ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 09, Issue, 08, pp. 29205-29210, August, 2019

RESEARCH ARTICLE **OPEN ACCESS**

BIOACTIVE COMPOUNDS AND REOLOGICAL STUDY OF *PHYSALIS* (*P. peruviana*) PULP AS A RESULT OF MALTODEXTRIN CONCENTRATION

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ARTICLE INFO

Article History:

Received 20th May, 2019
Received in revised form
16th June, 2019
Accepted 26th July, 2019
Published online 30th August, 2019

Key Words:

Antioxidant activity,
Fluids, Exotic fruit,
Power law, Pseudoplastic.

ABSTRACT

This work aimed to characterize the bioactive compounds of *Physalis* pulp and perform its rheological study due to the addition of the encapsulating agent maltodextrin that acts as thermal protector of bioactive compounds in later processing steps. Fresh pulp was characterized by the following bioactive compounds: total phenolic compounds, flavonoids, anthocyanins, total carotenoids and antioxidant activity (ABTS + and DPPH). The rheological study was performed as a function of maltodextrin concentration (0, 5, 10 and 15%) and the rheological models of Bingham, Mizrahi-Berk, Casson, Herschel-Bulkley and Ostwald-de-Waelle (Power Law) were adjusted. to experimental data. Fresh pulp showed significant values of total phenolic compounds (208.93 mgGAE $100.g^{-1}$) with medium antioxidant activity being the highest activity obtained by the ABTS + method (42.68 μmol $Trolox.g^{-1}$). As well as presented significant values of flavonoids and carotenoids; Herschel-Bulkley and Mizrahi-Berk rheological models presented the best adjustments for all formulations with coefficients of determination (R2) greater than 0.99 and mean square deviations less than 0.12. Therefore, the bioactive compounds present in the *Physalis* pulp constitute a good attraction for the technological utilization of the fruits and their rheological study indicated that the pulp and its formulations, with the addition of the encapsulating agent, presented non-Newtonian fluid behavior, in this specific case of a pseudoplastic.

Citation: Raphael Lucas Jacinto Almeida, Ênio Rafael de Medeiros Santos, Tamires dos Santos Pereira *et al.* 2019. "Bioactive compounds and reological study of physalis (p. peruviana) pulp as a result of maltodextrin concentration", *International Journal of Development Research*, 09, (08), 29205-29210.

INTRODUCTION

The genus *Physalis* includes about 100 species and belongs to the family Solanaceae, is characterized as a group of high economic importance. Edible *Physalis* (*P. peruviana*) is the species that stands out in Brazil because it has extensive planting and higher consumption, it is defined as a small fruit that has a coloration that varies between yellow and orange, has a sweet taste and is rich in several nutrients such as vitamin A and C, iron and phosphorus, as well as alkaloids, flavonoids, carotenoids and bioactive compounds, which are considered functional (MUNIZ *et al*. 2015; SOUZA *et al*. 2017). Being marketed in its in natura form and is mainly used as raw material for the production of new products such as: juices, jams, jellies, ice cream and yogurts (LANDIM *et al*., 2016; OLIVARES *et al*., 2017). As it is a climacteric fruit with

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high production during the harvest period, technological alternatives are sought to increase the shelf life of the fruits, and pulp processing is a form of utilization (FISCHER *et al*., 2011). The pulp produced can be used as an ingredient to obtain other products, without having to perform additional processing steps (CARVALHO *et al*., 2017) or even applied in processing new products. Studying rheological behavior helps to better understand the structural organization of food. Several factors affect the rheological behavior of fruit pulps: temperature, soluble solids and particle size. Rheology covers different properties associated with the deformation of matter, including: extrussibility, compressibility, ductility, spreadability, elasticity, fluidity and viscosity (VRIESMANN, 2008). Viscosity, for example, is the physical property of a liquid to resist the flow induced by the applied stress (shear). It is dependent on the physicochemical nature of the substance, temperature, pressure, shear rate and time and to define viscosity as a function of one of these factors the others must be kept constant and well defined (CASTRO, 2007). The fundamental operation in a rheological test is to apply a tangential force to the material to be investigated, also called shear stress and to measure its deformation, or, equally, to apply a deformation and measure the resistance (VANDRESEN, 2007). In the food industry, rheology is also of fundamental importance. Rheological flow measurements under temperature, pressure and concentration variations directly influence the sizing of pumps, pipelines, as well as the optimization of the entire industrialization process (SANTOS, 2013). In this context, the objective of the present work is to characterize the bioactive compounds of *Physalis* pulp and perform its rheological study due to the addition of the maltodextrin encapsulating agent that acts as a thermal protector of the bioactive compounds in later processing steps.

