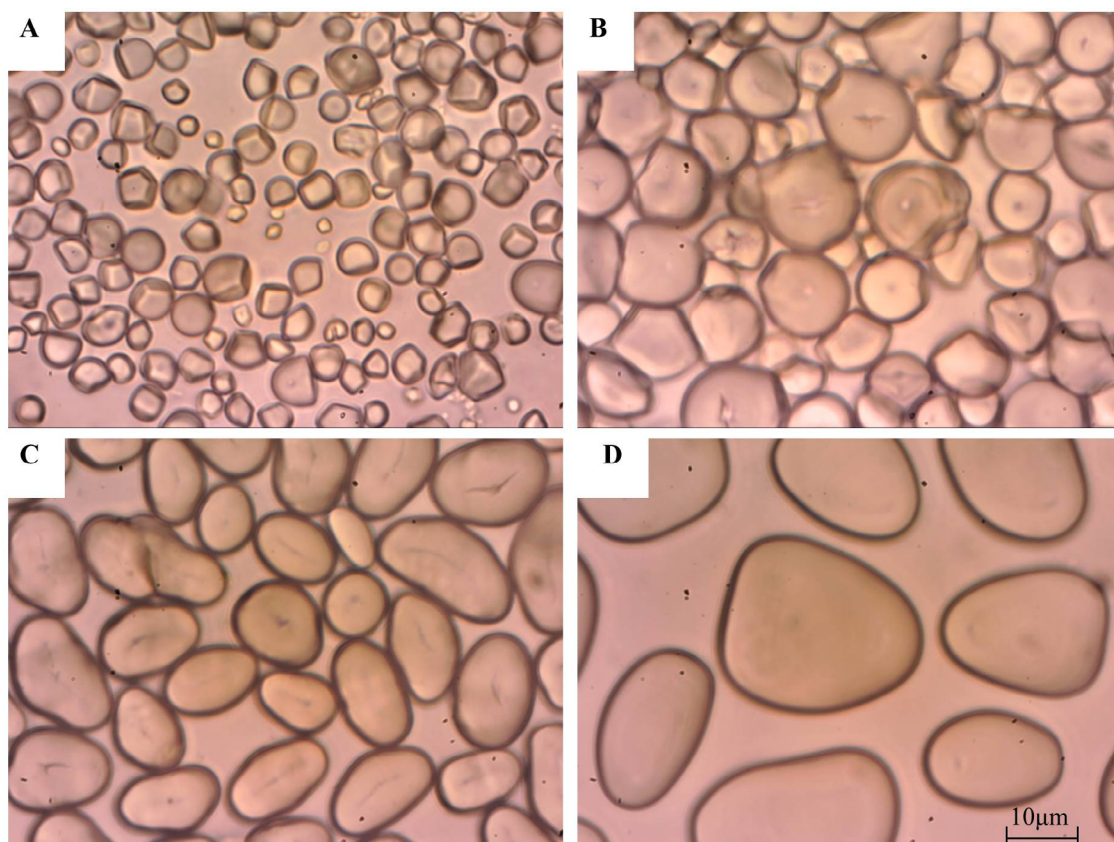
Figure 2: Microphotograph of starch granules from jackfruit (A), cassava (B), mango seed kernel (C) and yam (D) at 400x magnification.

Table 1: Chemical composition of starches extracted from cassava, yam, jackfruit seed and mango seed kernel (mean ± standard deviation)*.

Starch source	Total starch (g 100 g^{-1})	Amylopectin (g 100 g^{-1})	Amylose (g 100 g^{-1})
Cassava	89.26 ± 1.42a	68,32 ± 1.67a	20.94 ± 0.99c
Yam	70.00 ± 2.43c	34.91 ± 1.30c	35.09 ± 1.68a
Jackfruit seed	79.83 ± 3.02b	44.85 ± 4.12c	34.98 ± 1.78a
Mango seed kernel	88.42 ± 1.46a	57.97 ± 3.54b	30.45 ± 0.95b
CV (%)	2.53	2.02	4.63

* Means followed by the same letter in the column do not differ from each other by the Tukey's test (p≤0.05).

