Rheological and physicochemical stability of hydrolyzed jackfruit juice (*Artocarpus heterophyllus* L.) processed by spray drying

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Abstract Spray drying represents a viable alternative for the stabilization of juice and extract of a great diversity of plant in tropical zones, such as jackfruit from Nayarit, Mexico. The jackfruit powder allows physicochemical and microbiological stability for storage, transportation, and marketing. In addition, this allows expansion of consumption and use of these exotic tropical fruits. The aim of this work was to find the best enzymatic hydrolysis and spray drying treatment for obtaining jackfruit pulp and juice in powder without affecting its rheological and physicochemical properties. Jackfruit pulp was treated with three commercial enzymes and their mixtures, and the best treatment was then optimized by Response Surface Methodology. The jackfruit pulp and the hydrolyzed juice were spray dried using maltodextrin as a carrier agent. The best hydrolysis was obtained with Celluzyme[®] and Pectinex Ultra Pulp[®] and the optimal conditions were 1% of enzyme concentration, during 3 h at 37 °C ($p = 0.92$), that leads reducing sugar of $78.50 \pm 1.93 \text{ mg mL}^{-1}$ and viscosity of $7.94 \pm 0.82 \text{ cps}$ (94.7% reduction). The enzyme concentration is a direct function of reducing sugars content, while incubation time is an inverse function of viscosity. The spray drying treatment with the highest yield (74%) without affecting rheological and physicochemical properties compared to the fresh hydrolyzed juice was the treatment with 50% (TSS/weight) maltodextrin.

Keywords Jackfruit · Spray drying · Rheological behavior · Hydrolyzed fruit juice · Maltodextrin

Introduction

Jackfruit (*Artocarpus heterophyllus* L.) is an exotic fruit that can be described as a rich source of carbohydrates, minerals, carboxylic acids, dietary fiber, ascorbic acid, flavonoids, acid sterols, tannins, thiamin, carotenoids (De Faria et al. 2009) and functional compounds, including anticancer compounds (Sun et al. 2017). However, another important component are pectins, with a content of 3.2–5.8% in bulbs (Haq 2006). Pectins are the mainly responsible for the viscosity in fruits and may represent a problem for the handling and processing of jackfruit pulp. Enzymatic hydrolysis is an alternative, which improves the sensory and physicochemical properties (Chauhan et al. 2010). Additionally, this climacteric tropical fruit is perishable and has a reduced shelf life (Prette et al. 2013). The edible fruit is processed in jams, snacks, fruit wine, fruit juice and dehydrated products (Zhang et al. 2017). Recently, the industrialization of fruit juice powder has grown in economic importance. This physical state provides stability during storage, increases shelf life and facilitates transportation (Shrestha et al. 2007).

Spray drying is a widely used method for dehydrating fruits juices and is based on the exposition of the liquid feed to a hot stream of air in order to obtain dry powders (Chong and Law 2011). However, spray drying of fruit concentrates is a problem due to the sticky behavior of the powders. This is due to the low glass transition temperatures (T_g) of fruits sugars (glucose, fructose and sucrose). When the T_g of the carbohydrates is exceeded during drying, a physical change takes place; the increase of the

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specific heat and molecular mobility induces a decrease in viscosity, causing the dust to stick on dryer walls (Goula et al. 2008). This effect can be avoided by increasing the T_g of the mixtures by addition of wall materials such as maltodextrin. Maltodextrin is one of the chief wall materials due to its ability to form a cover for aromas and flavors, thereby minimizing exposure to oxygen, this is a key feature for powder stabilization (Pourashouri et al. 2014). The microparticles obtained by spray drying are able to protect the nuclei for prolonged periods and release them under digestive conditions. Therefore, spray drying in presence of wall materials that increase the T_g of the drying mixture is suitable to increase the stability of the bioactive compounds during storage of the obtained capsules, preserving their biological activity (Mahdavi et al. 2014). The aim of this work was to optimize the enzymatic hydrolysis using Response Surface Methodology (RSM), in order to obtain jackfruit pulp and juice in powder by spray drying, without affecting its rheological and physicochemical properties.

