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Rheological behavior of dehydrated cranberry suspensions: Analysis of the influence of temperature and solid concentration on Casson's model parameters

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ABSTRACT. Dehydrated cranberries (*Vaccinium macrocarpon*) are dried fruits known for their high antioxidant potential. Changes in their mechanical and rheological properties occur when cranberries are exposed to certain conditions, such as drying or immersion in a liquid medium (rehydration). To evaluate the rheological behavior of solid suspensions made from dehydrated cranberries, the effects of different temperatures and concentrations of dissolved solids were evaluated using a factorial experimental design (2^2) with three replications at the center point. Five models were used to investigate the suspensions' flow behavior: Ostwald de Waelle, Newton, Herschel-Bulkley, Casson, and Bingham. The rheometry of the suspensions showed that the fluids presented non-Newtonian behavior, with a satisfactory fit for the Casson model ($R^2 > 0.94$) in all evaluated temperature and concentration ranges. Furthermore, the effects of temperature and solid concentration of cranberry suspensions on the rheological parameters of the fitted model, Casson's initial shear stress (K_{0c}), and Casson's plastic viscosity (K_c) were evaluated. From the response and the contour surfaces, it was found that increasing the concentration of the suspension above 20% resulted in higher initial shear stress, which was influenced by temperature, whose increase resulted in a significant reduction in the shear stress at a concentration of 30%. The plastic viscosity (K_c) was highly influenced by the solid's concentration, and higher temperatures caused a decrease in the value of this parameter. So, the highest value of plastic viscosity was found for concentrations above 20% and at lower temperatures. Therefore, considering the results and for practical purposes, it can be concluded that the flow of the suspensions is facilitated if rehydration is conducted at high temperatures.

Keywords: *Vaccinium macrocarpon;* rheometry; experimental design; casson model.

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Introduction

In the last years, researchers in human nutrition have shown great interest in small fruits, especially red ones such as berries, because they contain high concentrations of phenols, including ellagic acid, anthocyanins, chlorogenic acid, quercetins, flavonoids, and kaempferol (Zhang et al., 2013).

Berries are commonly sold and eaten fresh, especially during the ripening season. However, due to their generally short shelf life, are often stored frozen or dried, and used as ingredients in many types of food products and supplements, such as juices, jams, jellies, and extracts (Salo et al., 2021).

The cranberry, considered one of the main crops in certain American states and Canadian provinces, stands out among berries. The fruits are red and processed into juices, jellies, and dried (Rajan, Hasna, & Muraleedharan, 2018). According to Nemzer, Al-Taher, Yashin, Revelsky, and Yashin (2022), cranberries are rich in nutritional components and many bioactive compounds with antioxidant properties.

The methods used for processing berries during the manufacture of jellies and juices can affect their quality, leading to the degradation of phenolic compounds. The application of heat for long periods and the continuous agitation resulting from pumping can cause irreversible damage to the structure of foods and make them unattractive to consumers, even if their bioactive compounds are preserved (Nindo, Tang, Powers, and Takhar, 2007).

Kechinski, Schumacher, Marczak, Tessaro, and Cardozo (2011) point out that the processing conditions and the type of product to be processed influence the quality and benefits foods offer. For blueberries, for example, losses of anthocyanins may occur, due to their instability under certain processing conditions, such as at pasteurization temperature.

Rheological properties are determined by measuring strength and strain as a function of time. The behavior of a fluid is defined through a mathematical model, which relates how the shear stress varies with the strain rate (Toneli, Murr, & Park, 2005).

Studies on the rheology of berry suspensions have been carried out in order to explain how the solid concentration and temperature parameters interfere with rheological behavior. Nindo et al. (2007) characterized the rheological behavior of suspensions of blueberry solids at 10, 15, 20, and 25 °Brix. The authors verified that the concentration of solids and the temperature significantly influenced the viscosity of the purees in the ranges of temperature and concentration used. Sisko's model best fitted the experimental data with $R^2 > 0.99$. The activation energy (E_a) ranged linearly ($R^2 = 0.98$) with the concentration of dissolved solids, showing an increase, except for the experiments at 25 °Brix. Apparent viscosity was expressed as a function of the solid concentration, and this relationship is important, as it allows monitoring of changes in viscosity during processes such as evaporation.

