



Reagent behavior of jabuticaba pulp with different maltodextrin concentrations

Gustavo Santos de LIMA¹ , Romário Oliveira de ANDRADE¹ , Josivanda Palmeira GOMES¹ , Ana Paula Trindade ROCHA¹ , Katcilanya Menezes de ALMEIDA² , Jessica Bezerra dos Santos RODRIGUES² , Júlio César Bezerra Vilar da SILVA³ , Maiza Araújo CORDÃO⁴ , Natália Ferreira NEGREIROS² , Radmila Raianni Alves RIBEIRO² , Myrella Cariry LIRA⁴ , Thyago Araújo GURJÃO¹ , Caio Franklin Vieira de FIGUEIREDO¹ , Raimundo BERNADINO FILHO⁵ , Neila Lidiany RIBEIRO^{2*}

Abstract

Viscosity is the main parameter studied in liquid and semi-liquid foods and is considered an important means of characterizing fluid texture. Therefore, this study aimed to determine the influence of maltodextrin concentration on the physical, chemical, and physicochemical properties and apparent viscosity of jabuticaba pulp at different temperatures. Four formulations were evaluated with maltodextrin concentrations of 0, 15, 25, and 35%. These were characterized in terms of physical, chemical, and physicochemical parameters and bioactive compounds. The rheological behavior of the formulations was assessed at temperatures of 10, 20, and 30 °C, with rotational speeds ranging from 50 to 200 rpm, and fitted to the Casson, Herschel–Bulkley, Mizrahi–Berk, and Ostwald-de-Waele models. The formulated pulps showed altered characteristics with increasing concentrations of the additive, including reductions in water content, acidity, anthocyanins, flavonoids, and colorimetric parameters, and increases in total soluble solids and glucose. The rheological models studied showed good fits to the flow curves of jabuticaba pulps with varying maltodextrin concentrations, with the Mizrahi–Berk model providing the best fit, showing the highest coefficients of determination and the lowest root mean square deviations.

Keywords: apparent viscosity; flow models; physicochemical properties; temperature variation.

Practical Application: Understanding the influence of maltodextrin concentration on the physicochemical and rheological properties of jabuticaba pulp enables the development of more stable and functional food products.

1 INTRODUCTION

Jabuticaba is a fruit from the tree species *Myrciaria* spp. Berg, native to the Atlantic Forest in southern Brazil, which has a subtropical climate and thrives in soils with a good water supply, flowering between late winter and early spring (Alves et al., 2014). It presents numerous varieties, with *Myrciaria cauliflora* standing out as the most widespread and appreciated by Brazilian consumers. It is consumed fresh or processed into juices, jams, wines, and liqueurs, thus having great potential in the food industry, in addition to containing substances with medicinal properties (Borges et al., 2014).

The development of new products is an essential factor for the food industry, which must constantly innovate to stay ahead of the competition. Understanding the rheological characteristics of food products and fruit derivatives is highly important during processing stages, including technological, sensory, and engineering applications such as the design of pumps, pipelines, heat exchangers, and mixing tanks (Granjeiro et al., 2007; Toralles et al., 2006). Viscosity is one of the main parameters

studied in liquid and semi-liquid foods and is considered a fundamental means of characterizing fluid texture. Several factors can alter the rheological behavior of foods, influenced by their quantitative and qualitative composition, depending on the type and treatments applied during manufacturing processes, including thermal heating and/or cooling procedures (Feitosa et al., 2015; Ferreira et al., 2008; Vandresen et al., 2009).

In this context, selecting an appropriate encapsulating material becomes essential for product characteristics, as it influences the retention of volatile compounds, the achievement of emulsifying properties, and the nutritional quality and shelf life of the final product (Souza et al., 2015). Maltodextrin is one of the main additives used to assist in the spray drying of fruit pulp. However, its addition directly affects the viscosity of the mixture and the drying process (Fernandes et al., 2008). Studies conducted by Fernandes et al. (2008) on umbu-cajá pulps formulated with maltodextrin (2.5, 5, and 7.5%); umê (Quast et al., 2013); and noni (Sousa et al., 2017) reveal that the concentrations of these additives directly influence the viscosity of the formulated pulps.

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¹Universidade Federal de Campina Grande, Campina Grande, Paraíba, Brazil.

²Universidade Federal da Paraíba, João Pessoa, Paraíba, Brazil.

³Instituto Federal da Paraíba, Areia, Paraíba, Brazil.

⁴Universidade Estadual da Paraíba, Campina Grande, Paraíba, Brazil.