Materials and methods

Sample preparation

The raw material used in this work was obtained from Compostela Nayarit, Mexico (21°14'17"N, 104°54'0"W altitude of 850 m). All the fruits were disinfected with sodium hypochlorite at 200 ppm for 5 min and cut into four pieces. The center was removed and the bulbs were extracted and then pulped in a pulper (CONNECTOR 16/20/26A) with 0.5 mm diameter mesh. Then, the obtained jackfruit pulp (JP) was enzymatically treated, resulting in the hydrolyzed juice (HJ).

The HJ and JP were processed by spray drying, where the JP was diluted with 50% water (DJP) and filtered through a 300 μ m diameter sieve. Thereafter, the DJP and HJ were mixed with two different maltodextrin concentrations (DJPM and HJM). After the spray drying treatment, the samples were reconstituted (DJPMR and HJMR) in water to the initial total soluble solids concentration.

Enzymes

Three different commercial enzymes were used; (1) Pectinex Ultra Pulp® (PUP®) with pectinase activity provided by Novozymes® (Cuautitlán Izcalli, México), (2) Celluzyme® (C®) where the cellulase, hemicellulase, and beta-glucanase activities are the principal, and (3) Celluzyme X Conc® (CC®) with xylanase as main activity and hemicellulase and beta-glucanase as secondary activities.

C® and CC® enzymes were provided by PIQ® (Cuautitlán Izcalli, México).

Enzymatic hydrolysis

A volume of 100 mL of jackfruit pulp was treated with the 3 individual commercial enzymes (Pectinex Ultra Pulp®, Celluzyme® and, Celluzyme X C®) and their binary mixtures (3 treatments) in a ratio of 1:1 (volume/volume), under constant incubation conditions (37 °C, pH 5.3, 200 rpm, 3 h, concentration 3% v/v). A simplex lattice mixture design with 3 factors (individual enzymes) was used, using the Analysis of variance (ANOVA) for the comparison of means with the viscosity and reducing sugar as studied responses. Then, the best enzymatic treatment was optimized by RSM with 2 chosen factors (enzyme concentration and incubation time) at three levels (Table 1). A 2-second order polynomial model (Eq. 1) was used for the response parameter ($\hat{y}$), measured as viscosity ($\hat{y}_{\text{viscosity}}$) and reducing sugars ($\hat{y}_{\text{RS}}$):

$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_{i < j} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

STATISTICA version 10.0 software package was used for statistical analysis.

Spray drying

Drying was carried out in a rotary disc particle dryer LPG-5 (CIMA INDUSTRIES INC, China). Two different spray drying conditions were used for the samples. The DJP was dried at 110 °C inlet temperature (T_i), 16.7 mL min⁻¹ feed speed (F_s), 25,000 rpm nozzle rotation velocity (R_n), 10 and 25% maltodextrin concentration (MC) in relation to the total soluble solids/weight (TSS/w). The HJ was dried at 110 °C (T_i), 8.3 mL min⁻¹ F_s and to 40 and 50% MC (TSS/w).

Table 1 Factorial 3² experimental design used by RSM for the enzymatic hydrolysis with PUP® + C® applied to jackfruit pulp

Treatments	Enzyme concentration (EC) x_1 (%w/v)	Incubation time (T) x_2 (h)
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Drying yield

Drying yield was calculated by the relation between the solid content in powder and the solid content in the feeding material (Eq. 2):

$$\text{Yield} = \frac{\text{Solids content in powder}}{\text{Solids content in the feeding material}} \times 100 \quad (2)$$

Rheological measurements

The rheological study was performed on the samples (JP, DJP, HJ, DJPM and HJM) before the drying process, as well as on the reconstituted powders (DJPMR and HJMR), using a DISCOVERY HR-1 (TA Instrument, New castle DE) rheometer with a Peltier plate system attached to a circulating water bath (WiseCircu, Korea, Mod. WCR-P6), at controlled stress and temperature (25 °C), with cone and plate geometry (d = 60 mm, 2° angle). The mechanical properties were measured under simple shear flow. The storage (G') and loss modulus (G'') were measured under small-amplitude oscillation with a frequency range from 0.1 to 200 rad s⁻¹ (Medina-Torres et al. 2016). The juice viscosity was measured under constant conditions of temperature (25 °C) and deformation speed (50 s⁻¹) during 5 min, with measurements each 30 s (10 points per decade).

