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Germination Impact in the Nutrition and Technological Properties of Jackfruit Seeds

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Abstract

The objective of this study was the production of flour from germinated jackfruit seeds. The seeds were germinated and dried at temperatures of 55, 65 and 75 ℃ under air drying speed of 1.0 and 1.3 m s^{-1}. Afterward, the seeds were grounded in order to obtain the flour and characterized for chemical, physical and technological properties. It was observed that the germination increased the moisture content, proteins, and fibers; decreased the content of lipids, reducing sugars, tannins and phenolic compounds of the seeds. After dried, the flour moisture content decreased and the proteins and reducing sugars were concentrated. The flours showed good results for solubility, water, oil absorption capacity, and emulsifying properties. The moisture adsorption isotherms of the flours were classified as Type II and the GAB model was the best fit to the experimental data.

Keywords: *Artocarpus heterophyllus* Lam., agroindustrial residues, germination process, drying

1. Introduction

Jackfruit (*Artocarpus heterophyllus* Lam.) is a tropical fruit widely consumed in countries such as Thailand, Indonesia, India, Philippines, Malaysia and Brazil (Madrigal-Aldana et al., 2011). The edible part of this fruit can be considered a good source of essential nutrients such as proteins, calcium, and iron when compared to other tropical fruits (Baliga et al., 2011). The pulp, although consumed *in natura*, can be used in the production of jams, jellies, ice cream, juices, and the seeds can be consumed roasted or cooked (Madruga et al., 2014). The seeds contain high quantities of carbohydrates and proteins and their flour has been investigated for application in bakery products (Madrigal-Aldana et al., 2011).

The germination process has been used to improve the nutritional quality of several seeds. In addition, it is a low-cost technology that provides better absorption of nutrients associated with biologically active compounds with antioxidant potential (Cornejo et al., 2015). During germination, the enzymatic activity promotes the hydrolysis of the starch into simple sugars and other changes in the nutritional components (Charoenthaikij et al., 2012).

After the germination process, which starts after hydration, the seed presents high moisture content. To avoid deterioration, the material must be dried as soon as possible. After dried, the seeds can be kept on hold for further processing steps and be stored in environmental conditions that may include transformation into flours.

Drying time combinations and temperatures directly affect the properties and nutritional composition, therefore, the analysis of the relations between the process conditions and these properties needs to be performed. Knowledge of the functional and technological properties of food is essential for the food industry since it is the physical and chemical aspects that reflect the characteristics desired by consumers (Naves et al., 2010). The moisture content, depending on the material and environmental conditions, significantly influence the characteristics of the product, in content and shape, for this reason, drying behavior and hygroscopicity needs to be determined individually for different materials.

Although used in the culinary, there are no studies available on the use of jackfruit flour and the use of germinated seed, thus there is a demand for studies that characterize its technological aspects, in addition to its applications in other products. Therefore, this work aimed to produce and evaluate the characteristics and hygroscopic properties of germinated jackfruit seeds flour.

2. Material and Method

2.1 Raw-material

Jackfruit seeds (*Artocarpus heterophyllus* Lam.) of the soft pulp variety were used as raw material. The seeds were extracted, sanitized with 1% sodium hypochlorite solution, washed and placed on a bench to dry, for approximately 2 h.

2.2 Seed Germination

The seeds were placed in plastic trays, containing vermiculite as substrate (700 g), and irrigated with 400 mL of distilled water each tray, every 2 days. After 15 days of germination, the radicle was obtained with the desired length of 2.5 cm (Silva et al., 2007).

2.3 Physico-chemical Characterization

Water activity (a_w) was determined in triplicate using Aqualab model 3TE equipment (Decagon Devices, Inc.); the moisture content, ash, total titratable acidity, pH and protein content were determined according to the analytical procedures of the Instituto Adolfo Lutz (IAL, 2008); the lipids content was determined by the methodology of Bligh and Dyer (1959); ascorbic acid was determined following AOAC procedures (2009); the total carbohydrates was calculated by the difference between the initial percentage of the sample (100%) and the percentage of moisture, protein, lipids, ashes and fiber content.

The total sugars quantification was performed using the methodology proposed by Yemm and

Willis (1954); the reducing sugar content was determined following the procedure proposed by Miller (1959) and starch by the anthrone method (Stevens and Chapman, 1955). The tannins were analyzed according to the methodology described by Goldstein and Swain (1963). The total phenolic compounds content was determined by the Folin-Ciocalteau spectrophotometric method, according to the methodology proposed by Waterhouse (2006), with modifications.

The determination of neutral detergent fiber content was performed as described by Souza (1999). The color parameters of the samples were determined with the MiniScan HunterLab XE Plus spectrophotometer in the CieLab color system (L*, a*, and b*), where L* is the luminosity, a* is the transition from green color (-a*) for the red color (+a*) and b* the transition from the blue color (-b*) to the yellowness (+b*).