Kechinski et al. (2011) evaluated the influence of temperature and xanthan gum and fructose concentrations on the flow of blueberry purees. The researchers verified that the purees with gums added presented thixotropic responses and characterized their rheological behavior as pseudoplastic. The best adjustment of the experimental data was carried out by the Casson model, and the rheological behavior of the berries showed a complex dependence on the concentration of additives and the increase in temperature. Also, the concentration of xanthan gum proved to be a determining variable of the rheological behavior of purees. The fructose concentration had a pronounced effect on thixotropy; however, it did not significantly influence the viscosity of the samples.

Since cranberries are very rich sources of compounds beneficial to the body, such as antioxidants, and considering that in many countries this fruit is consumed in dehydrated form and that data on fluid transport are essential for the industry, the determination of rheological parameters and evaluations of how process variables affect the rheological parameters of small fruit suspensions are relevant.

Thus, the present work aimed to evaluate the rheological behavior of dehydrated cranberry suspensions and the influence of process variables (temperature and concentration of dissolved solids) on the rheological parameters of the fitted model.

Material and methods

Raw material

The dehydrated cranberries were purchased at the local market in Medianeira - PR in February 2016.

Rheometry and statistical analysis

The rheological analyses were carried out in a Brookfield (Middleboro – MA, USA) rotational viscometer with concentric cylinders, model LVDV – III ULTRA, according to a methodology adapted from Nindo et al. (2007) and Kechinski et al. (2011).

Shear stress and strain rate data were collected for cranberry solids suspensions at concentrations of 10%, 20%, and 30% w/w at 20, 40, and 60°C.

The suspensions were prepared with 10 g, 20 g, and 30 g of rehydrated berries, adding distilled water to complete the mass to 100 g. The dehydrated fruits were rehydrated in water for 45 min at 29 °C (the local room temperature). The choice of rehydration time was based on the percentage of water gained by the berries during the rehydration operation so that the rehydrated fruit presented characteristics similar to those of fresh ones in the shortest possible time of operation. After 45 minutes of operation, the berries showed a mass gain, due to water absorption, greater than 40%. Subsequently, the fruits were crushed to form the suspensions, with the aid of a Black & Decker food mixer (Towson – MD, USA). This procedure was performed immediately before the analyses to avoid excessive rehydration of the solids.

The viscometer was calibrated to allow the sample to equilibrate to the chosen temperature before data collection, with a 3-min step between readings.

The rheological models used to predict the rheological behavior of cranberry suspensions are shown in Table 1.

Table 1. Mathematical models used to predict the rheological behavior of the suspensions.

Model		
Ostwald de Waelle or Power law	$\tau = K\dot{\gamma}^{n}$	(1)
Newton	$\tau = \mu\dot{\gamma}$	(2)
Herschel-Bulkley	$\tau = \tau_0 + K_H\dot{\gamma}^{n_H}$	(3)
Casson	$\tau^{0.5} = {K_{0c}}^{0.5} + K_c(\dot{\gamma})^{0.5}$	(4)
Bingham	$\tau = \tau_0 + \mu_{pl}(\dot{\gamma})$	(5)

In which: τ is the shear stress, in Pa; τ_0 is the initial shear stress, in Pa; $\dot{\gamma}$ is the shear rate, in s^{-1}; μ is the viscosity, in Pa·s; μ_{pl} is the Bingham plastic viscosity, in Pa·s; K, K_H, K_{0c}, K_c are consistency indexes of the fluids; n, n_H are the dimensionless flow behavior indexes of the fluids.

Source: The authors.

To verify the adjustment of the models to the experimental data, Equations 1 to 5, the values of the coefficient of determination (R^2), the mean squared error (*RMSE*, Equation 6), the mean relative error (*P*, Equation 7), the bias factor (B_f, Equation 8) and the existence of initial shear stress (τ_0) were evaluated. The statistical parameters to verify if the experimental data fit the rheological models were calculated using Excel (Office 2013).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(x_{calc}-x_{exp}\right)^2}{n}} \tag{6}$$

$$P = \frac{100}{n}\sum_{i=1}^{N}\frac{\left|x_{exp}-x_{calc}\right|}{x_{exp}} \tag{7}$$

$$B_f = 10^{\left[\sum\frac{log\frac{x_{calc}}{x_{exp}}}{n}\right]} \tag{8}$$

In which: x_{exp} is the experimental value; x_{calc} is the value predicted by the model; and n is the number of experimental observations.