⁵Universidade Federal do Agreste de Pernambuco, Garunhuns, Pernambuco, Brazil.

*Corresponding author: neilalr@hotmail.com

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Research by Feitosa et al. (2015) shows a decrease in apparent viscosity of approximately 86% between rotational speeds of 20 and 200 rpm, with 29% observed between the first two speeds (20 and 40 rpm), for murta pulp at different temperatures. Given the widespread use of maltodextrin in fruit pulps, it is of interest to the industry to understand its influence on rheological behavior and to evaluate the effect of this additive on pulp formulations.

Therefore, the objective of this study was to determine the influence of maltodextrin concentration on the apparent viscosity of jabuticaba pulp at different temperatures, identify the model that best describes the rheological behavior of the formulations, and analyze the physicochemical properties and bioactive compounds of both fresh and formulated pulps.

1.1. Relevance of the work

Understanding the influence of maltodextrin concentration on the physicochemical and rheological properties of jabuticaba pulp enables the development of more stable and functional food products. The findings support the formulation of jabuticaba-based beverages, sauces, and encapsulated bioactive compounds with tailored viscosity and texture profiles. The optimal rheological model (Mizrahi–Berk) can be applied in industrial processing to predict flow behavior under varying temperature and shear conditions, improving efficiency in mixing, pumping, and packaging operations. Additionally, the modulation of bioactive compound retention through maltodextrin levels offers potential for nutraceutical applications and shelf-life enhancement.

2 MATERIAL AND METHODS

2.1 Experimental location and sample preparation

The research was conducted at the Cold Technology Laboratory, part of the Academic Unit of Food Engineering at the Center for Technology and Natural Resources (CTRN), Federal University of Campina Grande (UFCG), located in Campina Grande, Paraíba, Brazil. Mature jabuticaba fruits were sourced from the Brejo Paraibano region. After selection, the fruits were washed and sanitized in chlorinated water (50 ppm of active chlorine) for 15 min. Pulping was performed using a horizontal pulper with a 2 mm mesh to obtain a uniform product. The pulp was homogenized, packaged in 1000 mL low-density polyethylene bags, frozen, and stored at $-18\text{ }^{\circ}\text{C}$ until analysis.

2.2 Formulation and homogenization

Following preliminary tests to determine ideal concentrations, four formulations were prepared using maltodextrin DE 10 (Equivalent Dextrose 10). Homogenization was performed using a Britânia brand 2-in-1 food processor for 60 s. The formulations were as follows:

- Type A: jabuticaba pulp without additive
- Type B: jabuticaba pulp with 15% maltodextrin
- Type C: jabuticaba pulp with 25% maltodextrin
- Type D: jabuticaba pulp with 35% maltodextrin

2.3 Physicochemical and bioactive characterization

All analyses were performed in triplicate. The following parameters were evaluated:

- Moisture, total solids, and total soluble solids (TSS): measured using a portable refractometer (Abbe-RT32)
- pH: determined by potentiometric method using a digital pH meter (Tecnal-TEC-2)
- Titratable acidity: measured by the acidimetric method
- Ash content and reducing sugars (glucose): determined by the Lane and Eynon method, following protocols from the Instituto Adolfo Lutz (IAL, 2008)
- Ascorbic acid: measured according to Association of Official Analytical Chemists (1997), modified by Benassi and Antunes (1988)
- Water activity (a_w): measured using a hygrometer (Aqualab 4TE–Decagon Devices)
- Ratio: calculated as the ratio between TSS and titratable acidity (TA)
- Anthocyanins and flavonoids: determined by the method of Francis (1982)
- Color: measured using a Delta Color reflectance colorimeter (Delta Vista d.0), calibrated with a D65 light source and a 10° observation angle. Color parameters included L^* (lightness), a^* ($+a^*$ red, $-a^*$ green), and b^* ($+b^*$ yellow, $-b^*$ blue)

2.4 Rheological measurements

Rheological behavior was assessed using a programmable rotational viscometer (DV-II, Brookfield), coupled to a thermostatic bath for temperature control. Measurements were taken using spindle number 05 at 13 rotational speeds (50–200 rpm) and three temperatures (10, 20, and $30\text{ }^{\circ}\text{C}$). A 150 mL double-walled beaker was used to maintain sample temperature. Data were recorded 30 s after equilibrium at each speed. All tests were performed in triplicate.

Shear stress and shear rate were calculated from the viscometer data using the methodology proposed by Mitschka (1982).