The bulk density was determined by immersion of individual seeds into a beaker filled with distilled water, in an analytical scale. The seeds were fixed with an entomological pin attached to a mobile support until completely immersed, but as close as possible to the surface, the relation between the seed mass and its unit volume was determined, the unit mass corresponded to the volume of water displaced. It was considered for distilled water 1 L = 1 cm^3, and for the unit masses, the individual weight of the seeds. The bulk density was determined by the mass/volume ratio of the samples using a 600 mL beaker filled with seeds.

The minerals determination was carried out in an X-ray fluorescence spectrometer by Shimadzu, model EDX-720.

2.4 Convective Drying

The germinated (whole) seeds of jackfruit were dried in six different temperatures and air velocity, they were dehydrated to a moisture content of approximately 9.5%, in order to inhibit the development of microorganisms and biochemical reactions. To obtain the flour, dehydrated jackfruit seeds were ground in a knife mill and received the following codes: F1 (55 ℃ and 1.0 m s^{-1} air velocity); F2 (55 ℃ and 1.3 m s^{-1} air velocity); F3 (65 ℃ and 1.0 m s^{-1} air velocity); F4 (65 ℃ and 1.3 m s^{-1} air velocity); F5 (75 ℃ and 1.0 m s^{-1} air velocity) and F6 (75 ℃ and 13, m s^{-1} air velocity).

2.5 Flour Characterization

Flours of the germinated jackfruit seeds were characterized for the chemical and physical parameters described above, bulk density, tapped density and particle density. For the bulk density, a mass of known flour was used and transferred to a graduated cylinder in which the volume was used to calculate the bulk density by the ratio of mass to volume. For the determination of the tapped density, the methodology of Tonon et al. (2013) was used. The particle density was determined by the pycnometric method, toluene was used as an immiscible liquid, at 25 ℃.

The Hausner factor was calculated by the ratio between the tapped density and the bulk density. The Carr index was calculated according to Bhusari et al. (2014).

Solubility was determined by the method of Eastman and Moore (1984) modified by

Cano-Chauca et al. (2005). The method of Beuchat (1977) was used with adaptations for the determination of water and oil absorption capacity. The method of Yasumatsu et al. (1972), with adaptations, was used to determine emulsions activity and stability. The results for emulsion activity (EA) were expressed as percentage of emulsion formed in the total volume. Emulsion stability (ES) was measured by centrifugation of the samples after heating the emulsion in a water bath at 80 ℃ for 30 min and cooling to room temperature. The height of the emulsified layer, as a percentage of the total height of the material, was used to calculate the emulsion stability.

2.6 Moisture Adsorption Isotherms of Flour

The moisture adsorption isotherms of the jackfruit seed flour germinated at 25 ℃ were determined according to the special static indirect method proposed by Crapiste and Rotstein (1982). To measure the water activity, the Hygrometer Aqualab model 3 TE, Decagon Devices was used.

On Table 1 are presented the Oswin, Peleg and GAB models that were fitted to the moisture adsorption isotherms using non-linear regression. The Quasi-Newton method was used in the statistics 7.7 software.

Table 1. Mathematical models for adjustment of moisture adsorption isotherms

Designed models	**Equation**	
Oswin	$X_e = a\left(\frac{a_w}{1-a_w}\right)^b$	(1)
Peleg	$X_e = k_1 a_w{}^{n1} + k_2 a_w{}^{n2}$	(2)
GAB (Gugghenheim, Anderson e Boer)	$X_e = \left(\frac{X_m.C.K.a_w}{(1-K.a_w).(1-K.a_w+C.K.a_w)}\right)$	(3)

Where: X_e – Equilibrium moisture content, kg/kg; X_m – moisture content in the molecular monolayer, kg/kg; a_w – water activity, dimensionless; T – temperature (℃); a, b, c, k, k_1, k_2, n_1, n_2 – equation constants.

The criteria used to determine the best fit of the models to the experimental data were the coefficient of determination (R^2) and the mean percentage deviation (P), calculated according to Equation 4.

$$P = (100/n).\sum_{i=1}^{n}\left(X_{exp} - X_{pre}\right)/X_{exp} \quad (4)$$

Where: P - average deviation percentage (%); X_{exp} - values obtained experimentally; X_{pre} - values predicted by the model; n - number of experimental data.

2.7 Flour Particles Morphology

An X-ray diffraction pattern equipment model Shimadzu XRD-6000 with CuKα radiation, 40 kV, 30 mA current, step size of 0.020 2θ and time per step of 1,000 s, the speed of scan of 2º (2θ)/min, with angle 2θ traversed from 4 to 50º. The particle morphology was detailed using SSX-550 Superscan Scanning Electron Microscope (SEM) from Shimadzu, Japan, operated at 15 kV. To obtain the images, the sample was metalized with a gold alloy and fixed in the sample port with carbon fiber. The metallization was carried out for 3 min under high vacuum, with a 10 mA current. The images were collected with magnification from 500 to 2000x.

