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Influence of variable water-soluble soy extract and inulin contents on the rheological, technological and sensory properties of grape-flavored yogurt-like beverages made from caprine milk

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ABSTRACT
The present study aimed to evaluate the influences of the partial substitution of caprine milk for water-soluble soy extract (WSSE) and the addition of inulin on the rheological, technological and sensory properties of grape-flavored yogurt-like beverages. For this purpose, a Central Composite Design (CCD) in conjunction with Response Surface Methodology (RSM) was employed. WSSE and inulin influenced the overall acceptability of the product, whereas syneresis, water holding capacity and rheological properties (the consistency index and the flow behavior index) were influenced only by the WSSE content. RSM was shown to be an adequate statistical tool that can be used for the development of formulations with specified properties in the range of the ingredient concentrations studied.
***Keywords*:** Response surface methodology, Overall acceptability, Flow behavior, Rheological modeling, Dairy products

I. INTRODUCTION

The manufacture of fermented dairy products such as yogurt made from caprine milk faces several problems, including over-acidification due to the low buffering capacity of caprine milk [1]. Caprine milk also has a slightly lower casein content than bovine milk, with a very low proportion or an absence of α_{s1}-casein and a higher degree of casein micelle dispersion. All of these factors influence the rheological properties of the coagulum in caprine milk, which is almost semi-liquid [2]. Therefore, it is difficult to produce caprine milk yogurt with a consistency comparable to bovine milk yogurt [3].

Water-soluble soy extract (WSSE) is an oil-in-water emulsion with a continuous phase consisting of a complex protein dispersion that has been widely used for the elaboration of yogurt-like fermented beverages and possesses good nutritional properties [4-6]. Soybeans contain high-quality proteins with a capacity to form gels in an acidified medium [7]. The partial substitution of bovine milk by WSSE for the elaboration of fermented beverages has been examined in several studies [8,9]. According to Kaur, Mishra, and Kumar [8], yogurts containing WSSE have several nutritional advantages including low fat content, high protein content, and the presence of vitamins and a variety of trace elements.

Inulin is a carbohydrate composed of β(2,1)-linked fructosyl residues mostly ending with a glucose residue that is present as a storage carbohydrate in many plants. The extensive use of inulin in the food industry is based on its nutritional and technological properties. The technological use of inulin is based on its properties as a sugar replacer, a fat replacer and a texture modifier that can improve the sensorial and rheological properties of food products [10].

Rheology concerns the flow and deformation of substances and particularly their behavior in the transient area between solids and fluids. Rheology attempts to define a relationship between the stress acting on a given material and the resulting deformation and/or flow that occurs [11]. In processed food, the composition and addition of ingredients to obtain certain characteristics of quality and performance require a profound rheological understanding of individual ingredients, their relation to food processing, and their final perception [12]. It is well known that the overall acceptance of yogurt-like beverages is correlated with the rheological properties of the product.

A central composite design (CCD) in conjunction with response surface methodology enable the evaluation of the influence of different WSSE and inulin contents on the properties of a yogurt-like product, using a small number of experiments. The partial substitution of caprine milk by WSSE and the incorporation of inulin in the manufacture of yogurt-like beverages can provide a novel alternative product for the dairy market. Furthermore, good sensory, physical and nutritional characteristics can be obtained in these substituted products due to the nutritional and technological properties of soy proteins and inulin. Thus, this study aimed to evaluate the influence of the addition of WSSE and inulin on the rheological, technological and sensory properties of yogurt-like beverages made from caprine milk.

II. MATERIALS AND METHODS

2.1 Experimental design

A CCD for two independent variables was used in this study, where the independent variables selected were the contents of WSSE (mL 100 mL^{-1}) and inulin (g 100 mL^{-1}). The codified levels of the variables and their real values are shown in Table 1. The experimental design included 11 assays; four factorial (the combinations of variables at -1 and +1), four axial (one variable set to ±α and another set to zero) and three repetitions at a central point (two variables set to zero). The dependent variables (responses) were pH, acidity (g 100 g^{-1} lactic acid), syneresis index (SI), water holding capacity (WHC), sensory properties and rheological parameters, consistency index (*K*) and flow behavior index (n), obtained from the model of Ostwald-de-Waelle. The software *Statistica* 7.0 was used for calculations and the results were analyzed by Response Surface Methodology (RSM).

2.2 WSSE and caprine milk

Whole caprine milk (Alpine breed) used in the manufacture of yogurt-like beverages was obtained from the Department of Goat and Cattle breeding of the Centre for Humanities, Social and Agrarian Sciences at the Federal University of Paraíba (Bananeiras, Paraíba, Brazil). Milking was performed under recommended hygienic procedures [13] and the milk was pasteurized (72 °C for 20 s) and then stored under refrigeration (5 °C) until use. WSSE was prepared in accordance with the procedures described by Li *et al.* [5], with modifications. First, whole dry soybeans (Yoki Alimentos®, Cambará, Paraná, Brazil) were washed and soaked overnight in 0.5% $NaHCO_3$ solution. After decanting the water, the soaked soybeans were ground into a homogenate using a blender and a volume of water (60 °C) equal to 7 times the dry weight of the soybeans, and the homogenate was then filtered through a cheese cloth to yield WSSE. The physicochemical parameters of caprine milk and WSSE were determined in accordance with the recommendations of the Association of Official Analytical Chemists [14] and the following mean values were obtained: 10.26 and 7.91 (g 100 g^{-1}) for total solids; 3.03 and 3.47 (g 100 g^{-1}) for total protein; 2.70 and 2.45 (g 100 g^{-1}) for fat; and 0.80 and 0.32 (g 100 g^{-1}) for ash, in caprine milk and in WSSE, respectively.