2.5 Rheological modeling and temperature effect

The rheological models—Casson, Herschel–Bulkley, Mizrahi–Berk, and Ostwald–de-Waele (Power Law)—were fitted to shear stress versus shear rate curves using Statistica software version 8.0.

To evaluate the effect of temperature on apparent viscosity, the Arrhenius equation was applied. Apparent viscosity (Pa·s) was plotted as a function of the inverse of temperature (K^{-1}) at a shear rate of 100 s^{-1} , a typical industrial agitation rate (Krokida et al., 2001). Linear regression was performed using Origin software version 8.0. Model performance was assessed using the coefficient of determination (R^2) and root mean square deviation (RMSD).

3 RESULTS

The results obtained for the physical, chemical, physicochemical parameters, and bioactive compounds of jabuticaba pulp formulated with different concentrations of maltodextrin are presented below. The moisture content of the fresh jabuticaba pulp was 84.77%, while in the formulations with 15, 25, and 35% maltodextrin, the values progressively decreased, reaching 66.0% in the formulation with the highest concentration. Water activity (a_w) showed an average value of 0.978 across all samples, with no significant variations between formulations.

Total solids increased proportionally with the concentration of maltodextrin. The average value of TSS in the fresh pulp was 15.23%, with increases observed in the formulations containing the additive. The pH of the fresh pulp was 3.44, with elevated values in the formulations with maltodextrin. TA showed an average value of 1.17% in the fresh pulp and 0.88% in the formulation with 35% maltodextrin (Table 1).

The levels of anthocyanins and flavonoids showed a decreasing trend with increasing maltodextrin concentration. The luminosity (L) of the fresh pulp was 27.06, with similar values in the formulations containing 15, 25, and 35% maltodextrin. The a^* and b^* color coordinates of the fresh pulp were 13.85 and 11.46, respectively, while in the formulation with 35% maltodextrin, the average values were 10.78 for both (Table 1).

The rheological models of Casson, Herschel–Bulkley, Mizrahi–Berk, and Ostwald-de-Waele were fitted to the experimental data of jabuticaba pulps with different maltodextrin concentrations (0, 15, 25, and 35%) and temperatures (10, 20, and 30 °C). All models showed coefficients of determination (R^2) above 93%. The Mizrahi–Berk model provided the best fits, with R^2 values above 97% and RMSDs below 0.0042.

Table 2 presents the parameters of the Mizrahi–Berk model fitted to the shear stress versus shear rate curves for the different formulations and temperatures. Figure 1 shows the rheological

Table 1. Concentration of physical, chemical, physicochemical parameters, and bioactive compounds of jabuticaba pulp at different maltodextrin concentrations.

Parameters	Concentrations of maltodextrin (%)			
	0	15	25	35
Moisture content (%)	84.77 ± 0.12a	74.80 ± 0.30b	70.20 ± 0.2c	66.00 ± 0.28b
Water activity (a_w)	0.978 ± 0.00a	0.974 ± 0.00b	0.971 ± 0.02b	0.971 ± 0.00b
Total solids (%)	15.23 ± 0.12d	25.20 ± 0.30c	29.80 ± 0.20b	34.00 ± 0.28a
pH	3.44 ± 0.06d	3.62 ± 0.04c	3.70 ± 0.01b	3.81 ± 0.02a
Acidity (%)	1.17 ± 0.04a	1.05 ± 0.01b	0.95 ± 0.01b	0.88 ± 0.01c
Soluble solids (°Brix)	16.28 ± 0.16b	27.12 ± 0.15b	31.14 ± 0.12b	32.19 ± 0.00a
Anthocyanins	16.37 ± 0.20c	12.96 ± 0.87a	12.38 ± 0.44a	8.87 ± 0.20b
Flavonoids	39.04 ± 0.28a	36.13 ± 0.75b	34.54 ± 0.92b	24.90 ± 0.88c
Lightness (L^*)	27.06 ± 0.042a	26.71 ± 0.047b	26.18 ± 0.17c	25.94 ± 0.22c
Red intensity ($+a^*$)	13.85 ± 0.049a	12.97 ± 0.050b	11.63 ± 0.04c	10.78 ± 0.08d
Yellow intensity ($+b^*$)	11.46 ± 0.067a	11.41 ± 0.031a	10.86 ± 0.08b	10.78 ± 0.06b

Means followed by the same letter in the rows do not differ statistically from each other according to Tukey's test at a 1% probability level.