2.8 Data Analysis

The data obtained from the chemical, physical and technological characterization were submitted to analysis of variance and the comparison between means by the Tukey test at 5% of probability. The software Assistat, version 7.7 beta (Silva and Azevedo, 2016) was used.

3. Results and Discussion

3.1 Characterization of the in Nature and Germinated Jackfruit Seeds

Table 2 shows the average results for the chemical, physical and mineral characterization of the *in nature* and germinated jackfruit seeds.

Table 2. Chemical, physical and mineral profile characterization of the *in nature* and germinated jackfruit seeds

Parameter	**Jackfruit seed**	
	***In natura* (b.s.)**	**Germinated (b.s.)**
Water activity (a_w) at 25 ℃	0.983 ±0.001 b	0.989 ±0.001 a
Moisture content (%)	49.69 ±0.25 b	57.04 ±0.79 a
Ashes (%)	2.60 ±0.02 a	2.14 ±0.04 b
Titratable total acidity (%)	0.89 ±0.00 b	1.21 ±0.04 a
pH	5.71 ±0.01 a	5.54 ±0.05 b
Proteins (%)	8.90 ±0.10 b	11.95 ±0.07 a
Lipids (%)	27.81 ±0.81 a	15.38 ±0.04 b
Ascorbic acid (mg/100 g)	31.78 ±0.02 a	10.38 ±0.04 b
Total carbohydrates (%)	39.25 ±0.34 a	31.96 ±0.09 b
Total sugars (% glycose)	10.48 ±0.00 b	12.66 ±0.01 a
Reducing sugars (% glycose)	1.85 ±0.06 a	1.66 ±0.00 a
Starch content (%)	22.04 ±0.05 a	14.73 ±0.02 b
Tannins (g/100 g of sample)	0.23 ±0.003 a	0.17 ±0.005 b
Phenolic compounds (g/100 g of sample)	0.16 ±0.003 a	0.12±0.005 b
Neutral detergent fiber (%)	18.37 ±0.24 b	34.74 ±0.24 a
Luminosity (L*)	64.54 ±0.11 b	65.24 ±0.09 a
Redness (+a*)	3.86 ±0.08 a	3.73 ±0.06 b
Yellowness (+b*)	16.19 ±0.20 b	16.75 ±0.18 a
Particle density (g/cm^3)	1.2151 ±0.1260 a	1.1104 ±0.0642 b
Volume (cm^3)	4.3838 ±0.6610 b	5.9216 ±1.6844 a
Unit mass (g)	4.9141 ±0.8357 b	6.6319 ±2.1492 a
Bulk density (g/cm^3)	0.6373 ±0.0114 a	0.5925 ±0.0030 b
Potassium (K) (mg/100 g)	712.98	563.15
Phosphorus (P) (mg/100 g)	227.71	172.45
Magnesium (Mg) (mg/100 g)	200.24	184.22
Sulfur (S) (mg/100 g)	51.19	28.97
Calcium (Ca) (mg/100 g)	42.99	45.58
Zinc (Zn) (mg/100 g)	0.67	0.54
Iron (Fe) (mg/100 g)	0.59	0.62
Cupper (Cu) (mg/100 g)	0.31	0.29

Means followed by the same letter in the rows are not statistically different at 5% probability, by the Tukey test. Moisture content-dependent values expressed as dry basis (d.b.).

The water activity showed a small increase after the germination process, this is associated with the watering of the seeds, which induces water absorption. There are no studies in the literature that mention the water activity increase resulted from the seed germination process. The moisture content increased by more than 7% between *in natura* seeds and germinated seeds, this corroborates with the detected increase in water activity. Increased moisture content was also verified by Martinez et al. (2011) in samples of germinated soybean when compared to the control, with averages of 63.73 and 6.71%, respectively, and by Leite et al. (2016) for sorghum seeds *in natura* and germinated, with values of 12.16 and 36%, respectively.

It was observed a decrease in ash content after the germination process which is probably due to the proportionally larger amount of minerals present in the radicle, discarded after germination. Conversely, there was an increase in titratable total acidity after germination. Leite et al. (2016) also reported an increased acidity in sorghum seeds after the germination process and reported values of 1.08 g equivalent acid/100 g (*in natura*) and 1.99 g equivalent acid/100 g (germinated). The decreased value for pH, from 5.71 to 5.54, between the *in natura* and germinated seeds, respectively, was expected, an inverse behavior to what was observed for the acidity.

There was an increase of more than 34%, in absolute values, for protein content in the germinated seeds in relation to the *in natura* seeds. Martinez et al. (2011) also observed an increase in protein content, from 35.67 to 42.02% (17.6% in absolute values) in control and germinated soybeans, respectively. For the lipid content, a statistical difference was observed between the samples, after the germination process, where the lipid content decreased to just over half the content of the sample *in natura*.