The enzymatic hydrolysis was estimated by a viscosity reduction curve. First, the enzymatic mixture was added to 3 kg jackfruit pulp contained in an incubation tank with controlled temperature, provided with a pump ProMinent (Heidelberg, Germany) for the sample recirculation (3.3 L min⁻¹). Then, 5 mL of sample were taken and immediately placed in the rheometer for the viscosity determination. The first measurements were taken each 30 s during 20 min at incubation temperature, later the samples were taken and measured, each 20 min for 3 h.

Physicochemical properties

The physicochemical properties were determined according to the following methods: The humidity, water activity (a_w), titrable acidity, total ash, total soluble solids (TSS), reducing sugars content (dinitrosalicylic acid DNS), ascorbic acid (2,6 dichloro indophenol colorimetric method) were determined by AOAC and Horwitz (2005). The total sugars using the methodology of DuBois et al. (1956), the solubility with the method described by Eastman and Moore (1984) and the color using a tristimulus colorimeter (Konica Minolta CR 400, Japan) under D65 lamp (Saxena et al. 2012). All samples were evaluated in triplicate and analyzed by one-way ANOVA at a

significance level of $p < 0.05$ and a LSD test for mean differences with STATISTICA version 10.0.

Total carotenoids

5 g of sample were immersed in 20 mL of acetone reactive grade (99.5%, reagent ACS) for 2 h. The carotene layer was separated using petroleum ether (reagent ACS) through a separating funnel. The volume was adjusted to 50 mL with petroleum ether and the layer was passed through sodium sulfate over the funnel in order to remove moisture. The optical density of the layer was measured at 452 nm using a CARY 50 Bio UV visible spectrophotometer (Agilent Technologies, CA, United States) and ether as a blank (Ranganna 1986). The total carotenoids were calculated with Eq. 3.

$$\text{Total carotenoids} \left(\frac{\text{mg}}{100 \text{ g}} \right) = \frac{(3.856 * po * Vm * 100)}{Ws * 100} \quad (3)$$

where: po = optical density of the sample (mg/mL); Vm = adjusted volume (mL); Ws = weight of sample (g).

Differential scanning calorimetry

4 mg of powder samples equilibrated at 20 °C were placed in a perforated aluminum pan (aluminum standard, 40 µL of internal volume) and an empty perforated crucible was used as the reference before heating. Two cycles of heating and cooling ramp from 0 to 110 °C at 10 °C min⁻¹ with a nitrogen gas flow (60 mL min⁻¹) were used for the differential scanning calorimetry analysis (Mettler-Toledo 823, Greifensee, Switzerland).

Quantification of carbohydrates by high performance anion exchange chromatography (HPAEC)

The concentration of carbohydrates was determined by HPAEC thanks to a Dionex ICS-5000 (Thermo Fisher Scientific, CA, USA) chromatographic system equipped with a pulsed amperometric detector (PAD). A guard column and a CarboPac PA100 column were stabilized at 28 °C with 28 mM NaOH with a 0.28 mL min⁻¹ flow rate for 10 min before the injection of 70 µL of each sample at a concentration of 0.2 mg mL⁻¹. Samples and standards were eluted with a 28 mM isocratic NaOH gradient, at a flow rate of 0.28 mL min⁻¹ for 65 min at 28 °C. To define the elution time of the standards in the gradient and the concentration curve, a mixture of standard sugars was used (α-L-rhamnose (6-deoxy-L-mannose) monohydrate (≥ 98.0%), D-(+)-mannose (≥ 99.5%), D-(+)-xylose (≥ 99.0%), L-(+)-arabinose (≥ 99.0%), D-(+)-fructose (≥ 99.0%), sucrose (≥ 99.5%) and D-(+)-anhydrous glucose (≥ 99.5%), all of them from Sigma Aldrich) were

injected at 4 concentrations (0.025, 0.05, 0.1 and 0.2 mg mL⁻¹).