Table 2. Parameters of the Mizrahi and Berk model, coefficient of determination, and mean square deviations of the rheological models applied to jabuticaba pulp in different formulations.

Parameters		K_{OM}	K_M	n_M	R^2 (%)	MSD
Concentrations of maltodextrin (%)	Temperature (°C)					
0	10	3.9987	0.0054	0.802581	99.352	0.0085
	20	3.2404	0.0460	0.639583	98.999	0.0212
	30	3.4395	0.0008	1.212276	97.661	0.0218
15	10	3.7850	0.0209	0.886756	99.568	0.0215
	20	2.5459	0.4017	0.377131	99.981	0.0042
	30	3.5262	0.0108	0.904701	99.933	0.0058
25	10	3.1289	0.3424	0.472057	99.916	0.0129
	20	2.5952	0.4427	0.411116	99.902	0.0126
	30	2.0977	0.5968	0.336536	99.751	0.0168
35	10	1.8159	1.0182	0.330904	99.979	0.0075
	20	-1.2656	3.2423	0.169857	99.967	0.0082
	30	0.0556	3.0290	0.204075	99.904	0.0182

R^2 : coefficient of determination; MSD: mean square deviations; K_{OM} : consistency constant (modified); K_M : consistency coefficient; n_M : flow behavior exponent.

behavior of the formulations with 0, 15, 25, and 35% maltodextrin, with shear stress values (Pa) plotted against shear rate (s^{-1}), fitted using the Mizrahi–Berk model.

The results indicate that, in the Mizrahi–Berk model, deformation in the control formulation decreases with increasing temperature, except at 20 °C, where an increase occurs.

In formulations F1 and F2, deformation decreases with increasing temperature, while in F3, deformation increases with temperature. The lowest shear stress values were observed at higher temperatures, at a fixed shear rate.

Table 3 presents the parameters of the Casson model fitted to the shear stress versus shear rate curves for the formulations