Once chosen the best fit of the experimental data to the proposed models, a 2^2 factorial design was carried out with three repetitions at the central point, as shown in Table 2, for the investigation of the effects of the variables temperature (x_1) and solid concentration (x_2) on the model parameters with the best fit to the experimental data.

Table 2. Experimental and coded levels of the variables studied in the 2^2 factorial design.

Variables	Code	Levels		
		-1	0	1
Temperature (°C)	x_1	20	40	60
Solid concentration (%)	x_2	10	20	30

Source: The authors.

The results obtained were treated with the aid of Statistica 7.0 software to obtain a linear model of the initial shear stress and viscosity of cranberry solid suspensions as a function of the variables temperature and solid concentration within the studied ranges. The adequacy of the models was evaluated from the analysis of variance (ANOVA) at a significance level of 95% ($p \leqslant 0.05$) obtaining the response surfaces and contour curves for the response variables as a function of the independent variables studied.

Results and discussion

The mathematical modeling of the rheological data of the suspensions of dehydrated cranberries, in the different concentrations and temperatures evaluated, indicated that the models adequately fitted the experimental data, except the Newton model, which presented a good fit only for the suspensions at a concentration of 10%. This indicates that at most of the concentrations studied in the present research the rehydrated berry suspensions can be classified as non-Newtonian fluids.

Table 3 presents the statistical parameters used to evaluate the adjustment of the models presented in Table 1 to the data for each experiment of the factorial design presented in Table 2.

Although the experimental data had shown a good fit to the proposed non-Newtonian models, one was selected to represent the responses of the factorial design. Casson's model showed the overall best fit in the concentration and temperature ranges studied, with correlation coefficients in the range of 0.944 to 0.995, low values of *P* and *RMSE*, ideal values of B_f (close to or equal to 1), and lower initial shear stresses (τ_0), as can be seen in Table 3.

Table 3. Statistical parameters to evaluate the adjustment of the data to the models.

x_1[a]	x_2[b]	Model	R^2	RMSE	P (%)	B_f
20	10	Newton	0,990	$1.57 \cdot 10^{-2}$	4,20	1,02
		Power law	0.993	$3.53 \cdot 10^{-3}$	4.20	0.91
		Herschel-Bulkley	0.999	$1.65 \cdot 10^{-10}$	0.691	1.00
		Casson	0.991	$3.51 \cdot 10^{-11}$	2.03	0.995
		Bingham	0.991	$2.71 \cdot 10^{-10}$	4.38	0.953
60	10	Newton	0,974	$1.62 \cdot 10^{-2}$	7,51	1,22
		Power law	0.990	$3.16 \cdot 10^{-3}$	5.794	0.853
		Herschel-Bulkley	0.999	$2.94 \cdot 10^{-10}$	1.525	0.998
		Casson	0.980	$2.11 \cdot 10^{-15}$	3.568	0.992
		Bingham	0.983	$4.33 \cdot 10^{-10}$	7.659	0.914
40	20	Newton	0,048			
		Power law	0.996	$1.01 \cdot 10^{-3}$	1.405	0.988
		Herschel-Bulkley	0.998	$1.96 \cdot 10^{-10}$	1.033	1.001
		Casson	0.995	$8.25 \cdot 10^{-11}$	0.961	1.001
		Bingham	0.976	$1.24 \cdot 10^{-10}$	4.435	1.026
40	20	Newton	0			
		Power law	0.998	$3.10 \cdot 10^{-4}$	0.935	0.997
		Herschel-Bulkley	0.998	$1.95 \cdot 10^{-9}$	0.908	1.001
		Casson	0.989	$7.58 \cdot 10^{-11}$	1.241	1.002
		Bingham	0.965	$1.25 \cdot 10^{-10}$	4.841	1.024
40	20	Newton	0			
		Power law	0.992	$1.05 \cdot 10^{-3}$	1.766	0.990
		Herschel-Bulkley	0.995	$3.40 \cdot 10^{-10}$	1.425	1.001
		Casson	0.992	$1.33 \cdot 10^{-11}$	1.073	1.001
		Bingham	0.973	$6.09 \cdot 10^{-10}$	4.050	1.020
20	30	Newton	0			
		Power law	0.987	$4.85 \cdot 10^{-3}$	1.937	0.995
		Herschel-Bulkley	0.992	$4.36 \cdot 10^{-9}$	1.615	1.001
		Casson	0.988	$3.45 \cdot 10^{-11}$	0.814	1.001
		Bingham	0.969	$2.29 \cdot 10^{-9}$	3.303	1.011
60	30	Newton	0,838	1.2729	11,56	0,65
		Power law	0.950	$7.99 \cdot 10^{-2}$	7.683	1.116
		Herschel-Bulkley	0,986	3.70	2,91	1,01
		Casson	0.944	$2.18 \cdot 10^{-15}$	3.927	1.013
		Bingham	0.925	$2.73 \cdot 10^{-8}$	9.256	1.092