Results and discussion

Enzyme selection

All enzymatic treatments show important reductions from 88.52 to 94.76% in the viscosity values compared with the control (Table 2). Nagar et al. (2012) report a decrease of 11.4% and 15.04% for apple and pineapple fruits respectively. Sreenath et al. (1995) performed enzymatic liquefaction in pulp of some mango varieties, where the highest yield was obtained for the Raspuri variety with Pectinex and Cellulast, resulting in a reduction between 60 and 80%. Finally, Chauhan et al. (2004) achieved a viscosity reduction up to 94.6% in jackfruit pulp after filtration through muslin cloth, this coincides with the current study without filtering after enzymatic hydrolysis, for treatments with CC[®], the mixture of CC[®] with PUP[®] and the mixture of PUP[®] with C[®] (Table 2). In this sense, the matrix composition defines the initial viscosity, which is affected by enzymatic treatment. However, there is a statistically significant difference between the viscosity measured for samples treated by an enzymatic mixture and the viscosity measured for samples obtained by single enzyme treatment ($p < 0.05$).

Regarding reducing sugars (RS) (Table 2), a statistically significant difference was also found among the treatments, where the greatest release of reducing sugars was obtained with the treatment with the enzyme PUP[®], followed by its mixing PUP[®] + C[®] and PUP[®] + CC[®]. In this sense, Nagar et al. (2012) reported an increase for this parameter by 4.01 and 18.35% in apple and pineapple pulp respectively, these samples were treated with xylanase. In this regard, Molina (2011) attribute the RS increase to the polysaccharides hydrolysis into monosaccharides. In this way, the pectin in the samples is hydrolyzed in

galacturonic acid by the action of pectinase. However, this increase is influenced by the specificity of the enzymes involved in the treatments, in relation with the composition of substrates (polysaccharides) contained in the food matrix. GuptaU and RaoC (1963) reported the presence of L-rhamnose, D-xylose, L-arabinose, D-glucose, D-galactose and D-galacturonic acid as the main components in jackfruit after acid hydrolysis. In this study, the presence of fructose, glucose, sucrose, and mannose in the jackfruit pulp was found (Table 2); an increase of the first three sugars and a diminution of mannose by enzymatic hydrolysis were observed.

Sreenath et al. (1995) reported when treating mango pulp with Pectinex and Cellulast a reduction of viscosity higher than that obtained by the exclusive use of individual enzymes. It can be attributed to the synergy that exists when combining enzymes with pectinolytic and cellulase activities; long chains of pectin and cellulose are separated simultaneously and each substrate is more available for enzymatic reactions (Vaillant et al. 1999). Taking the viscosity reduction as the first criterion and the RS increase as the second criterion, the best treatment ($p < 0.05$) appeared to be the mixture C[®] + PUP[®] with 94.76% and 347% respectively. Therefore, this treatment was the most appropriate to be optimized.

Enzymatic optimization using response surface methodology (RSM)

A correlation model was found for viscosity parameter ($\hat{y}_{\text{viscosity}}$) with a value of p equal to 0.98 for lack of fit test (Eq. 4). The contour graph shows an inverse dependence between viscosity and time (T); as time increases, viscosity decreases and the lowest value is obtained at 3 h (Fig. 1a). However, viscosity is not really influenced by enzyme concentration (EC). This can be explained by the amount of pectin present in the pulp (from 3.2 to 5.8%), since pectin is the main polymer responsible for viscosity (Haq 2006). An important consideration is the mixture of the

Table 2 Effect of the enzymatic treatments of the jackfruit pulp on the viscosity and reducing sugars

Treatment (tmt)	Viscosity (Cps)	Viscosity reduction (%)	Reducing sugars (mg mL ⁻¹)	Increase reducing sugars (%)
1 Celluzyme (C) [®]	12.57 ± 6.41 ^{ab}	91.70 ± 3.67 ^{ab}	24.54 ± 0.19 ^c	39.64 ± 1.1 ^c
2 Celluzyme X C (CC) [®]	10.88 ± 3.74 ^a	92.82 ± 2.14 ^a	32.46 ± 1.35 ^d	84.74 ± 7.7 ^d
3 Pectinex Ultra Pulp (PUP) [®]	17.39 ± 0.60 ^b	88.52 ± 0.35 ^b	98.31 ± 3.28 ^a	459.51 ± 18.69 ^a
4 C [®] + CC [®]	12.37 ± 4.87 ^{ab}	91.83 ± 2.78 ^{ab}	30.55 ± 4.83 ^{de}	73.86 ± 27.49 ^{de}
5 C [®] + PUP [®]	7.94 ± 0.82 ^a	94.76 ± 0.47 ^a	78.50 ± 1.93 ^b	346.77 ± 11 ^b
6 CC [®] + PUP [®]	9.93 ± 2.25 ^a	93.45 ± 1.28 ^a	63.74 ± 0.38 ^c	262.8 ± 2.2 ^c