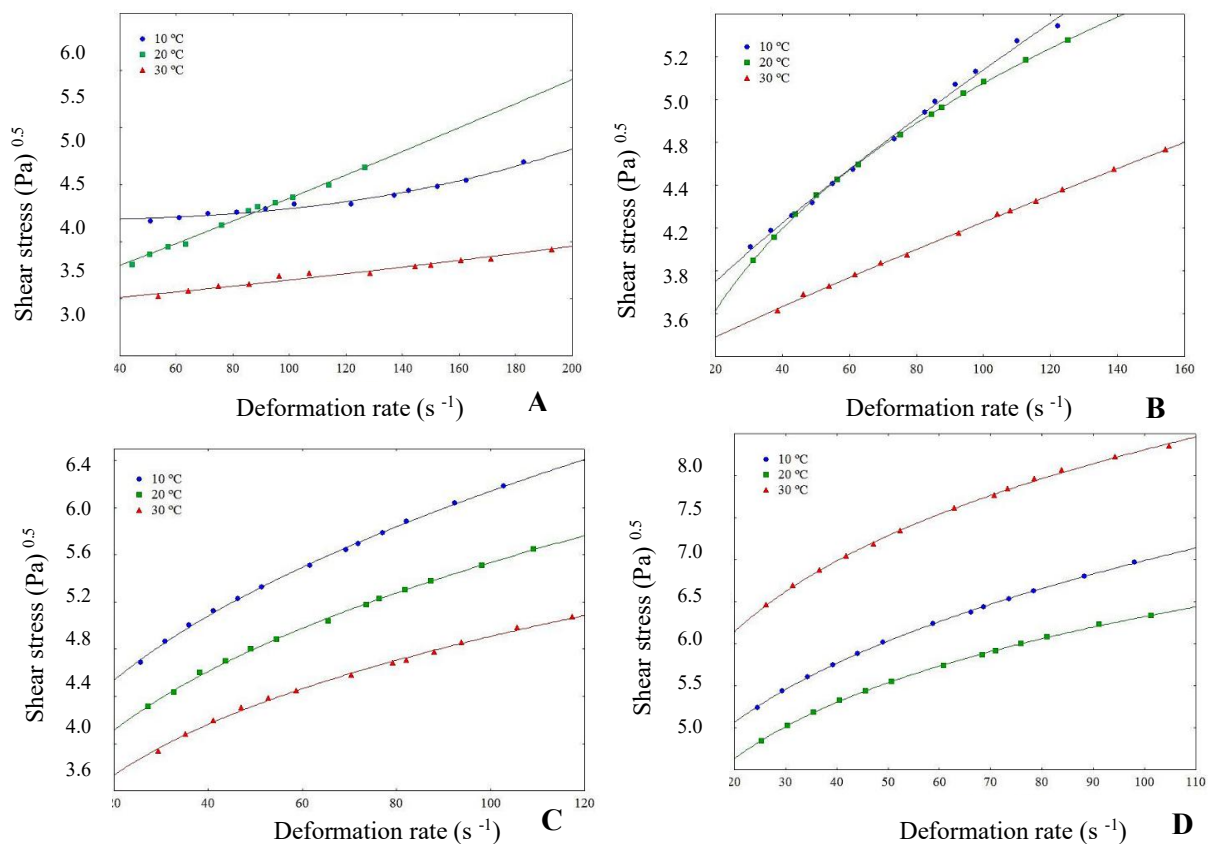


Figure 1. Experimental and predicted values from the Mizrahi and Berk model of shear stress versus shear rate for jabuticaba pulp: (A) fresh, (B) F1, (C) F2, and (D) F3.

Table 3. Parameters of the Casson model, coefficient of determination, and mean square deviations for jabuticaba pulp formulations with different maltodextrin concentrations.

Parameters					
Concentrations of maltodextrin (%)	Temperature (°C)	K_{Oc}	Kc	R^2 (%)	MSD
0	10	3.8122	0.0404	99.066	0.0102
	20	3.0227	0.1099	98.928	0.0219
	30	3.0562	0.0623	96.266	0.0276
15	10	3.1139	0.1915	99.027	0.0323
	20	3.0226	0.1804	99.928	0.0082
	30	3.0510	0.1192	99.382	0.0177
25	10	3.2540	0.2889	99.914	0.0133
	20	3.0086	0.2533	99.875	0.0142
	30	2.8740	0.2039	99.663	0.0195
35	10	3.0771	0.3445	99.881	0.0179
	20	2.9200	0.2949	99.587	0.0291
	30	4.0967	0.3755	99.587	0.0376

R^2 : coefficient of determination; MSD: mean square deviations; K_{Oc} : consistency coefficient (original); Kc: consistency coefficient.

with 0, 15, 25, and 35% maltodextrin at temperatures of 10, 20, and 30 °C. The coefficients of determination (R^2) were above 96.26%, and RMSD values were below 0.0037. The Koc parameter decreased with the inclusion of maltodextrin, being higher in F2 compared to F1 and F3. Regarding temperature, Koc decreased up to 20 °C in the control, F1, and F3 formulations, increasing at 30 °C. In F2, Koc decreased with increasing temperature. The plastic viscosity coefficient (Kc) increased with the inclusion of maltodextrin. Regarding temperature, an irregular behavior was observed: in the control, Kc increased up to 20 °C and decreased at 30 °C; in F1 and F2, Kc decreased with increasing temperature; in F3, there was a decrease from 10 to 20 °C and an increase at 30 °C.

Table 4 presents the parameters of the Herschel–Bulkley model fitted to the experimental data of the formulations with different maltodextrin concentrations and temperatures. R^2 values were above 97.58%, and RMSD values were below 0.2692.

Initial shear stress (τ_0H) decreased with increasing maltodextrin concentration. Regarding temperature, τ_0H decreased from 10 to 20 °C in the control, F1, and F3 formulations, and increased at 30 °C. In F3, the variation ranged from 6.41 to –2.43. In F2, τ_0H decreased with increasing temperature. For a fixed shear stress, the shear rate decreased with increasing temperature in all formulations.

Table 5 presents the parameters of the Ostwald–de-Waele model fitted to the shear stress versus shear rate curves. R^2 values were above 93.90%, and RMSD values were below 0.4584. The consistency index (K) decreased with the inclusion of maltodextrin, with the lowest value observed in F2 at 30 °C and the highest in the control at 10 °C. In the control, F1, and F3 formulations, K decreased from 10 to 20 °C and increased at 30 °C. In F2, K decreased with increasing temperature. The flow behavior index (n) ranged from 0.11 to 0.44 in all samples, with a decreasing trend as temperature increased.

Table 4. Parameters of the Herschel–Bulkley model, coefficient of determination, and mean square deviations for jabuticaba pulp formulations with different maltodextrin concentrations.