In general, most native starches have between 18 and 30 g 100 g^{-1} amylose content and 70 to 82 g 100 g^{-1} amylopectin content, as well as other constituents (lipids, proteins and minerals). The lower the amount of these other constituents and the higher the amount of amylose, the better the film and coating formation because amylose is directly linked to the chemical and physical characteristics of the film (Baldwin; Hagenmaier; Bai, 2011; Nakamura, 2015; Zhu, 2016).

Regarding optical characteristics, mango seed kernel starch had the lowest luminosity, the lowest a* attribute value, the highest b* value and the highest color difference, statistically differing from the others (Table 2). This response is associated with the yellowish coloration of starch from mango seed kernel, which, according to Torres-Leon et al. (2016), is due to the synthesis of carotenoids in the seed. Therefore, it was different from the others, with a visually observable white coloration. Among the other starch sources, yam had the highest luminosity while jackfruit seed starch had the smallest color difference compared to the standard.

The difference in color among the different starch sources can be attributed to the presence of materials found in small amounts in starch, such as proteins, fibers, sugars, latex, pigments, lipids, minerals, among others, which are not removed during extraction. These other constituents have a natural occurrence and may also affect the formation of films and coatings due to changes in the chemical characteristics of starch (Falade; Ayetigbo, 2015). However, the relevance of these changes depends on the contents of these constituents in the sample. Regarding to the color of the starch, it is not expected to be a practical problem, as the concentration used in solutions to form films or coatings generally results in transparency with the naked eye.

Solubility and swelling power of starches extracted from different sources increased at temperatures ranging from 60 to 90 ºC (Figure 3). Cassava starch showed the highest solubility and swelling power, with the highest increase rates of solubility from 60 to 70 ºC and from 80 to 90 °C. The highest gain in swelling power was observed from 80 to 90 °C.

Behavior of solubility and swelling power is expected to be similar because both factors depend on the arrangement of amylose and amylopectin molecules. Jackfruit seed was the starch with the lowest solubility and lowest swelling power. This fact is related to the amount of amylose present, as it restricts swelling power and maintains the integrity of swollen granules, while lipid complexed amylose chains restrict both granular swelling and amylose leaching (Martins; Gutkoski; Martins, 2018).

Differences in solubility and swelling power during heating are due to molecular structure, granule size, and botanical source, as well as differences in starch amylose and amylopectin (Huang et al., 2015). Generally, the higher the amylose content, the more compact the starch becomes, and the more difficult it is to exude in swollen granules, which reduces solubility and indicates leaching behavior during gelatinization. Swelling power is a measure of starch hydration at different temperatures and under excess water. The higher this power, the lower the bond strength of hydrogen bonds between amylose and amylopectin molecules (Kumar et al., 2018).

Even with lower amylose content and high amylopectin content compared to other sources, the medium granule size may explain the relative high solubility of cassava starch. Besides, a smaller breakdown of starch granules results in less amylose leaching (Kumar et al., 2018) from cassava starch.

Amylose and amylopectin can be arranged in a semi crystalline structure with alternating amorphous (amylose) and crystalline (amylopectin) material. This structure affects the preparation of coatings and films since the gelatinization process begins in the amorphous region, favored by weak hydrogen bonds. After, the process extends to the crystalline region. Amylose presence reduces the fusion point in the crystalline region and the amount of energy necessary to initiate gelatinization (Sasaki et al., 2000).

Table 2: Optical characterization of starches extracted from cassava, yam, jackfruit seed and mango seed kernel (mean ± standard deviation)*.