(n ± SD) Different letters in the same column indicate significant difference between enzymatic treatments ($p < 0.05$). Initial viscosity value = 141.46 ± 0.85 cps; initial reducing sugar value = 17.57 ± 0.55 mg mL⁻¹

Fig. 1 Contour plot of the influence of PUP® + C® enzyme concentration and incubation time on **a** viscosity and **b** reducing sugars. **c** Decrease in viscosity due to the effect of treatment with PUP® + C® at (1%, 3 h) on the jackfruit

enzymes, which includes pectinlyases for PUP® as cellulases, hemicellulase and beta glucanases for C®, acting together in a synergistic and specific manner. In a first time, the cellulases and hemicellulases depolymerize the cell wall, and then, the pectinlyase catalyzes the eliminatory cleavage of (1,4)- α -D-galacturonan methyl ester (Vaillant et al. 1999). In this sense, increased hydrolysis times let to a complete hydrolysis of polysaccharides complexes.

$$\begin{aligned} \hat{y}_{\text{viscosity}} = & -14.2078T + 2.8388T^2 - 5.8160EC \\ & + 0.9873EC^2 + 7.8423TEC - 1.4016TEC^2 \\ & - 1.9481T^2EC + 0.3581T^2EC^2 \end{aligned} \quad (4)$$

Regarding reducing sugars parameter ($\hat{y}_{\text{RS}}$), the proposed response surface model (Eq. 5) presented a satisfactory value of R^2 of 0.9213. The contour plot indicates RS directly depends on the enzymatic concentration, since the maximum values are obtained at high enzyme

concentration (2.8–3%) and the minimum at low enzyme concentrations (1%). On the other hand, it was observed that the reducing sugars liberation is not time dependent (Fig. 1b). Thus, while viscosity depends directly on the incubation time due to the concentration of pectin in the bulbs of jackfruit, the release of RS is dependent on enzyme concentration, because their release is controlled by the depolymerization of polysaccharides in the pulp. Chowdhury et al. (1997) found the main sugars in the edible part of the jackfruit were glucose, fructose and sucrose.

$$\begin{aligned} \hat{y}_{\text{RS}} = & 127.05T - 19.95T^2 + 152.39EC - 23.98EC^2 \\ & - 131.42TEC + 26.78TEC^2 + 21.72T^2EC \\ & - 4.24T^2EC^2 \end{aligned} \quad (5)$$

Finally, the viscosity kinetics shows a decrease of 79.28% (27.09 cps) in the first 20 min with respect to the

initial value (130.81 cps) and up to 94.6% (7.03 cps) at 180 min (Fig. 1c).

Rheological behavior of the different juices

The simple shear test was carried out for different samples: controls (DJP and HJ), HJ with maltodextrin (40 and 50% w/TSS) before (HJM) and after of drying (HJMR), as well as for DJP with maltodextrin (10 and 25% w/TSS) before (DJPM) and after drying (DJPMR).

Non-Newtonian fluid behavior was observed for shear thinning to flow (pseudoplastic), (Fig. 2a) for all samples; as the shear rate increases, the viscosity decreases. Also, these materials present structural changes as the deformation increases, which can generate a break or rearrangement of the chains until reaching a more stable state. At high concentrations, the polysaccharide molecules become entangled and unraveled after a period of time, being stabilized by intermolecular hydrogen bonding associations and non-covalent interactions (Garcia-Cruz et al. 2013). Thus, for the HJM (40%), a behavior very similar to starch is observed, due to the maltodextrin content. This sample has a non-Newtonian behavior because when the shear rate increases, its viscosity slightly decreases until it reaches a plateau; this behavior may be due to the low viscosity of the HJ and the possible rupture of the chains during spray drying.