Parameters						
Concentrations of maltodextrin (%)	Temperature (°C)	τ_{0H}	K_H	n_H	R^2 (%)	MSD
0	10	16.1122	0.0295	0.8760	99.335	0.0743
	20	10.7711	0.1990	0.7462	99.024	0.1700
	30	11.9673	0.0027	1.3617	97.588	0.1654
15	10	14.6716	0.0912	1.0328	99.566	0.2049
	20	7.92567	1.2841	0.5391	99.981	0.0380
	30	12.7088	0.0423	1.0432	99.936	0.0476
25	10	12.2249	1.0824	0.6859	99.918	0.1386
	20	8.95535	1.2595	0.6180	99.906	0.1227
	30	6.80067	1.4244	0.5422	99.749	0.1521
35	10	6.41373	2.6708	0.5631	99.978	0.0858
	20	–2.4383	6.1028	0.3875	99.965	0.0864
	30	–1.3217	10.1496	0.3939	99.89	0.2692

R^2 : coefficient of determination; MSD: mean square deviations; K_H : consistency coefficient (Herschel-type); n_H : flow behavior exponent (Herschel-type).

Table 5. Parameters of the Ostwald–de Waele model, coefficient of determination, and mean square deviations for jabuticaba pulp formulations with different maltodextrin concentrations.

Parameters					
Concentrations of maltodextrin (%)	Temperature (°C)	K	N	R^2 (%)	MSD
0	10	1.043.876	0.115683	97.514	0.1438
	20	5.388.083	0.250889	98.121	0.2358
	30	5.982.567	0.178686	93.901	0.2630
15	10	5.342.719	0.337903	97.829	0.4584
	20	5.141.088	0.328246	99.824	0.1168
	30	5.404.292	0.262815	97.895	0.2740
25	10	5.976.388	0.397754	99.637	0.2917
	20	5.021.897	0.391636	99.731	0.2077
	30	4.600.450	0.359313	99.638	0.1827
35	10	5.342.292	0.447156	99.932	0.1519
	20	4.824.500	0.423822	99.960	0.0919
	30	9.452.622	0.404768	99.889	0.2697

R^2 : coefficient of determination; MSD: mean square deviations; K: consistency (power law); n: flow behavior index (power law).

Figures 2 and 3 show the rheograms of the formulations with 0, 15, 25, and 35% maltodextrin, fitted using the Casson and Herschel–Bulkley models, respectively. In all models, deformation in the control formulation decreased with increasing temperature, except at 20 °C, where an increase was observed. In formulations F1 and F2, deformation decreased with increasing temperature, while in F3, deformation increased with temperature.

4 DISCUSSION

The results obtained demonstrate that the addition of maltodextrin significantly influenced the physicochemical and rheological properties of jabuticaba pulp. The reduction in moisture content with increasing carrier concentration confirms the effectiveness of maltodextrin in incorporating solids, a behavior previously reported by Galdino (2011) and Diógenes et al. (2015) in other food matrices. This reduction contributes to decreased perishability of the product, favoring its stability during storage.

Despite the decrease in moisture content, water activity (a_w) remained high, indicating that the pulp remains susceptible to microbial growth, reinforcing the need for proper preservation.

The increases in total solids and TSS with the addition of maltodextrin are consistent with studies by Melo (2011) and Oliveira (2012), highlighting the enrichment of the matrix with solid components from the additive.

The inverse behavior between pH and TA was also observed by Melo (2011), suggesting that maltodextrin acts as a diluent of the organic acids present in the pulp. The reduction in anthocyanin and flavonoid content with increasing maltodextrin concentration may be related to the dilution of bioactive compounds, as observed by Krumreich et al. (2016) in uvaia pulp.

Color parameters indicate that even with the addition of maltodextrin, the formulations maintained the dark coloration characteristic of jabuticaba, although there was a reduction in a^* and b^* coordinates, as also reported by Diógenes et al. (2015) in pitanga and “Haden” mango pulps.

Regarding rheological behavior, all models tested showed good fits to the experimental data, with the Mizrahi–Berk model standing out by presenting the highest R^2 values and the lowest RMSD. This result is supported by studies by Braga et al. (2013), Ongaratto and Viotto (2015), and Sousa et al. (2017), which also identified this model as the most