The ascorbic acid content decreased significantly after the germination process. Huang et al. (2014) also observed an increase in ascorbic acid content in mung bean (*Vigna radiata* L.) and soybean germinated for 3 days, followed by a decrease when reached the fifth day of germination, this indicates that the ascorbic acid content in germinated seeds depends on the transcurred period from the germination start. The carbohydrates content, obtained by difference, presented a decrease of 18.6% in germinated seeds. Similar results were found by Martinez et al. (2011) in soybean seeds, where the carbohydrate content decreased from 21.11 (*in natura*) to 9.81% after germination.

After the germination process, the total sugar content increased and the reducing sugars decreased. The increase in total sugars is probably due to the activity of α-amylase, resulted from the formation of simple sugars, which also explains the values obtained for the starch content, where a decrease in the germinated samples was observed. Tian et al. (2010) also observed a decrease in the starch content after germination in oat seeds and obtained values of 59.80% in the *in natura* seeds and 52.89% in the seeds with 24 h of germination. It was observed a significant decrease of the tannin content in the seeds after germination, which can be attributed to the oxidation of polyphenols, which is activated during germination and causes tannins enzymatic hydrolysis.

It was observed a decrease in the phenolic compounds content after germination, which corroborates that the germinative process decreases the antinutritional factors, consequently increasing the bioavailability of the nutrients. The neutral detergent insoluble fiber (NDF) content showed a significant increase after the germination process.

The germination process caused significant changes in the color parameters, but not expressive, with increases in luminosity (L*), justified by the reduction of tannin content, also for yellowness (+b*), and decrease in redness (+a*).

Germination reduced the absolute and bulk density, which is justified by the increase of moisture content incorporated in the samples. The unit mass and volume increased, both 35%, indicating a similar influence of moisture absorption on the volume and the size of the seeds. Devilla et al. (2010) studied the physical properties of common bean seeds (*Phaseolus vulgaris* L.) and found a unit mass value of 1.254 to 1.295 g for a moisture content range between 22.8 and 11%, a quadratic increase of the unit mass with the decrease of the moisture content was observed, with determination coefficients of 0.039 and 0.023. The authors related this difference to variations in seed size and shape.

There was a decrease for most minerals, such as potassium, phosphorus, and magnesium after the germination process. The microminerals zinc, sulfur, and copper also decreased. The decrease of these minerals may have occurred by water leaching from the irrigation used in the germination process or were eliminated in the discarded roots. The content of iron and calcium increased with the germination process, which is probably due to their absorption from the substrate.

3.2 Characterization of Germinated Jackfruit Seeds Flour

Table 3 shows the mean values of water activity, moisture content, protein, lipids, starch, crude fiber, redness, yellowness, luminosity, bulk density, tapped density, particle density, Hausner and Carr index of germinated jackfruit seed flour, dried at 55, 65 and 75 ℃ and air velocities of 1.0 and 1.3 m s^{-1}.

Table 3. Average values of the germinated jackfruit seed flour obtained at different drying temperatures and air velocities.

	Temperature (℃)	**Air velocity (m s^{-1})**	
		1.0	1.3
Water activity	55	0.410 cA	0.407 bB
	65	0.446 aA	0.419 aB
	75	0.414 bA	0.406 bB
Moisture content (%)	55	9.48 aA	9.26 aA
	65	9.39 aA	9.30 aA
	75	9.47 aA	9.31 aA
Proteins (%)	55	11.92 bA	12.24 aA
	65	11.06 cA	11.22 bA
	75	13.97 aA	11.42 bB
Lipids (%)	55	0.073 aA	0.069 aA
	65	0.080 aA	0.072 aA
	75	0.073 aA	0.069 aA
Starch (%)	55	30.81 cA	31.87 cA
	65	32.43 bB	33.86 bA
	75	35.10 aB	37.20 aA
Crude Fiber (%)	55	8.24 aA	7.69 aA
	65	5.19 bB	7.44 aA
	75	5.12 bA	5.23 bA
Redness (+a*)	55	3.20 aA	2.71 aB
	65	2.18 bA	2.25 bA
	75	2.07 bB	2.81 aA
Yellowness (+b*)	55	18.32 aA	17.37 bB
	65	16.25 bA	14.39 cB
	75	14.82 cB	18.95 aA
Luminosity (L*)	55	71.78 cB	72.88 cA
	65	75.12 bA	75.30 aA
	75	76.20 aA	73.80 bB
Bulk density (g/cm^3)	55	0.6367 aA	0.5967 aA
	65	0.5800 aA	0.5000 bB
	75	0.4767 bB	0.5400 abA
Tapped density (g/cm^3)	55	0.6667 aA	0.6233 aA
	65	0.6067 aA	0.5233 bB
	75	0.5000 bA	0.5467 abA
Particle density (g/cm^3)	55	1.5967 aA	1.3100 abB
	65	1.5533 aA	1.3233 aB
	75	1.4367 bA	1.2400 bB
Fator de Hausner	55	1.049 aA	1.048 aA
	65	1.047 aA	1.050 aA
	75	1.045 aA	1.018 aA
Carr index (IC) (%)	55	4.69 aA	4.62 aA
	65	4.49 aA	4.77 aA
	75	4.35 aA	4.55 aA

Means followed by the same lowercase letter in the columns and upper case in the rows do not differ statistically by the Tukey test, at 5% probability.