Starch sources	L*	a*	b*	ΔE
Cassava	96.68 ± 1.24 b	-0.15 ± 0.07 a	1.98 ± 0.34 c	3.10 ± 0.68 c
Yam	97.76 ± 0.41 a	-0.34 ± 0.01 b	2.38 ± 0.09 c	3.73 ± 0.40 b
Jackfruit seed	92.68 ± 0.44 c	-0.40 ± 0.01 b	3.22 ± 0.03 b	1.86 ± 0.38 d
Mango seed kernel	82.68 ± 0.86 d	-1.23 ± 1.11 c	13.57 ± 0.08 a	15.23 ± 0.68 a
CV (%)	0.41	6.36	2.94	3.92

*Means followed by the same letter in the column do not differ from each other by Tukey's test (p≤0.05).
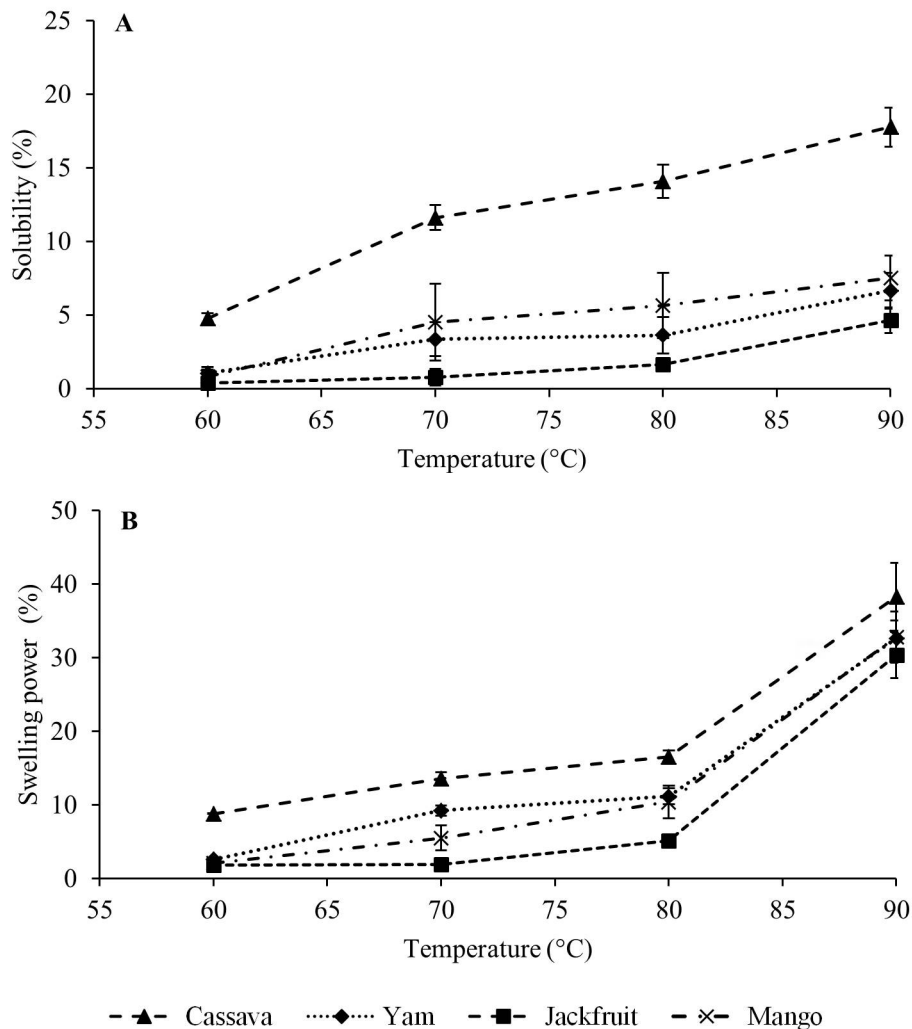
Figure 3: Solubility (A) and swelling power (B) of starches extracted from cassava, yam, jackfruit seed and mango seed kernel at different temperatures.

Vertical bars indicate standard deviation.

Starch from mango seed kernel had the highest syneresis compared to the others during freezing and thawing cycles (Figure 4). In the first defrosting cycle (first day), this starch had a significant percentage of syneresis, 48.99 g 100 g^{-1}, while yam had 8.33 g 100 g^{-1} and jackfruit and cassava starches had 0 g 100 g^{-1}. Cassava, jackfruit seed and mango seed kernel starches had a marked growth in syneresis in the third defrosting cycle (fifth day). At the end of the fifth cycle (eighth day), mango seed kernel starch had syneresis of 68.6 g 100 g^{-1} while syneresis in the others was below 52 g 100 g^{-1}. Doan et al. (2019) associated the lower ability to withstand freeze-thaw cycles with high swelling power, which in turn is associated with low amount of amylopectin.