MATERIALS AND METHODS

The experiment was carried out at the Physical Properties Laboratory of the Food Engineering Academic Unit of the Technology and Natural Resources Center and at the Biochemical Engineering Laboratory of the Technology Science Center at the Federal University of Campina Grande.
Physalis (*P. peruviana*) at mature maturation stage were used as raw material. The fruits were washed in running water, sanitized in chlorinated water (100 ppm) for 15 minutes, manually pulped with the aid of stainless steel knives. The pulp was then packed in low density polyethylene bags and stored in a freezer at a temperature of approximately -20 ° C.

Characterization of bioactive compounds of fresh pulp: The total anthocyanin and flavonoid content followed the single pH method described by Francis (1982). Quantification of total carotenoids (lycopene) followed the methodology described by Davies (1976). The determination of total tannins was according to the study by Pansera *et al.* (2003) with adaptations. Total phenolic compounds were quantified using the Folin-Ciocalteau method described by Waterhouse (2006), using gallic acid as standard. The calculations performed for the determination of phenolic compounds were based on a standard curve with gallic acid, and the spectrophotometer readings at 765 nm, with the results expressed in mg $100g^{-1}$ gallic acid. The antioxidant activity by the ABTS + method was determined by the method proposed by Re *et al.* (1999), with modifications made by Rufinoa *et al*., (2007), expressed as (μmol Trolox g^{-1}), while antioxidant activity by DPPH was made according to the methodology described by Rufino *et al*., (2007). , with adaptations, showing the final result in g of sample / g of captured DPPH (EC50). For both analyzes distilled water was used as extractive solvent.

Study of rheological behavior: To determine the rheological study of *Physalis* pulp formulations, a Brookfield model DV II + Pro viscometer was used to read the apparent viscosity values and torque percentage of each sample with the addition of maltodextrin: 0, 5, 10 and 15% and at different rotational speeds: 50, 60, 70, 75, 80, 90, 100, 105, 120, 135, 140, 150, 160, 180 and 200 rpm. Data on rotational speed, apparent viscosity and torque obtained from the viscometer were used to obtain rheological measurements (shear stress and strain rate) following the methodology of MITSCHKA (1982). The rheological models (Table 1) of Bingham, Mizrahi-Berk, Casson, Herschel-Bulkley and Ostwald-de-Waelle (Power Law) were adjusted to the experimental values of shear stress and strain rate and the adjustment of the Mathematical models to experimental data were applied to nonlinear regression analysis by the Quasi-Newton method, using the Statistica 8.0 software (STATSOFT, 2008).

Table 1. Rheological models used for data prediction

Rheological Models	Equations
Bingham	*(1)*
Mizrahi-Berk	*(2)*
Casson	*(3)*
Herschel-Bulkley	*(4)*
Ostwald-de-Waelle (Lei da Potência)	*(5)*

Note: ηa = apparent viscosity (Pa s); γ = strain rate (s^{-1}); k = fluid behavior index (dimensionless); τ e τ0 = shear stress (Pa); n and nH = fluid behavior index (dimensionless); KOC = square root of initial stress (Pa); τOH = initial shear stress (Pa); K0C0.5 = initial shear stress (Pa) 0.5; and KC = Casson plastic viscosity (Pa s) 0.5.