It was observed that there is no defined tendency for water activity, due to the no significant differences in the moisture contents with the increase of drying temperature and the increase of air velocity.

There was no direct relationship between the protein content and the drying conditions used, which also did not influence the lipid content. Similar behavior was reported by Oliveira et al. (2010) for white oat grains submitted to drying at different temperatures (50, 75 and 100 ℃), with no significant statistical changes in the lipid content found.

There was an increasing tendency for the starch content as the drying temperature increased, in which the values varied up to 21% between the lower and higher sets of temperature and air velocity. Higher values of starch were determined by Chisté et al. (2011) in flours elaborated with fermented roots (70.20 to 71.40%).

There was a decreasing tendency for the crude fiber content as the drying temperature increased. The variations observed in the color parameters do not allow to determine a tendency of variation with the temperature or the air velocity, coinciding only the lower value of luminosity in the lower temperature, for both air velocities.

As the drying temperature increased, there was a decrease in bulk density values, possibly reflecting a more irregular pattern on the surface of the particles. Close values were found by Falade and Christopher (2015) for bulk rice flour, with an bulk density that varied from 0.46 to 0.60 g/cm^3.

The tapped density also presented a decreasing tendency as observed for the bulk density, with the increase of the drying temperature, which corroborates with the influence of the temperature on the surface conformation and consequent volumetric accommodation of the particles. It was observed that as the temperature increased the particle density tended to decrease. This decrease may be associated with the fact that higher temperatures create pores and channels for toluene

The Hausner Factor was developed to evaluate the fluidity of materials by the ratio between the bulk and tapped density. Values smaller than 1.25 indicate good flow; greater than 1.5 indicate poor flow; values between 1.25 and 1.5 require the addition of adjuvants to improve flow. It was verified that there was no significant difference in HF between the averages of the flours, with results between 1.045 and 1.050, indicative of low cohesiveness, according to Quispe-Condori et al. (2011). The Carr Index, which also indicates powder and flour fluidity, was not influenced by increases in temperature or air velocity. All flours presented good fluidity since CI values between 15-20% represent good fluidity, between 20-35% poor fluidity, between 35-45% bad fluidity and CI > 45, very poor fluidity (Santhalakshmy et al. 2015).

Table 4 shows the values of solubility, water absorption capacity (WAC), oil absorption capacity (OAC), activity and emulsion stability of germinated jackfruit seed flour dried at three temperatures and two air velocities.

Table 4. Mean values of the technological properties of germinated jackfruit seed flour obtained under different drying temperatures and air velocities

	Temperature (℃)	**Air velocity (m s^{-1})**	
		1.0	1.3
Solubility (%)	55	19.76 aB	20.52 bA
	65	19.95 aA	20.19 bA
	75	20.01 aB	21.63 aA
CAA (g of water/100 g of sample)	55	205.25 aA	208.97 aA
	65	222.48 aA	202.83 aB
	75	207.49 aA	203.26 aA
CAO (g of oil/100 g of sample)	55	73.55 aA	74.62 aA
	65	74.44 aA	74.85 aA
	75	74.93 aA	74.90 aA
Emulsion activity (%)	55	40.88 aA	40.10 aA
	65	39.21 aA	39.68 aA
	75	39.34 aA	38.35 aA
Emulsion stability (%)	55	41.26 aA	40.11 aA
	65	38.53 bB	40.74 aA
	75	39.28 abA	36.61 bB

The solubility of the flours varied in a small margin, statistically not significant in most cases. Elkhalifa and Bernhardt (2010) evaluated the solubility of the germinated sorghum grain flour and observed an increase in the 5th day of germination, from 42.32 to 63.20%, which was attributed to the gradual degradation of reserve proteins in amino acids and peptides by increased levels of proteases.

In general, it was observed that there was no influence by the increase in temperature and air velocity on the water absorption capacity. Cheng and Bhat (2016) found a water absorption capacity of 82.28% in wheat flour while jering seed flour (*Pithecellobium jiringa* Jack) reached 288.25%. According to Elkhalifa and Bernhardt (2010), the increase of the water absorption capacity in germinated seed flour compared to the *in natura* seeds can be attributed to an increase in the content and alteration in the quality of the protein caused by the germination.

No statistical difference was observed for oil absorption capacity, between the flours evaluated. Close values for oil absorption capacity were determined by Falade and Christopher (2015) in flours from six rice cultivars in Nigeria, with values varying from 59.97 to 72.98%; higher values were found by Cheng and Bhat (2016) for wheat flour and jerry seed (*Pithecellobium jiringa* Jack), with oil absorption capacity of 147.39 and 163.02%, respectively. These values indicate high potential for use in food products, particularly for bakery products and meat products, considering that the water and oil absorption capacity are parameters that affect texture, taste, and consistency.