Syneresis is an indicator of freezing and thawing stability and is quantified by the percentage of water that the starch gel loses after undergoing temperature cycles. Some undesirable physical changes that may occur are simulated in these cycles. This stability may be affected by molecular structure, amylose and amylopectin content, and water content present in the starch (Zhu, 2014). Syneresis has important practical implications as it is directly related to the resistance of the coating on the fruit's surface at the moment it leaves the refrigerated storage.

Potential for application of coatings from non-traditional starch sources in 'Palmer' mango fruit

Difference in fruit weight loss occurred according to coatings applied and throughout storage (Figure 5A).

Over the 12 days, there was a linear increase in weight loss of mango fruits coated with yam, cassava and mango seed kernel starches, which had the lowest weight loss values, represented by 4.96; 4.68 and 4.68%, respectively. Fruits coated with jackfruit seed starch had a weight loss of 6.11%, at 12th day. Overall, coatings with the four starch types caused decreased weight loss in treated fruit compared to the control, particularly cassava and mango seed kernel starches, with values 33.8% lower than control fruits. This lower weight loss in coated fruits may be associated with decreased water loss to the environment and with the presence of lipids in starches that contributed to form a better moisture barrier, as they are hydrophobic (Madruga et al., 2014; Torres-Leon et al., 2016). The low lipids content in jackfruit seed starch, as observed by Madruga et al. (2014), may contribute to a limited water loss barrier property in fruits coated with this starch source.

An acceptable weight loss for fresh fruits is approximately 5%. The major factor that causes weight loss in storage is water loss from the fruit to the environment, causing the fruit to wilt, and thus, lose consumer acceptance (Pareek, 2016).