[a]Temperature (°C); [b]Solid concentration of the suspensions (%).

Source: The authors.

Thus, in Table 4, the rheological parameters of Casson's model, adjusted from the non-linear regression of the experimental data, are presented.

Table 4. Adjusted rheological parameters of Casson's model.

x_1[a]	x_2[b]	Parameter	
		K_{0c} ($Pa^{0,5}$)	K_c ($Pa^{0,5} \cdot s^{0,5}$)
20	10	-0.001 ± 0.0293	0.086 ± 0.0041
60	10	-0.04 ± 0.0358	0.07 ± 0.0050
40	20	0.520 ± 0.0154	0.335 ± 0.0124
40	20	0.589 ± 0.0197	0.305 ± 0.0159
40	20	0.598 ± 0.0176	0.320 ± 0.0142
20	30	1.873 ± 0.0470	0.702 ± 0.0379
60	30	-0.677 ± 0.3026	0.382 ± 0.0467

Results presented as mean ± standard error. [a]Temperature (°C); [b]Solid concentration of the suspensions (%).

Source: The authors.

It was found that some samples showed negative shear stresses (*K_{0c}*), and others had very low shear stresses, with the highest value (1.873 ± 0.0470 $Pa^{0.5}$) being found for the experiment carried out at 30% and 20 °C and the lowest value (-0.677 ± 0.3026 $Pa^{0.5}$) for the experiment carried out at 30% and 60 °C. This indicates that dehydrated cranberry suspensions need, at most, negligible initial shear stresses to start yielding in the evaluated condition.

Similar behavior was also verified by Carneiro et al. (2013) when evaluating the rheological behavior of commercial grape nectars (traditional and light) at a temperature of 25 °C. The Casson model fitted the data, and negative initial shear stresses were found. The highest value for the initial shear stress was 0.112 ± 0.0723 $Pa^{0.5}$ for the traditional grape nectar sample (Carneiro et al., 2013).

For the experiments carried out at 10%, it was possible to verify that there was a slight decrease in the value of K_c with the increase in temperature. In the experiments carried out at 20%, it was observed that the value of K_c was in the range of 0.30 – 0.33 $Pa^{0.5}\cdot s^{0.5}$, indicating good experimental repeatability. For the experiments carried out at 30% suspension concentrations, it was possible to notice a great increase in the value of K_c for the experiment carried out at 20 °C when compared to the other suspensions, and a high decrease occurred when the temperature increased to 60 °C.

Influence of temperature and solid concentration on Casson's initial shear stress (K_{0c}) and Casson's plastic viscosity (K_c)

The matrices of the tests carried out using the complete factorial design (2^2) with the experimental and coded values of the dependent variables, and responses, initial shear stress (K_{0c}), and Casson's plastic viscosity (K_c) are presented in Tables 5 and 6, respectively.

Table 5. Factorial design with experimental and coded levels of the independent variables, responses of K_{0c} ($Pa^{0.5}$), model predicted values, and relative deviations for cranberry suspensions.