For the oscillatory shear stress test for DJP, DJPM (10%), DJPM (25%), DJPMR (25%), HJMR (40%), HJM (50%) and HJMR (50%), it was observed that the storage (G') or elastic modulus is greater than the loss (G'') or viscous modulus. This evidences the formation of a strong gel (Fig. 2b). This behavior coincides with that reported for mango peel pectin (Koubala et al. 2009). On the other hand, for the samples of HJ, DJPMR (10%), HJM (40%)

the viscous modulus (G'') is greater than the elastic (G'), this is characteristic of samples without gelatinization due to their low viscosity. Thus, it was found that DJPMR (10%) and HJMR (40%) do not exhibit a behavior similar to that of the control (DJP and HJ), nor to their controls before drying (DJPM (10%) and HJM (40%)). This is possibly due to the low concentration of the encapsulating material. The thermal treatment and the atomization could generate a breakdown of the structures, so that they lose their capacity to rearrange.

Glass transition temperature and drying performance

The T_g value (Table 3) in the samples decreases with the addition of maltodextrin in mixtures with high sugar contents, this phenomenon is attributed to the interaction of the simple sugar (Table 4) in the jackfruit samples and the maltodextrin (glucose and fructose at $0.22 \pm 0.07 \text{ mg mL}^{-1}$ and sucrose at $0.15 \pm 0.03 \text{ mg mL}^{-1}$) with the water causing a plasticizing effect. In this sense, Goula et al. (2008) reported the plasticizing behavior in mango fruit with above 40% maltodextrin content (weight fraction). This is explained by the interaction of water with the insoluble material (pulp) and the soluble low-molecular-weight carbohydrates by means of dipole–dipole interactions of intra and inter macromolecular hydrogen bonds of water with soluble solids (sugars), this difficult the drying process and increase the humidity in the powder (Goula and Adamopoulos 2010) as a result of low moisture diffusibility. Moreover, there is a relationship between the concentration of sugars and acids present in the samples with the easy of water evaporation during drying. Shavakhi et al. (2012) found drying indexes of 0.27, 0.51 and 0.85 for fructose, glucose, and sucrose respectively; this

Fig. 2 Graphics simple test (a) and oscillatory shear (b) in pulp samples (JP) and hydrolyzed juice jackfruit (HJ) spray dried

Table 3 Physicochemical characteristics of samples treated by spray drying and controls

Treatment		TSS (°Brix)	Viscosity (cps)*		T _g (°C)	Drying yield (%)
			Initial solution	Reconstituted solution		
1	DJP	11.7 ± 0.8 ^f	79.61 ± 11.68 ^c	UD	UD	UD
2	DJPM 10%	13.5 ± 0.5 ^e	100.83 ± 11.17 ^{bA}	96.72 ± 11.86 ^{bA}	65.76 ± 0.41 ^a	50 ± 1.8 ^c
3	DJPM 25%	15.6 ± 0.3 ^d	130.89 ± 16.90 ^{aA}	123.57 ± 14.93 ^{aA}	44.62 ± 0.50 ^c	57 ± 4.7 ^{bc}
4	HJ	24.6 ± 1.4 ^c	7.66 ± 0.45 ^d	UD	UD	UD
5	HJM 40%	31.2 ± 1.7 ^b	13.27 ± 0.74 ^{dA}	11.53 ± 0.06 ^{cA}	57.25 ± 0.42 ^b	65.4 ± 5.8 ^{ab}
6	HJM 50%	35.3 ± 0.2 ^a	15.12 ± 0.41 ^{dA}	14.33 ± 0.1 ^{cA}	40.76 ± 0.64 ^d	74 ± 3.3 ^a

(n ± SD) Different lowercase letters in the same column indicate significant difference between samples ($p < 0.05$) and *different uppercase letters in the same row indicate significant difference between the viscosity values ($p < 0.05$). Total soluble solids (TSS), Diluted jackfruit pulp (DJP at 50%), Hydrolyzed juice (HJ), Maltodextrin (M), Glass transition temperature (T_g), Undetermined (UD)

Table 4 Physicochemical characteristics of the best treatments in enzymatic hydrolysis, spray drying and control