To determine the best fit, the determination coefficients (R²) and mean square deviations (DQM) (Equation 6) were analyzed:

$$DQM = \sqrt{\frac{\left(\sum V_{exp} - V_{pre}\right)^2}{N}} \qquad (6)$$

Where: V_{exp}-Values obtained experimentally; V_{pre}-Values predicted by the mathematical model; N-number of observations.

RESULTS

Table 2 shows the values of bioactive compounds found for *Physalis* in natura.

Table 2. Bioactive compounds of *Physalis* in natura

Parameters	*Physalis* in natura
Total phenolic compounds (mgGAE 100 g^{-1})	208.93 ± 22.13
Flavonoids (mg $100g^{-1}$)	20.74 ± 4.12
Anthocyanins (mg $100g^{-1}$)	0.77 ± 0.07
Total carotenoids (μg g^{-1} licopeno)	4.516 ± 2.15
Antioxidant activity by $ABTS^+$ (μmol Trolox g^{-1})	4.268 ± 5.07
Antioxidant activity by DPPH (% de obtaining)	87.47 ± 2,47

The total phenolic compound content in the present study was 208.93 (mgGAE.100 g^{-1}). Studies by Lima *et al.* (2012) found variations between 150.04 and 210.04 mgGAE.100 g^{-1} and Rockenbach *et al.* (2008) obtained values between 57.9 and 47.8 mgGAE 100.g^{-1} of total phenolic compounds with methanolic and aqueous extracts in *Physalis* fruit, respectively. The physicochemical properties of fruits are influenced by

Table 3. Rheological models and parameters for *Physalis* pulp in natura with different proportions of maltodextrin

Models	Maltodextrina proportion	τ_o	τ_{0H}	K	K_{oc}	K_c	K_{oh}	K_{0m}	n	R² (%)	DQM
Bingham	0%	6.952	-	0.083	-	-	-	-	-	96.94	0.063
	+ 5%	6.967	-	0.077	-	-	-	-	-	96.76	0.549
	+ 10%	7.871	-	0.058	-	-	-	-	-	96.88	0.118
	+ 15%	8.775	-	0.042	-	-	-	-	-	96.87	0.114
Mizrahi & Berk	0%	-	-	-	-	-	$^{-1}$5.30	13.43	0.175	99.30	0.063
	+ 5%	-	-	-	-	-	-21.23	18.84	0.138	99.45	0.118
	+ 10%	-	-	-	-	-	$^{-1}$9.97	19.13	0.123	99.64	0.091
	+ 15%	-	-	-	-	-	-20.38	21.07	0.101	99.73	0.077
Casson	0%	-	-	-	6.952	0.083	-	-	-	96.94	0.063
	+ 5%	-	-	-	6.967	0.077	-	-	-	96.76	0.549
	+ 10%	-	-	-	7.871	0.058	-	-	-	96.88	0.118
	+ 15%	-	-	-	8.775	0.042	-	-	-	96.87	0.114
Herschel-Bulkley	0%	-	$^{-1}$5.30	13.43	-	-	-	-	0.175	99.30	0.063
	+ 5%	-	$^{-1}$7.23	18.84	-	-	-	-	0.138	99.45	0.118
	+ 10%	-	$^{-1}$9.97	19.13	-	-	-	-	0.123	99.64	0.091
	+ 15%	-	-20.38	21.07	-	-	-	-	0.101	99.73	0.077
Ostwald-de-Waele	0%	-	-	2.326	-	-	-	-	0.404	99.11	0.211
	+ 5%	-	-	2.377	-	-	-	-	0.392	99.20	0.153
	+ 10%	-	-	2.994	-	-	-	-	0.330	99.48	0.121
	+ 15%	-	-	3.764	-	-	-	-	0.272	99.62	0.149