Essay	x_1[a]	x_2[b]	K_{0c} ($Pa^{0.5}$)[c]	K_{0c} Predictedd	Relative deviation (%)g
1	-1 (20)	-1 (10)	0	0.043	NC*
2	+1 (60)	-1 (10)	0	0.043	NC*
3	-1 (20)	+1 (30)	1.873 ± 0.0470	1.916	-2.305
4	+1 (60)	+1 (30)	0	0.043	NC*
5	0 (40)	0 (20)	0.520 ± 0.0154	0.511	1.648
6	0 (40)	0 (20)	0.589 ± 0.0197	0.511	13.170
7	0 (40)	0 (20)	0.598 ± 0.0176	0.511	14.477

[a]Temperature (°C); [b]Solid concentration of the suspensions (%); [c]Square root of Casson's initial shear stress (experimental values) ± standard error; [d]Square root of the Casson's shear stress predicted by the model; [e]Square root of Casson's plastic viscosity (experimental values) ± standard error; [f]Square root of Casson's plastic viscosity predicted by the model; [g]Relative deviation = $[((x_{exp} - x_{calc})) / x_{exp}] \cdot 100$, in which: x_{exp} is the experimental data and x_{calc} is the value predicted by the model; *NC – not calculated.

Source: The authors.

Table 6. Factorial design with experimental and coded levels of the independent variables, responses of K_c ($Pa^{0.5}$ $s^{0.5}$), model predicted values, and relative deviations for cranberry suspensions.

Essay	x_1[a]	x_2[b]	K_c ($Pa^{0.5}\cdot s^{0.5}$)[e]	K_c Predicted[f]	Relative deviation (%)[g]
1	-1 (20)	-1 (10)	0.086 ± 0.0041	0.090	-4.983
2	+1 (60)	-1 (10)	0.070 ± 0.0050	0.074	-6.122
3	-1 (20)	1 (30)	0.702 ± 0.0379	0.706	-0.611
4	+1 (60)	1 (30)	0.382 ± 0.0467	0.386	-1.122
5	0 (40)	0 (20)	0.335 ± 0.0124	0.314	6.183
6	0 (40)	0 (20)	0.305 ± 0.0159	0.314	-3.044
7	0 (40)	0 (20)	0.320 ± 0.0142	0.314	1.786

[a]Temperature (°C); [b]Solid concentration of the suspensions (%); [c]Square root of Casson's initial shear stress (experimental values) ± standard error; [d]Square root of the Casson's shear stress predicted by the model; [e]Square root of Casson's plastic viscosity (experimental values) ± standard error; [f]Square root of Casson's plastic viscosity predicted by the model; [g]Relative deviation = $[((x_{exp} - x_{calc})) / x_{calc}] \cdot 100$, in which: x_{exp} is the experimental data and x_{calc} is the value predicted by the model.

Source: The authors.

The lowest value found for the initial shear stress within the responses of the experimental design was -0.001 $Pa^{0.5}$ in test 1, and for the plastic viscosity was 0.070 $Pa^{0.5}\cdot s^{0.5}$ in test 2. The highest values within the responses were K_{0c} = 1.873 $Pa^{0.5}$ in test 3 and K_c = 0.382 $Pa^{0.5}\cdot s^{0.5}$ in test 4. The negative values found for the initial shear stresses were adopted as zero for statistical analysis.

With the data in Table 5, the effects of the two variables studied on Casson's initial shear stress (K_{0c}) were calculated. As a result, it was found that all variables had statistically significant effects ($p \leqslant 0.05$) on this response. The temperature had a negative effect on the initial shear stress response (K_{0c}), indicating that at a fixed strain rate, the initial shear stress decreased as the temperature increased.

The concentration of the solids in suspension had a positive effect on the initial shear stress, indicating that the shear stress necessary to initiate the flow of the suspension increases with the increase in its concentration. This result corroborates the study by Stafussa et al. (2019) in which the authors evaluated the rheological behavior of several fruit pulps and found that the soluble solid content was the physicochemical property that most influenced the rheological parameters.

In addition, it was verified that the interaction between the variables temperature and solid concentration had a negative effect on the initial shear stress. This fact is highlighted when comparing experiments 3 and 5 (Table 5) in which the 33% reduction in concentration and the 20 °C increase in temperature resulted in a 72.24% decrease in the initial shear stress.

Considering the statistically significant parameters ($p \leqslant 0.05$), after the regression analysis, the effect of the independent variables of the experimental design on Casson's initial shear stress response was described by a first-order model, presented in Equation 9.

$$K_{0C} = 0.41 - 0.47x_1 + 0.47x_2 - 0.47x_1x_2 \tag{9}$$

In which: K_{0c} is Casson's initial shear stress, in $Pa^{0.5}$; x_1 is the temperature, in °C; x_2 is the concentration of the suspension, in %.