It was observed that there was no significant difference between the emulsion activity of the flours, not affected, therefore, by the drying temperature and air velocity. Leite et al. (2016) reported that, after germination, there was an increase of emulsion activity (EA) of sorghum flour by about 5%, but with a decrease in the emulsion stability (ES).

The results for emulsion stability (ES) did not show a well-defined tendency, although under the extreme conditions of 55 ℃ and air velocity of 1.0 m s^{-1} and 75 ℃, and air velocity of 1,3 m s^{-1} showed the highest and lowest values of emulsion stability, respectively.

3.3 Moisture Adsorption Isotherms of Flours

Table 5 shows the adjustment parameters of the Oswin, GAB and Peleg models adjusted to the moisture adsorption data at 25 ℃, determined in the six flours produced under drying temperatures of 55, 65 and 75 ℃ and air velocities of 1.0 and 1.3 m s^{-1}, with respective determination coefficients (R^2) and the mean percentage deviations (P).

Table 5. Parameters of the Oswin, GAB and Peleg models adjusted to the data of moisture adsorption of germinated jackfruit flours, at 25 ℃

Models	**Temp. (℃) / Air Veloc. (m s^{-1})**	**Parameters**				**R^2**	**P (%)**
		a	b				
Oswin	55 - 1.0	8.4952	0.5128			0.9962	2.28
	55 - 1.3	8.3293	0.5433			0.9969	2.56
	65 - 1.0	6.6516	0.5956			0.9972	3.06
	65 - 1.3	8.0478	0.6535			0.9934	3.55
	75 - 1.0	6.9259	0.6445			0.9965	3.36
	75 - 1.3	7.7498	0.5699			0.9993	0.90
	Temp. (℃) / Air Veloc. (m s^{-1})	X_m	C		K	R^2	P (%)
GAB	55 - 1.0	4.6596	34.1737		0.9179	0.9929	2.98
	55 - 1.3	4.4647	158.1783		0.9342	0.9975	1.76
	65 - 1.0	4.2173	4.5625		0.9304	0.9981	2.63
	65 - 1.3	5.9182	2.2338		0.9324	0.9976	2.49
	75 - 1.0	4.6132	3.3921		0.9417	0.9969	2.67
	75 - 1.3	4.2020	34018.72		0.9414	0.9987	0.91
	Temp. (℃) / Air Veloc. (m s^{-1})	k_1	n_1	k_2	n_2	R^2	P (%)
Peleg	55 - 1.0	35.0589	11.8710	18.6999	1.0883	0.9938	3.16
	55 - 1.3	15.8871	0.8389	39.0701	9.8725	0.9961	2.23
	65 - 1.0	17.5919	1.4318	34.5270	11.870	0.9991	1.55
	65 - 1.3	45.3412	8.9871	19.1243	1.3649	0.9965	2.65
	75 - 1.0	44.5359	13.6700	21.9112	1.7372	0.9974	2.16
	75 - 1.3	40.4980	12.6263	19.5598	1.3360	0.9983	1.39

It was verified that all the models had good adjustments to the experimental data, with values of $R^2 > 0.96$ and $P < 10\%$, the Oswin, GAB and Peleg models, presented the best adjustments with $R^2 > 0.99$ and $P < 3\%$. Kartika et al. (2012) when evaluated the moisture adsorption isotherms of *Pinhão Bravo* seeds verified good adjustments by the GAB and Oswin models to the experimental data.

Oscillations are observed in the moisture content values in the molecular monolayer (Xm) of the GAB model with no demonstration of the effects of temperature and air velocity. Xm is a critical parameter since it represents the moisture content in which the rate of any associated reaction will be negligible due to the strong binding of water to the surface (Yogendrarajah et al., 2015). The molecular monolayer is the primary food layer and its moisture content interferes with the hygroscopicity or affinity of the molecules with water (Ribeiro et al., 2016).

The values of the C parameter of the GAB model, which is related to the adsorption heat of the water on the product (Velázquez-Gutiérrez et al., 2015), also did not follow a tendency with temperature or air velocity. According to Velázquez-Gutiérrez et al. (2015), lower values of C occur the greater interactions between the product and the water vapor. The constant K of the GAB model, which represents the water adsorption capacity in the multilayers (Abebe et al., 2015), showed an increasing tendency with temperature but did not demonstrated influence of air velocity.