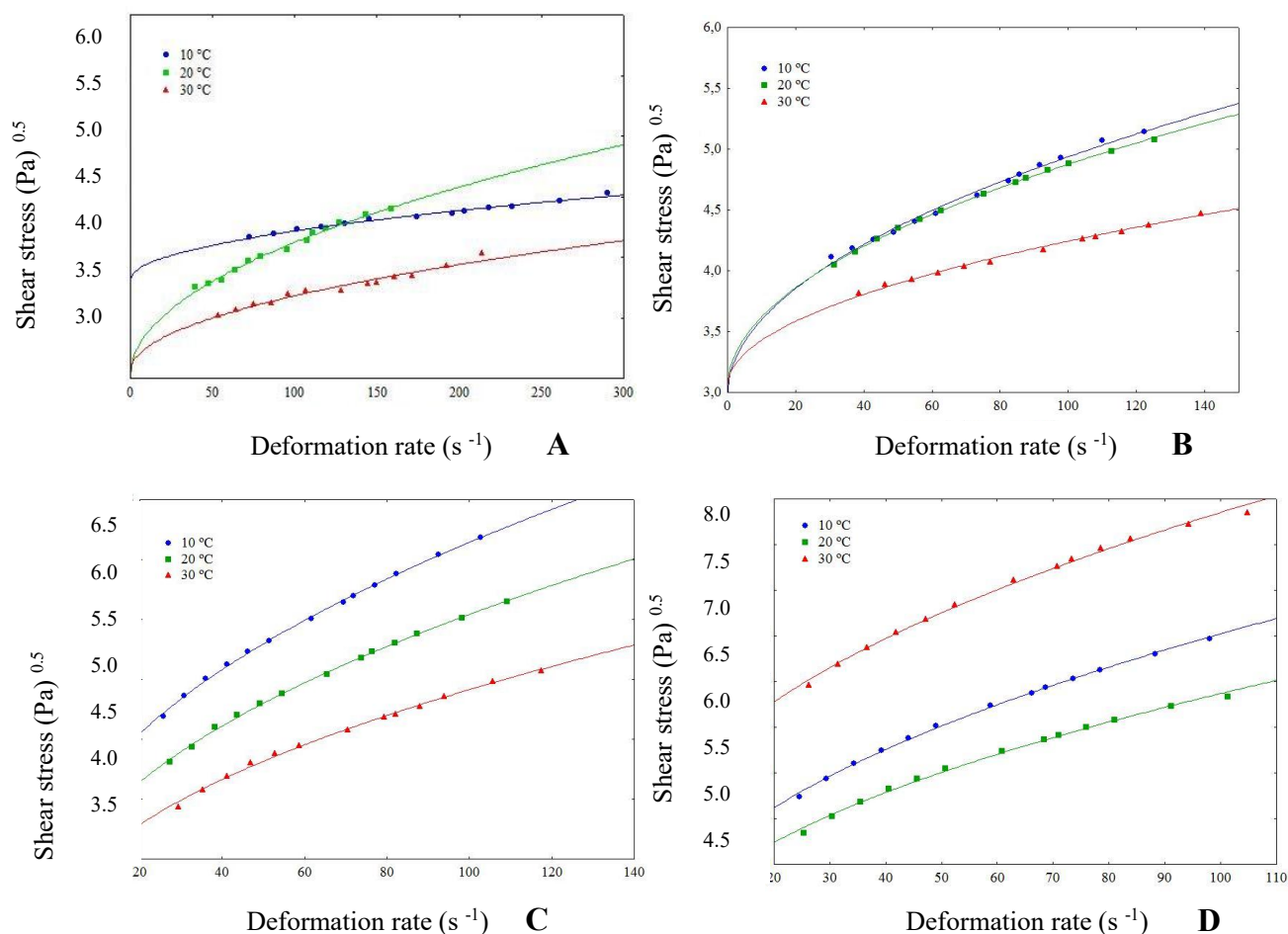


Figure 2. Experimental and predicted values from the Casson model of shear stress versus shear rate for jabuticaba pulp: (A) fresh, (B) F1, (C) F2, and (D) F3.