Physicochemical characteristics	JP	HJ	HJM*	HJMR*
Humidity (%)	74.92 ± 0.26 ^c	79.38 ± 0.00 ^d	71.38 ± 0.00 ^b	69.06 ± 1.14 ^a
Ashes (%)	0.78 ± 0.01 ^b	0.78 ± 0.01 ^b	0.69 ± 0.00 ^a	0.70 ± 0.01 ^a
Titrateable acidity (%AC)	0.40 ± 0.02 ^a	0.55 ± 0.02 ^{bc}	0.49 ± 0.02 ^b	0.62 ± 0.05 ^c
TSS (°Brix)	24.1 ± 0.42 ^a	24.25 ± 0.78 ^a	31.40 ± 0.42 ^b	32.0 ± 0.85 ^b
Total sugars (g/100 g)	12.41 ± 4.52 ^b	15.12 ± 1.37 ^b	21.75 ± 1.13 ^a	23.85 ± 1.49 ^a
Reducing sugars (g/100 g)	4.27 ± 0.07 ^b	15.96 ± 2.57 ^a	16.69 ± 0.38 ^a	16.95 ± 1.84 ^a
Glucose and fructose (mg mL ⁻¹)	1.35 ± 0.14 ^a	2.18 ± 0.27 ^a	2.33 ± 0.65 ^a	2.18 ± 0.74 ^a
Sucrose (mg mL ⁻¹)	1.20 ± 0.07 ^a	1.85 ± 0.21 ^a	1.69 ± 0.69 ^a	1.65 ± 0.91 ^a
Mannose (mg mL ⁻¹)	1.0 ± 0.14 ^a	0.14 ± 0.14 ^b	0.33 ± 0.21 ^b	0.27 ± 0.16 ^b
Ascorbic acid (mg/100 g)	15.67 ± 1.15 ^a	17.33 ± 4.62 ^a	17.33 ± 2.52 ^a	18.33 ± 2.08 ^a
Total carotenoids (µg/100 g)	64.40 ± 5.99 ^b	113.37 ± 0.55 ^a	81.74 ± 0.55 ^{ab}	71.72 ± 22.36 ^b
Color				
L	41.89 ± 1.83 ^a	42.15 ± 3.3 ^a	35.18 ± 0.30 ^b	34.43 ± 0.05 ^b
a	− 0.95 ± 0.34 ^a	− 2.46 ± 1.03 ^{ab}	− 2.96 ± 0.48 ^b	− 3.77 ± 0.69 ^b
b	25.17 ± 0.66 ^a	23.19 ± 0.71 ^{ab}	18.59 ± 2.55 ^{bc}	19.51 ± 1.08 ^c

(n ± SD) Different letters in the same column indicate significant difference between samples ($p < 0.05$). Citric acid (CA), *(50%: TSS/weight)

indicates that fructose is more difficult to dry followed by glucose and sucrose. This behavior is in accordance with the results obtained for this study, where lower fructose, glucose and sucrose concentrations were found for the DJP than for the HJ (Table 4). This explains the lower required maltodextrin concentration for DJP drying, compared to the amount used for the HJ. In addition, the quantity of water presents in the sample before drying is related to performance process. Thus, a low yield was observed in the DJP drying, which is due to the energy required for evaporating the water of the sample in the drying process. According to Grabowski et al. (2006), hydrolyzed samples with high solids contents and low viscosity show high drying performance (Table 3), because of the enzymatic treatment and the addition of maltodextrin. In this way, the

HJM 50% treatment presents a higher performance and its rheological properties are not affected by spray drying. Then, this treatment is suitable for the stabilization of the hydrolyzed jackfruit pulp.

In another hand, the physical parameters of the spray drying treatments and the controls (DJP and HJ) show an increase in TSS and viscosity with the addition of maltodextrin. This is in accordance with the results found by Quek et al. (2007) in watermelon juice. A non-significant reduction in viscosity was found between the initial and reconstituted solution in the treatments; this behavior can be associated with the rearrangement capacity of the sample's molecules, induced by the spray drying temperature and the particle size (Goula and Adamopoulos 2010).