factors such as edaphoclimatic conditions, variety, time and place of harvest, crop treatment and postharvest management (SENHOR *et al.* 2009). According to Damodaran, Parkin and Fennema (2010), phenolic compounds comprise a large group of organic substances, with flavonoids being an important subgroup. González-Mendoza *et al.* (2010, 2011) reported values between 4.68 and 9.65 mgGAE.100 g^{-1} and 5.3 and 10.08 mgGAE.100 g^{-1} in both studies, respectively, both evaluating different genera of *Physalis*. Wu *et al.* (2006) in their studies on the phenolic content of *Physalis Peruviana* L., reported that the values range from 57.9 mgGAE.100 g^{-1} to 90.80 mgGAE.100 g^{-1}. Machado *et al.* (2019) in their studies on *Physalis* pulp stability obtained 60.87 mgGAE.100 g^{-1} for phenolic compounds. Teixeira *et al.* (2016) when quantifying total phenols with ethanolic extract *of Physalis Peruviana* L fruit presented an amount equivalent to 149.3 mgGAE.100g^{-1}. Mier *et al.* (2011) obtained for the same parameter a value of 131.19 mgGAE.100 g^{-1}. Curi *et al.* (2018) performed the characterization of different species of native American *Physalis* and obtained for *Physalis peruviana* (24.91 mgGAE.100 g^{-1}) for total phenolics, while Teixeira júri *et al.* (2016) obtained total polyphenol content of the ethanolic extracts of *Physalis peruviana* L. fruits (149.3 mgGAE 100.g^{-1}) for the total phenolic compounds.

According to Damodaran, Parkin and Fennema (2010), although most of the yellow color of foods is attributed to the presence of carotenoids, this color in some foods is attributed to the presence of non-anthocyanic flavonoids. In this study *Physalis* in natura presented a content of 20.74 mg.100g^{-1} for flavonoids. Anthocyanins are relatively unstable pigments, and their greatest stability occurs under acidic conditions. *Physalis* in natura had anthocyanin content of 0.77 mg.100g^{-1}. Anthocyanin degradation occurs not only during extraction from plant tissues, but also during food processing and storage. Knowledge of anthocyanin chemistry can be used to minimize degradation through proper selection of specific anthocyanin processes and pigments for the intended applications. The main factors governing anthocyanin degradation are pH, temperature and oxygen concentration (DAMODARAN, PARKIN and FENNEMA, 2010). In this study, for the total carotenoid content a total of 4,516 µg.g^{-1} lycopene was obtained. Oliveira (2016) found 5.95 µg / g carotenoids in *Physalis* in natura fruits. Machado *et al.* (2019) in their studies with *Physalis* pulp obtained 6.99 µg / g carotenoids. According to Damodaran, Parkin and Fennema (2010), carotenoids are sensitive to light, excessive heat and exposure to acids. This sensitivity makes them very vulnerable during their processing and storage, which means that many precautions must be taken to minimize their losses. The antioxidant activity by the ABTS + method was 4,268 µmol.Trolox g^{-1}. Machado *et al.* (2019) in their studies on the antioxidant stability of *Physalis* pulp obtained 1.98 µmol.Trolox g^{-1} for antioxidant capacity. Curi *et al.* (2018), performed the characterization of different species of native American *Physalis* and obtained for the peruvian *Physalis* 6.19 µmol.Troloxg^{-1} of fruit for antioxidant capacity by ABTS +. For the antioxidant activity by the DPPH method the content obtained for *Physalis in natura* pulp was 87.47% DPPH sequestration. Curi *et al.* (2018) performed the characterization of different species of native American *Physalis* and obtained for *Physalis* peruviana 75.06 (% sequestration) for antioxidant capacity by DPPH. Teixeira jury *et al.* (2016) evaluated the total polyphenol content and antioxidant capacity of ethanolic extracts of *Physalis peruviana* L. fruits obtained 100 (% sequestration) for antioxidant activity by DPPH. Table 3 shows the parameters of the rheological models of Bingham, Mizrahi & Berk, Casson, Herschel-Bulkley and Ostwald-de-Waele, respectively, adjusted to the experimental shear stress versus strain rate data of the different formulations studied as well as coefficients of determination (R2) and mean quadratic deviations (DQM).