The parameters found for the Oswin model $a > 0$ and $0 < b \leq 1$, this indicates that the curves have no inflection point and concavity changes. According to Rocha et al. (2014) these parameters are physically and mathematically consistent. From the C and K values of the GAB model, the moisture adsorption isotherms for the germinated jackfruit seed flours are Type II (sigmoid form), according to Blahovec's classification (2004), considered that they presented $0 < K \leq 1$ and $C > 2$, except for the dry flour at 65 °C and velocity of 1.3 $m\ s^{-1}$, which presented $0 < K \leq 1$ and $0 \leq C \leq 2$, classified as Type III (type J). The predominance of the first type reflects the higher proportion of carbohydrates, according to Chisté et al. (2011), where they affirmed that the number of sites that bind strongly to water molecules should be lower on the protein-rich substrate than on the carbohydrate-rich substrate, so that starch products generally have Type II isotherms.

In Figures 1 and 2 are presented the moisture adsorption isotherms of the flours at 25 °C, with adjustments by the GAB model. According to Yogendrarajah et al. (2015), the safe moisture content for storage is $a_w \leq 0.60$, which in the germinated jackfruit flours corresponds to moisture contents of less than 12% (b.s).

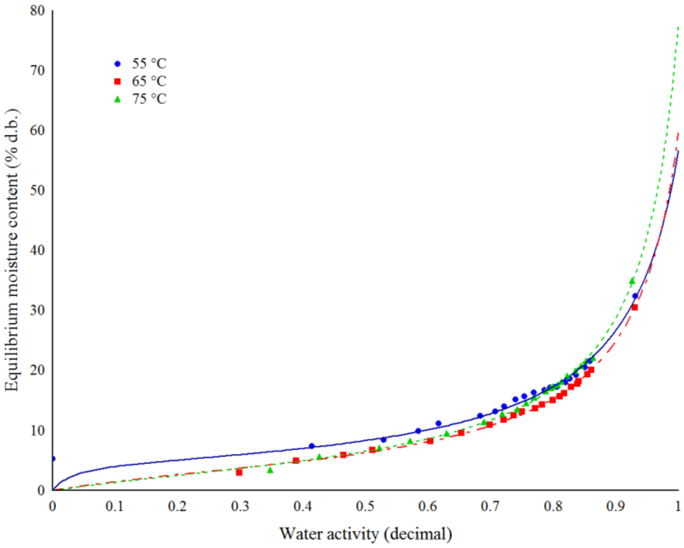

Figure 1. Moisture adsorption isotherms of germinated jackfruit flour at 25 ℃ adjusted by the GAB model for the different drying temperatures and air velocity of 1.0 m s^{-1}

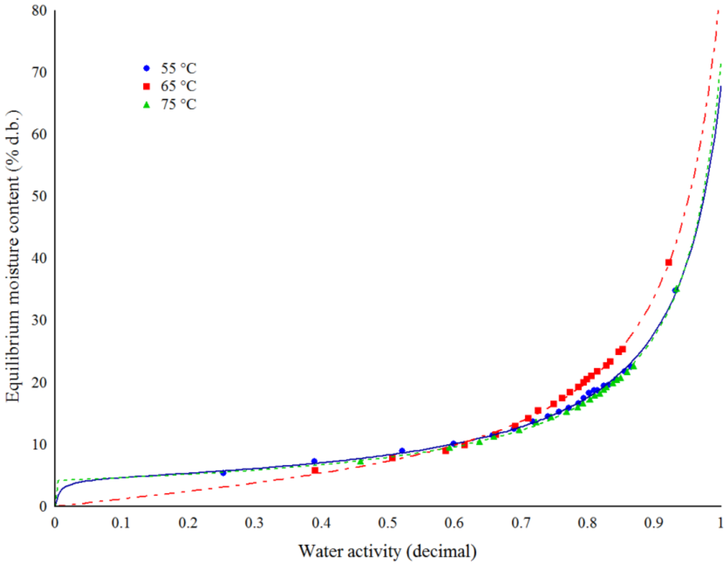

Figure 2. Moisture adsorption isotherms of germinated jackfruit flour at 25 ℃ adjusted by the GAB model for the different drying temperatures and air velocity of 1.3 m s^{-1}

The equilibrium moisture content of the flours ranged from 2,9454 to 39,38% (d.b.) for aw between 0.298 and 0.922, this range is close tow what is found for the biodegradable starch films of jackfruit and glycerol, with a range between 2,242 and 22,192% (d.b.) for aw between 0.113 and 0.836 (Barbosa et al., 2011). From the isotherms, there is no evident relation of the hygroscopic behavior of the flours with the temperature or the air-drying velocity of the seeds.

3.4 Flour Particles Morphology

The flour of the germinated jackfruit seeds was submitted to X-ray diffraction analysis

(Figure 3), presented three peaks between 15 and 25 diffraction angles, with a quality standard of type A. According to Lima et al. (2012), the X-ray diffraction technique allows to distinguish three types of crystallinity of the starch granules that, according to Zobel (1964), depending on their crystalline form and structure, are called type A, B and C. Lima et al. (2012) found in corn starch and wheat flakes x-ray diffractograms with 2q peaks related to the type A crystallinity pattern, whereas potato starch flour and banana flour showed characteristic peaks of type B crystallinity. Pattern A is characteristic of cereals, the B pattern is characteristic of tubers, fruits, high amylose corn, and retrograded starches. The C Pattern is considered a mixture of A and B patterns and is characteristic of legume starches (Bello-Perez et al., 2006).