The analysis of variance (ANOVA) of the model showed that it satisfactorily adjusted the experimental data, since the $F_{calculated}$ for the regression was significant ($p = 0.0012$), being 13.47 times greater than the $F_{tabulated}$, and the percentage of variation explained by the model was excellent ($R^2 \approx 99.21\%$).

Thus, it was possible to create the response and contour surfaces with the experimental data, which are presented in Figure 1. Furthermore, the relative deviations presented in Table 4 were less than 10%, except for tests 6 and 7, proving an adequate fit of the experimental data to Casson's model.

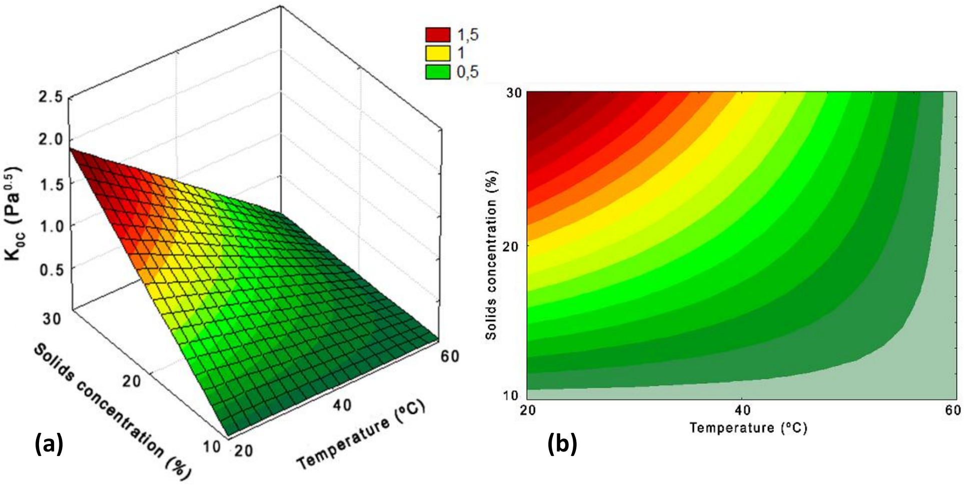

Figure 1. Response surface (a) and contour curve (b) for K_{0c} ($Pa^{0.5}$) as a function of solid concentration and temperature of the suspensions of dehydrated cranberries.

Source: The authors.

The results showed that increasing the suspension concentration above 20% resulted in higher initial shear stress. This fact is influenced by temperature, whose increase results in a significant decrease in the response when the concentration is 30%. In this way, it was verified that the maximum value of K_{0c} is obtained at low temperatures and a solid concentration of around 30%, as seen in Figure 1. Since most industrial processes and operations are carried out at higher temperatures, the results are of great importance, since they offer practical advantages, such as in the selection of pumps, as they provide the initial torque necessary to induce the flow of suspensions, especially those with a high concentration of solids (Nindo et al., 2007).

Kechinski et al. (2011) found similar results for blueberry purees enriched with xanthan gum and fructose, verifying that the maximum values for the initial shear stress are reached at low temperatures and a xanthan gum concentration of around 2.5%.

Nindo et al. (2007) studied the influence of temperature and solid concentration on the initial shear stress of blueberry purees and observed that the purees at 25 °Brix presented shear stress values 18 to 20 times higher than those for the purees at 10 °Brix for the temperature ranges studied. Furthermore, when the temperature ranged from 25 to 60 °C, the shear stress decreased by about 50%, as verified in the present study, when the temperature ranged from 20 to 60 °C at a 30% solid concentration.

The effects of the independent variables on Casson's plastic viscosity (K_c) were calculated using the data presented in Table 6. Once more, all variables had statistically significant effects ($p \leqslant 0.05$) on the response K_c. The temperature had a negative effect on the response, indicating that Casson's plastic viscosity decreased as the temperature increased. This behavior was also verified by Bezerra, Silva, Costa, Mattietto, and Rodrigues (2013) when evaluating the rheological behavior of different fruit juices.

The concentration had a positive effect on the response, as expected since increasing the concentration of suspended solids produced the highest viscosity values, and this fact was pronounced in the experiments with higher solid concentrations. The highest values for viscosity were found for the concentration of 30% solids.