Skin luminosity measured in the green part of the fruit was affected by the interaction between coatings and storage time (Figure 5B). Coated fruits had a decrease during storage while luminosity increased in control fruits during this period. According to Jongsri et al. (2016), luminosity is an indicator of change in skin color. As the fruit ripens, L values tend to increase.
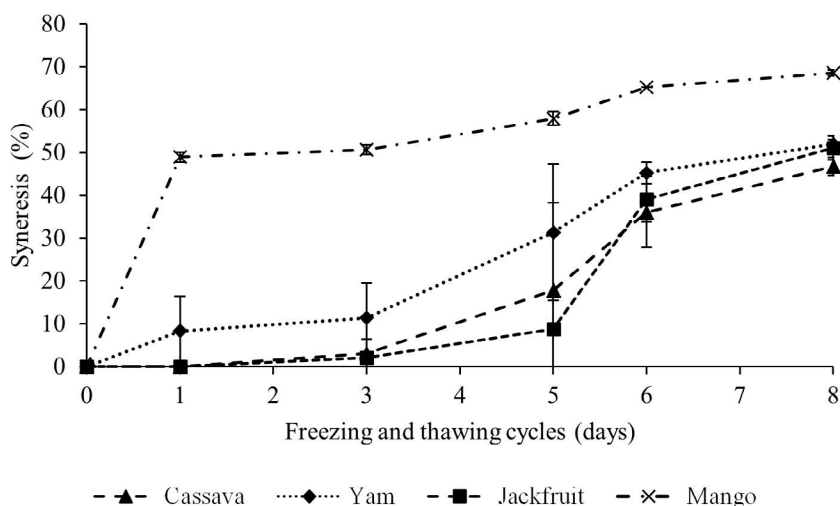
Figure 4: Syneresis of starches extracted from cassava, yam, jackfruit seed and mango seed kernel in freezing and thawing cycles.
Vertical bars indicate standard deviation.
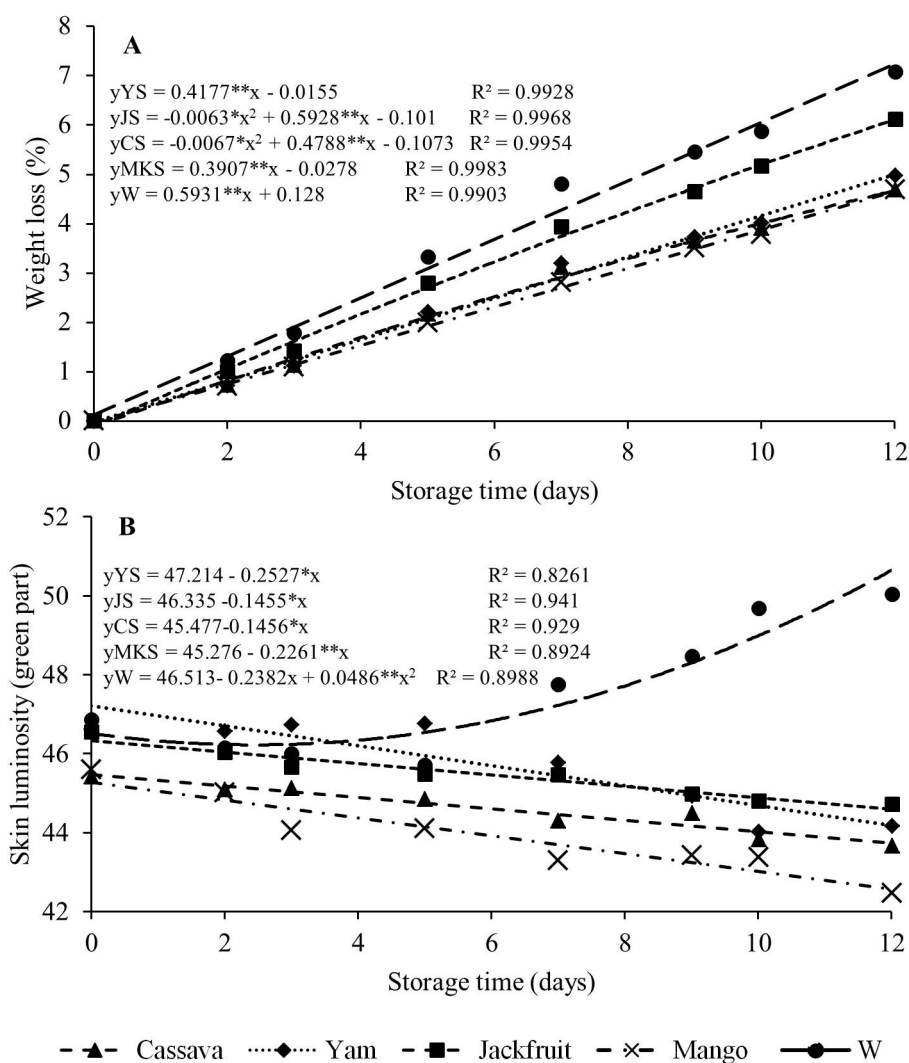
Figure 5: Weight loss (A) and luminosity (B) in the green part of the 'Palmer' mango fruit skin under inflluence of coatings of yam starch (YS); jackfruit seed starch (JS); cassava starch (CS); mango seed kernel starch (MKS) and the control (W) during storage at 24.4 ± 0.3 °C and 87 ± 2% RH.

* and ** statistical significance by the t test at p<0.05 and p<0.01, respectively.

Skin chroma was also affected by the interaction between coatings and shelf life (Figure 6A). Fruit skin chroma increased in the control over time. Fruits coated with yam, cassava, and mango seed kernel starches remained virtually unchanged. This response suggests a delay in maturation. Moreover, chroma may also be affected by skin scars, injured tissues, and chemical compounds that are deposited throughout storage.