Table 3 shows that for all rheological models, the determination coefficients (R2) were greater than 0.96 and the mean square deviations less than 0.6, meaning that all studied models can be used to estimate the rheological data of the formulations evaluated. However, the Herschel-Bulkley and Mizrahi-Berk models presented similar adjustments and were also the best models for all formulations studied, since, besides presenting coefficients of determination (R2) greater than 0.99, the quadratic mean deviations were less than 0.12. for both models. Bingham, Casson and Ostwald-de-Waele models presented values above 0.96 and 0.99 for the coefficients of determination (R2) and mean square deviations below 0.55 and 0.22, respectively. The initial shear stress (τ0H and K0M), which, according to Steffe (1996), is a finite stress necessary for the fluid to start flowing, increased with the addition of

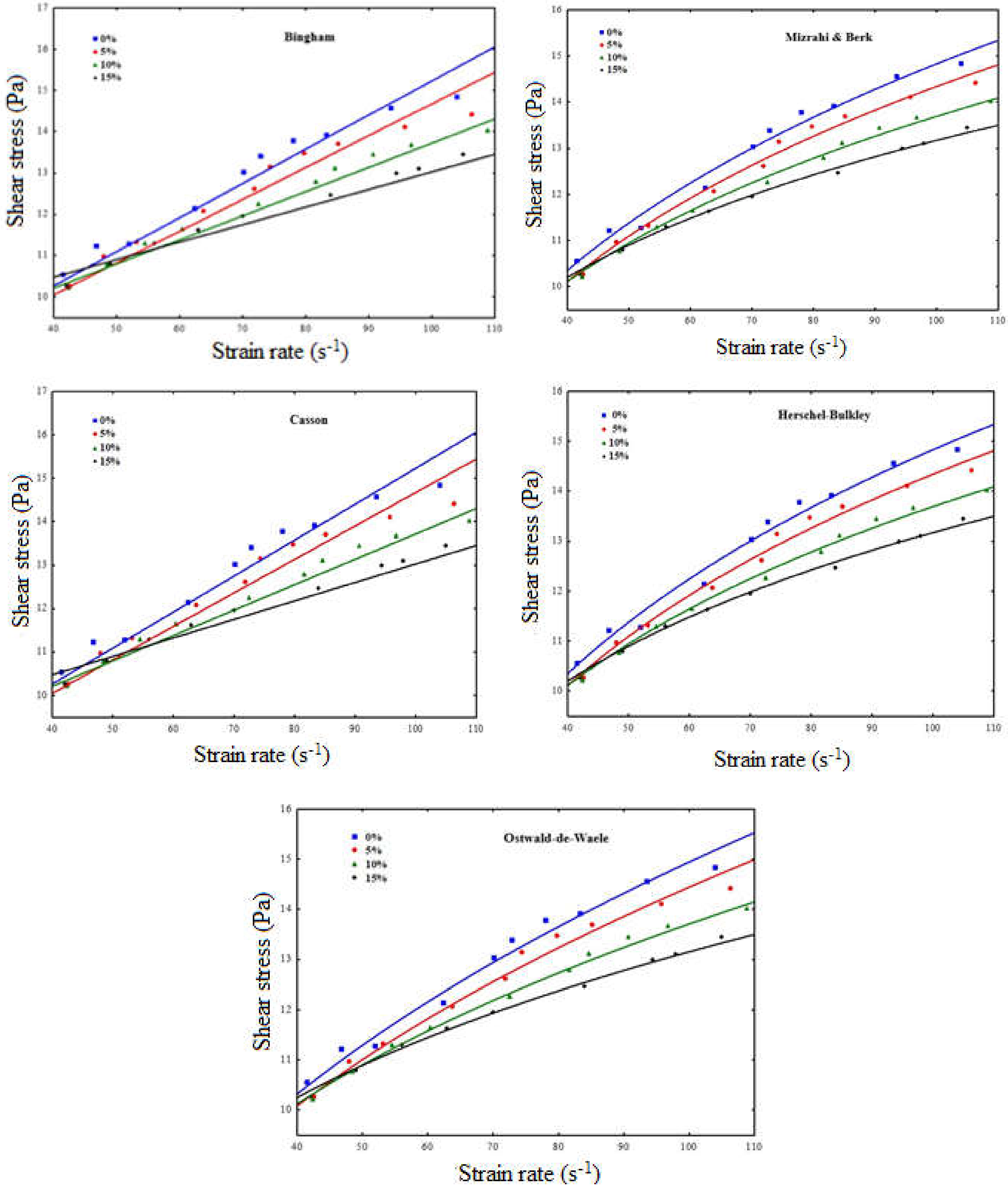

Figure 1. Shows the rheograms obtained by rheological analysis of *Physalis* pulp with the addition of different maltodextrin concentrations

maltodextrin to *Physalis* pulp. The (K) is the consistency index, this indicates the degree of fluid resistance to flow. K showed an upward trend with the addition of maltodextrin to the Herschel-Bulkley and Ostwald-de-Waele models, indicating that they became more consistent. The (n) behavior index in the Herschel-Bulkley, Mizrahi-Berk and Ostwald-de-Waele models was lower than 1 (n <1) for all formulations, thus characterizing a non- Newtonian with pseudoplastic behavior ie the viscosity decreases with increasing fluid deformation rate, confirming the result presented in Figure 1. The pseudoplastic character is also typical of fruit juices and pulps, being observed in acerola, cashew, mango and jabuticaba (SATO & CUNHA, 2007; SILVAb *et al.*, 2012), for gabiroba and guava (Oliveira *et al.*, 2011), strawberry (Oliveira *et al.*, 2012) and soursop (Quek *et al.*, 2013). The parameters with negative values Koh, do not have physical significance, compared to the Mizrahi-Berk model. Negative K0h values were also found by Gazola (2014) for the study of pitanga pulp. Fernandes *et al.