On the other hand, it was observed that the interaction between the independent variables (temperature and concentration) negatively affected Casson's plastic viscosity. Thus, changes in both the concentration and the temperature of the cranberry suspensions resulted in a decrease in viscosity values with an increasing strain rate.

Considering the statistically significant parameters ($p \leqslant 0.05$), it was possible to determine the first-order model, presented in Equation 10, which represents the effect of the independent variables (concentration and temperature of solid suspensions of dehydrated cranberries) on Casson's plastic viscosity (K_c).

$$K_C = -0.31 - 0.08x_1 + 0.23x_2 - 0.08x_1x_2 \quad (10)$$

In which: K_c is Casson's plastic viscosity, in $Pa^{0.5} \cdot s^{0.5}$; x_1 is the temperature, in °C; x_2 is the concentration, in %.

The analysis of variance (ANOVA) showed that the model adequately represented the experimental data, since the $F_{calculated}$ for the regression was significant (p = 0.0002), being 46.23 times greater than the $F_{tabulated}$, and the percentage of variation explained by the model was great ($R^2 \approx 99.77\%$). Therefore, it was possible to build the response and contour surfaces with the experimental data, which are presented in Figure 2. In addition, the relative deviations presented in Table 6 were less than 10%, proving an adequate fit of the experimental data to the model.

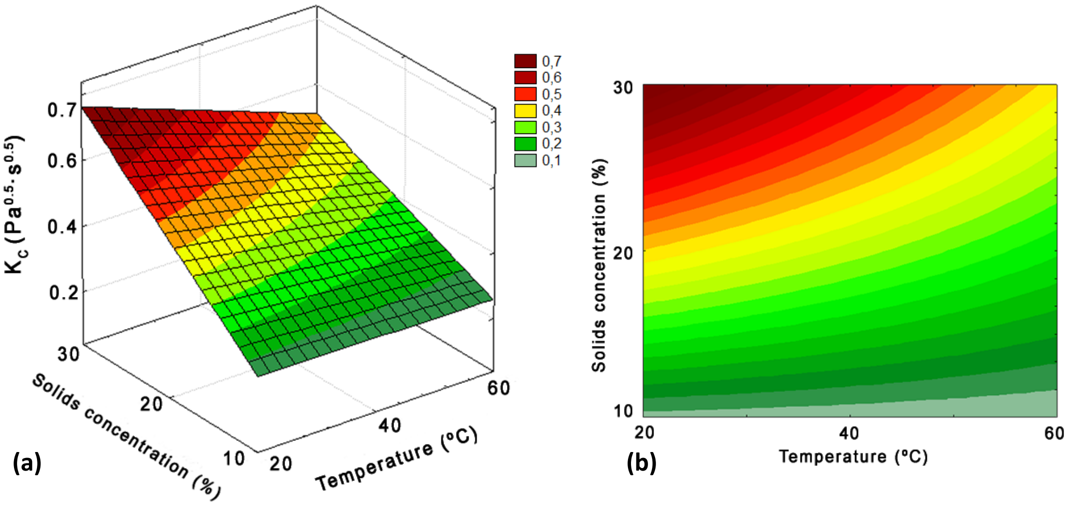

Figure 2. Response (a) and contour (b) surfaces for K_c ($Pa^{0.5} \cdot s^{0.5}$) as a function of solid concentration and temperature of the cranberry suspension.

Source: The authors (2022)

From the results, it was verified that the solid concentration was the most important variable influencing K_c and consequently the viscosity. Also, higher temperatures resulted in a decrease in the value of K_c, whose highest value was found for concentrations above 20% and at low temperatures. According to Chen and Martynenko (2016), the decrease in the viscosity of cranberry suspensions can improve the flow behavior of the product during processing and also improve consumer preference for this product.

Conclusion

The rheometry of the dehydrated cranberry suspensions in the evaluated concentration and temperature ranges showed that the fluids presented non-Newtonian behavior, satisfactorily adjusted to the Casson model.

The experimental design made it possible to obtain models for the calculation of the initial shear stress and Casson's viscosity as a function of the temperature and the concentration of suspended solids.

The highest initial shear stresses were achieved at low process temperatures and higher solid concentrations, and the highest viscosities were achieved for solid concentrations above 20% and at low temperatures, with solid concentration being the variable that had the greatest influence on this parameter. Thus, in practice, the flow of suspensions is facilitated if conducted at high temperatures.

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