Difference in °H among fruits was affected by the interaction between coating and storage time (Figure 6B). Fruits in the control had decreased °H compared to coated fruits, indicating that the latter had a delayed change in green coloration; control fruits exhibited a more yellowish coloration than the others at the end of storage. According to Hussain et al. (2015), delayed change in green color is an indication of slow ripening due to lower chlorophyllase activity, which is responsible for chlorophyll degradation during ripening.
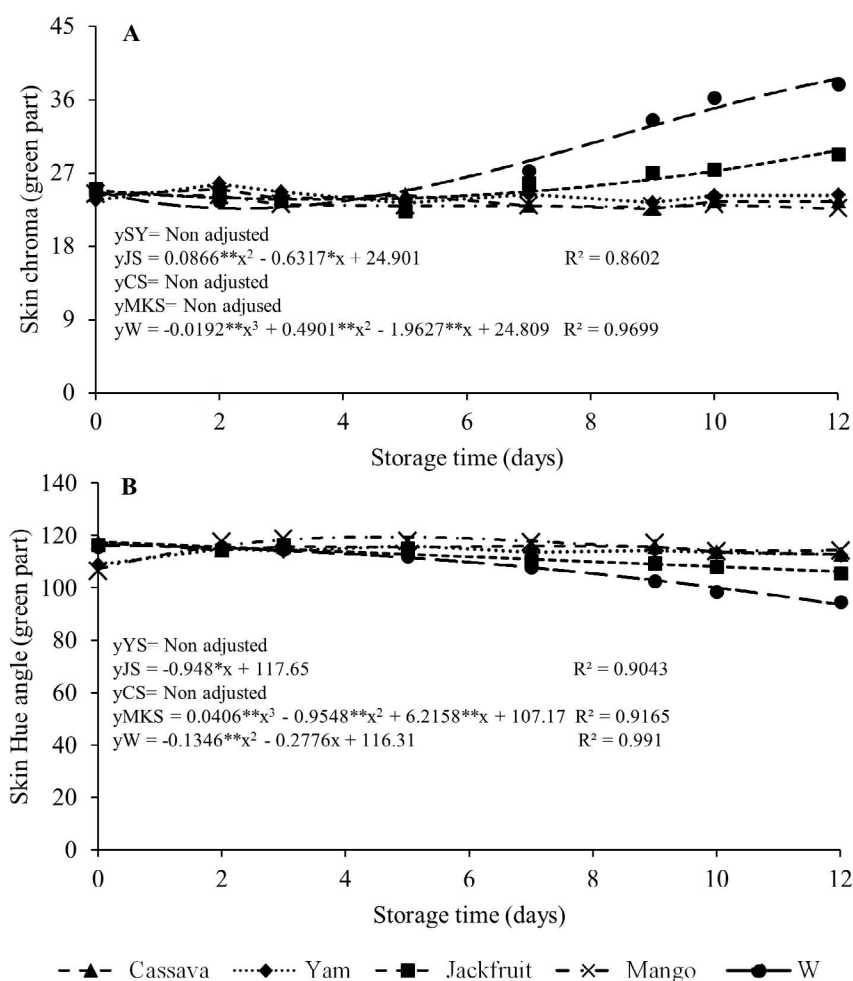
Respiratory peak occurred on the 7th day of storage for fruits coated with cassava starch, jackfruit seed starch, and uncoated fruits (Figure 7). The highest respiratory activity of fruits coated with yam and

mango seed kernel starches occurred on the 8th day of storage. Limitation of equipment sensitivity and reading intervals may have hampered to better visualize the climacteric peak. Fruits coated with mango seed kernel starch and cassava starch had the lowest respiratory activity, which was 27% and 21.6%, respectively, lower than the control at the end of storage. Treatments with the others coatings had a pattern response equivalent to the control.

The response for mango seed kernel starch and cassava starch is consistent with the hypothesis that coatings acted as a protective barrier around the fruits, changing the atmosphere, reducing metabolic rates, and helping to delay ripening. This fact was also reported by Jongsri et al. (2016), in 'Nam Dok Mai' mangoes treated with chitosan-based coatings.