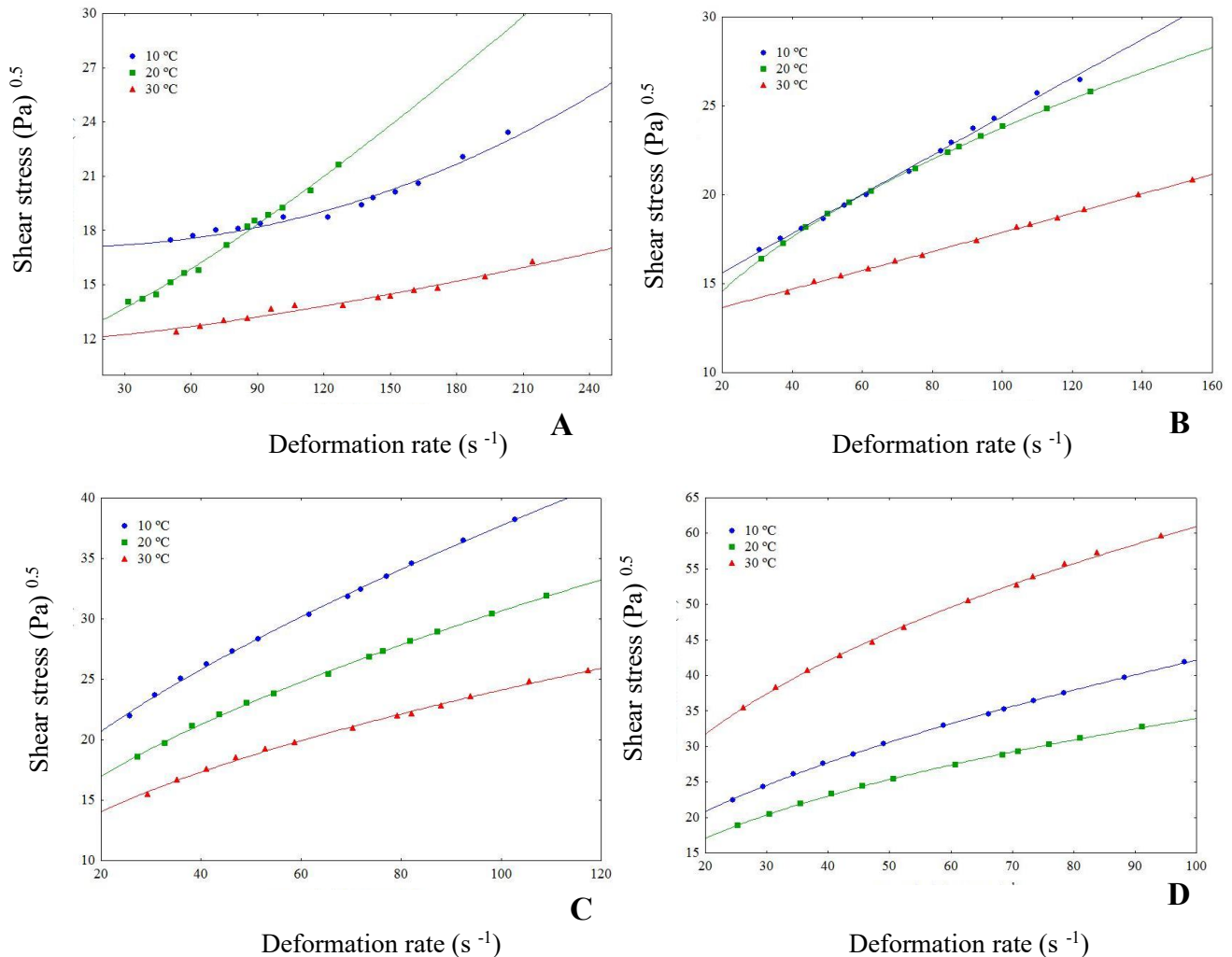


Figure 3. Experimental and predicted values by the Herschel-Bulkley model of shear stress versus shear rate for jaboticaba pulp: (A) fresh, (B) F1, (C) F2, and (D) F3.

suitable for describing the behavior of pulps and juices with similar characteristics.

The analysis of the Casson, Herschel-Bulkley, and Ostwald-de-Waele models revealed variations in rheological parameters with increasing maltodextrin concentration and temperature. The decrease in shear stress with increasing temperature confirms the pseudoplastic behavior of jaboticaba pulp, as observed by Oliveira et al. (2012) and Bezerra et al. (2013). The trend of decreasing consistency index (K) and flow behavior index (n) with increasing temperature reinforces the thermal influence on the molecular structure of the pulp, as described by Toneli et al. (2005) and Hassan and Hobani (1998).

These findings indicate that jaboticaba pulp formulated with maltodextrin exhibits non-Newtonian pseudoplastic rheological behavior, influenced by both additive concentration and temperature, which is essential for industrial applications involving pumping, mixing, and spray drying.

5 CONCLUSIONS

The jaboticaba pulps formulated with different concentrations of maltodextrin showed changes in their physical, chemical, and physicochemical characteristics with the increase of the additive. The rheological models studied showed good fits to the flow curves of jaboticaba pulps at different maltodextrin concentrations, with the Mizrahi-Berk model providing the best fit to the data, showing the highest coefficients of determination and the lowest RMSDs.

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