Physicochemical characterization

The physicochemical characteristics of JP and the optimized enzymatic hydrolysis treatment (HJ), show an increase of moisture, titratable acidity, reducing sugars, total carotenoids content and a decrease of the concentration of mannose in HJ (Table 4, $p < 0.05$). This can be explained by the hydrolysis treatment, since these components are liberated by cellular wall depolymerization of jackfruit. Chauhan et al. (2004) reported an increase in titratable acidity, related to the release of carboxyl groups from the pectin molecules. Also, Faria et al. (2009) reported a total carotenoids content from 34.13 to 150.34 μg per 100 g of the jackfruit fresh sample depending on the state of ripeness of the fruit. This coincides with the results obtained in this study. An increase of 75% in the total carotenoid content was observed in the HJ with respect to the JP, due to the release of compounds by enzymatic hydrolysis. In addition, a statistically significant difference ($p < 0.05$) was not found between the HJM and the HJMR, which means that drying temperature does not affect the carotenoid content, due to the protector effect of maltodextrin.

Moreover, a statistically significant difference is observed between the hydrolyzed juice and the hydrolyzed juice plus maltodextrin in the percentage of humidity, ash and total soluble solids (TSS). The hydrolyzed juice plus maltodextrin reconstituted presents lower humidity (69.0%), but higher ash (0.78%) while hydrolyzed juice presents higher humidity (79.38%) and lower ash (0.70%). This is due to the high amount of TSS present in the sample, because the maltodextrin addition increases the TSS from 24.25° Brix (hydrolyzed juice) to 32° Brix.

For the color parameter, Chauhan et al. (2004) observed a decrease of this parameter after enzymatic hydrolysis. This could be associated with the heat treatment for enzymatic inactivation. However, in this study, no statistically significant difference was found between the color parameter of pulp and the hydrolyzed juice. However, a statistically significant difference was found between the pulp, the HJM and the HJMR in all the parameters. This is due to the addition of the encapsulating material (maltodextrin), but there was no statistically significant difference between the hydrolyzed juice maltodextrin and the hydrolyzed juice maltodextrin reconstituted. In fact, for these parameters, it indicates that juice is not affected by the drying process.

The physicochemical characteristics of the spray dried jackfruit with 50% maltodextrin (TSS/w) were determined and values were obtained for humidity $7.4 \pm 0.13\%$, ash 2.06 ± 0.05 , water activity (a_w) 0.1987 ± 0.0042 , solubility $98.90 \pm 0.09\%$, color L 98.90 ± 0.09 , a^*

-2.03 ± 0.25 and b^* 21.32 ± 1.92 . These results differ from those obtained by Thaiphant (2012) when treating hydrolyzed jackfruit juice added with maltodextrin (38% w/volume) and spray drying (150 °C). A humidity of 57.37% and ash of 0.36% were reported. Additionally, Wong and Tan (2017) reported a humidity content of 6.68%, a_w of 0.2, solubility of 98.71%, L values of 86.49, a^* of 0.90 and b^* of 38.89 for jackfruit powder spray dried at 160 °C, with 30% maltodextrin from juice hydrolyzed with Cellulast® (yields of 66.9%); they consider that the values obtained for a_w are considered stable (< 0.6) against the browning, microbial activity, hydrolytic, enzymatic and auto-oxidation reactions (Marques et al. 2007). Furthermore, values lower than 10% for humidity are considered safe (Tze et al. 2012), the difference of colors obtained are influenced by the raw material and this differs depending on the state of maturity, harvest season and place of production (Goswami et al. 2011).

Conclusion

The enzymatic treatment with cellulzyme® and Pectinex Ultra Pulp® applied to the pulp of jackfruit favored the physicochemical properties by increasing the content of total carotenes and reducing sugars. They were released thanks to the synergistic action of the pectinase and cellulase activities. In the same way, the response surface model indicates a direct relationship between viscosity and incubation time, due to the concentration of pectin in the bulbs of jackfruit, as well as a dependence of the reducing sugars on enzyme concentration, since reducing sugars are released by the depolymerization of their respective polysaccharides present in the pulp. In fact, the viscosity reduction curve was correlated with the obtained response surface model with respect to the initial value (130.81 cps) up to 94.6% (7.03 cps) at 180 min. On the other hand, the hydrolyzed juice spray-dried with 50% of maltodextrin had the best yield and presents the rheological and physicochemical properties similar to the fresh product. However, the vitreous transition temperature of jackfruit powder was influenced by the addition of maltodextrin, inducing the plasticizing effect of water in the treatments because the simple sugars addition. In this case, we can conclude that the spray drying is suitable for jackfruit juice because it does not modify its physicochemical characteristics and rheological behavior.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests.

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