Overall, the four sources showed great potential for starch extraction. Furthermore, the starches extracted were effective as biodegradable coatings. Further studies are required, using these coatings at a large scale, to add value to these starch sources, particularly jackfruit seed and mango seed kernel, which are by-products of the agroindustry and currently underused. This new use would be beneficial for fruit producing regions, especially due to the availability of the four starch sources studied, particularly mango seed kernel, which can be obtained from several juice factories located in fruit producing regions, such as the São Francisco River Valley.

Figure 6 content (equations shown in plots):

Plot A (Skin chroma, green part):
ySY = Non adjusted
$yJS = 0.0866^{**}x^2 - 0.6317^*x + 24.901$ $R^2 = 0.8602$
yCS = Non adjusted
$yMKS$ = Non adjused
$yW = -0.0192^{**}x^3 + 0.4901^{**}x^2 - 1.9627^{**}x + 24.809$ $R^2 = 0.9699$

Plot B (Skin Hue angle, green part):
yYS = Non adjusted
$yJS = -0.948^*x + 117.65$ $R^2 = 0.9043$
yCS = Non adjusted
$yMKS = 0.0406^{**}x^3 - 0.9548^{**}x^2 + 6.2158^{**}x + 107.17$ $R^2 = 0.9165$
$yW = -0.1346^{**}x^2 - 0.2776x + 116.31$ $R^2 = 0.991$

Legend: Cassava — Yam — Jackfruit — Mango — W

Figure 6: Chroma (A) and Hue angle (B) in the green region of the 'Palmer' mango fruit skin under influence of yam starch (YS); jackfruit seed starch (JS); cassava starch (CS); mango seed kernel (MKS) starch coatings and the control (W) during storage at 24.4 ± 0.3 °C and 87 ± 2% RH.

* and ** statistical significance by the t test at p<0.05 and p<0.01, respectively.
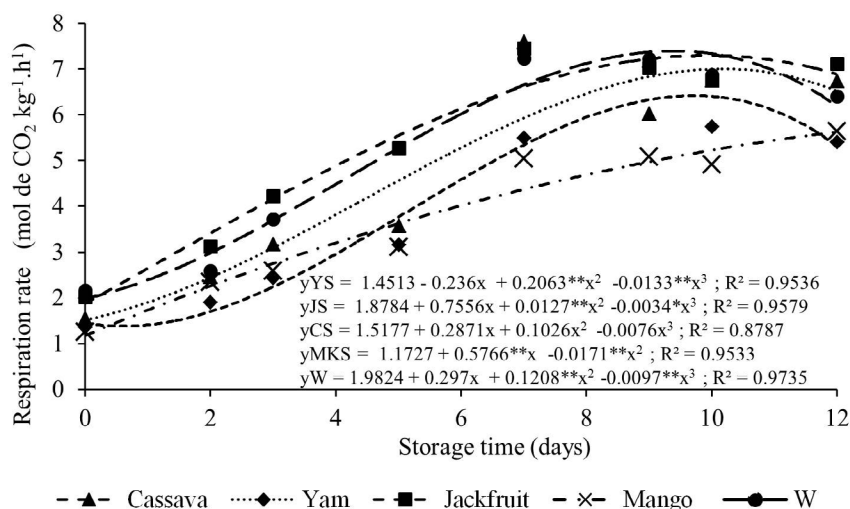
Figure 7: Respiration rate of 'Palmer' mango fruit under influence of yam starch (YS); jackfruit seed starch (JS); cassava starch (CS); mango seed kernel (MKS) starch coatings and the control (W) during storage at 24.4 ± 0.3 °C and 87 ± 2% RH. * and ** statistical significance by the t test at $p<0.05$ and $p<0.01$, respectively.

CONCLUSIONS

The four starch sources proved to be suitable for starch extraction, as they have high starch and amylose contents as well as low solubility and swelling power. Specifically, yam, cassava and jackfruit seed starches showed high luminosity and higher resistance at the end of freezing and thawing cycles. The four sources of starch showed potential as a coating to be applied on 'Palmer' mangoes as the weight loss and respiratory activity rate were reduced, delaying the fruit ripening. The best responses were obtained with mango seed kernel and cassava starch-based coatings as well as jackfruit starch for delaying skin yellowing.

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