In Figure 4 is presented the scanning electron microscope (SEM) photomicrograph of the jackfruit germinated seed flour at 500× magnification. Morphologically rounded structures with varying sizes and smooth surfaces were observed. According to Xue et al. (2017), the main component of the flour is starch, thus the polygonal or irregularly shaped granules observed in the microphotographs are starch granules. According to Otegbayo et al. (2013), the variation in shape (polyhedral, oval and rounded) and size of the starch granules, is due to the drying treatment used and can be influenced by the amount of amylose and amylopectin.

Similar behavior was observed by Ma and Boye (2018) with lentil seed (*Lens culinaris*) and by Zhang et al. (2014) for lotus seed (*Nelumbo nucifera*). The existence of irregular structures with pores, depressions, and cracks in the microstructure of the sample may affect its stability during storage (Laokuldilok and Kanha, 2015).

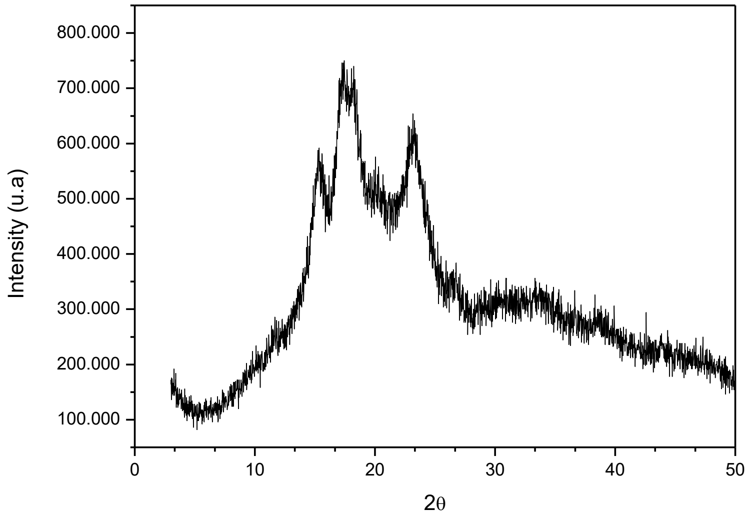

Figure 3. X-ray diffraction of the germinated seed flour (75 ℃, 1.3 m s^{-1})

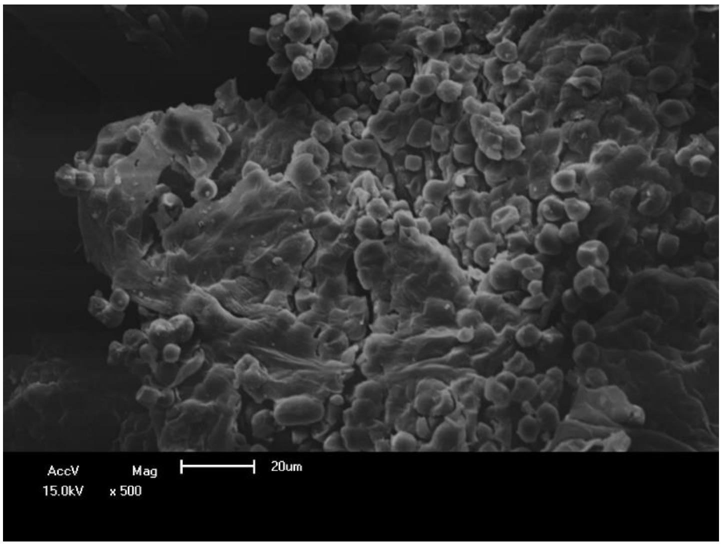

Figure 4. Scanning electron microscope (SEM) photomicrography of the germinated jackfruit seed flour (75 ℃, 1.3 m s^{-1}) at 500× magnification

4. Conclusion

Germination increased moisture content, titratable total acidity, protein content, total sugars, water activity, luminosity, and fiber content; reduced the ash content, pH, lipids, ascorbic acid, total carbohydrates, reducing sugars, tannins, phenolic compounds, specific mass and redness (+a*) and yellowness (+b*) intensities. The prospected minerals, potassium, phosphorus, magnesium, sulfur, zinc and copper also decreased with the germination process.

The germinated jackfruit seed flour had lower redness (+a*) and higher luminosity (L*). It showed good results for solubility, water absorption capacity, oil absorption capacity, and emulsifying properties .No well-defined influences of temperature and drying air velocity were detected on the chemical, physical and technological characteristics of the flour.

The moisture adsorption isotherms of the germinated jackfruit seed flour were classified as Type II. The GAB model was the one that best fit the experimental data, followed by the Peleg and Oswin models.

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