* (2008), when working with umbu cajá pulp as a function of maltodextrin concentration of 2.5; 5.0 and 7.5% at 10, 20, 30 40 and 50 ºC obtained the best adjustments with the Mizrahi-Berk model, with determination coefficients (R2) higher than 0.91. Silva *et al.* (2012), when studying the rheological behavior of mixed cajá and mango drinks added with prebiotics at 25 ºC, observed the highest coefficient of determination for the Herschel-Bulkley and Mizrahi-Berk models, higher than 0.91. Sousa *et al.* (2014), working with pequi pulp with different contents of total soluble solids (6, 8, 10 and 12 ° Brix) and different temperatures (25, 30, 35, 40, 45 and 50 ° C) adjusted the Mizrahi-Berk model for the rheogram and found a coefficient of determination greater than 0.93. Silvaa *et al.* (2012) analyzed the rheological behavior of mixed cajá and mango drinks, added with inulin and fructoligosaccharides and found that the Herschel-Buckley model was the best fit for the study, with determination coefficients greater than 0.93. Observing the rheological behavior of the pulps through Figure 1, when comparing with the rheological curves presented by Tadini, Telis, De Almeida (2016), it is possible to notice that the shear stress increases with the increase of the deformation rate, that is, the Viscosity decreases with increasing fluid deformation rate, indicating that the fluid under study is non-Newtonian, in the specific case of a pseudoplastic.

Conclusion

The characterization of the bioactive compounds of fresh pulp indicated that it has significant values of total phenolic compounds, with medium antioxidant activity, as well as presented significant values of flavonoids and carotenoids which is a good attraction for the technological utilization of the fruits. *Physalis* pulp and formulations made with the addition of maltodextrin showed non-Newtonian fluid behavior, in the specific case of a pseudoplastic. And the Herschel-Bulkley and Mizrahi-Berk rheological models presented the best adjustments for all formulations with coefficients of determination greater than 0.99 and mean square deviations of less than 0.12.

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