Table 1. Central Composite Design (CCD) for two independent variables for manufacture of yogurt-like beverages.

Assay	Independent variables			
	WSSE		Inulin	
	X_1[a]	x_1[b] (mL 100 mL^{-1})	X_2[a]	x_2[b] (g 100 mL^{-1})
1	-1	20	-1	1
2	1	50	-1	1
3	-1	20	1	4
4	1	50	1	4
5	- α[c]	13,79	0	2,5
6	+ α	56,21	0	2,5
7	0	35	- α	0,38
8	0	35	+ α	4,62
9	0	35	0	2,5
10	0	35	0	2,5
11	0	35	0	2,5

[a] X_1, X_2 = codified levels of independent variables.
[b] x_1, x_2 = real values of independent variables.
[c] $\alpha = (2^n)^{1/4} = 1,41$; where n = number of independent variables.

2.3 Grape pulp preparation

Mature grapes (cultivar Isabel) were selected, washed (under running water) and sanitized by immersion in sodium hypochlorite (10 ppm) for 15 min. The grapes were then rinsed, ground using a domestic blender, and filtered through a cheese cloth to yield fresh pulp. The total soluble solids from the grape pulp were adjusted to 18° Brix through the addition of sucrose (União®, Limeira, Brazil) and the pulp was heat treated (65 °C for 30 min), refrigerated in an ice bath, packaged in high-density polyethylene bottles (250 mL) and freeze-stored at -18 °C.

2.4 Manufacture of fermented beverages

Yogurt-like beverages were manufactured according to the methodology described by Tsai *et al.* [15], with modifications. Sucrose (União®, Limeira, Brazil) was added to caprine milk (10 g 100 mL^{-1}) and to WSSE (10 g 100 mL^{-1}). The caprine milk and WSSE were heat-treated individually at 90 °C for 10 min and at 95 °C for 15 min, respectively. Then, caprine milk and WSSE were mixed, and the mixture was added to standard inulin (Clariant®, São Paulo, Brazil) according to the experimental design (Table 1) and cooled to 42 °C. A thermophilic lactic culture (Christian Hansen®, Valinhos, Minas Gerais, Brazil) composed of *Streptococcus salivarius* subsp. *thermophillus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, was then added by direct inoculation according to the manufacturer's recommendation (3 mg 100 mL^{-1}). The mixture was transferred to a fermentation chamber at 42 °C for 4 hours and cooled (5 °C) at the end of the fermentation process. Grape pulp (10 mL 100 mL^{-1}) was added and gently stirred with a sterile glass stem until homogenized. The products obtained were packaged in high-density polyethylene bottles (180 mL) and stored under refrigeration (5 °C) until analysis.

2.5 Evaluation of technological properties

pH values were determined using a digital pH meter (model Q400AS, Quimis, Diadema, São Paulo, Brazil) and acidity (g 100 g^{-1} lactic acid) was measured through titration with sodium hydroxide [14]. The syneresis index (SI) was determined in accordance with the methodology described by Hassan *et al.* [16] by inverting a 10 g sample at 5 °C in a funnel lined with filter paper. After 4 h of drainage, the content (g) of whey collected in a beaker was measured and used to calculate the SI using the following formula: SI (g 100 g^{-1}) = [(m_1 M_1^{-1}) × 100]; where m_1 is the weight of whey collected after draining and M_1 is the weight of the yogurt-like beverage sample. The water holding capacity (WHC) was measured by the centrifugation of a 10 g beverage sample at 3,500 rpm for 15 min at 10 °C in a refrigerated centrifuge (CIENTEC, model CT-5000R, Brazil). The WHC was calculated as follows: WHC (g 100 g^{-1}) = [(1-(weight of whey after centrifugation /weight of sample)) × 100] [17].

2.6 Rheological behavior

Rheological behavior was analyzed using a rotational viscometer equipped with concentric cylinders MV/MV1 (Thermo Haake, model VT 550, Karlsruhe, Germany). Measurements were made at 10 °C and the temperature was controlled by a thermostatic bath coupled to the equipment (Thermo Haake, Karlsruhe, Germany). Rheowin Pro Job Manager software was used to control the process and record the data. Rheological analysis was performed by varying the shear rate from 1 to 600 s^{-1} (ascending curve) and from 600 to 1 s^{-1} (descending curve), within an interval of 300 s for each curve. Readings were taken twice, and a new sample was used for each measurement.

2.7 Rheological modeling

The rheological data obtained from the yogurt-like beverages were fitted to four different non-Newtonian rheological models Eq. (1-4):

Ostwald-de-Waelle: $\tau = K \cdot \gamma^n$ (1)

Herschel-Bulkley: $\tau = \tau_0 + K \cdot \gamma^n$ (2)

Casson: $\tau^{0.5} = K_{OC} + K_C \cdot \gamma^{0.5}$ (3)

Mizrahi-Berk: $\tau^{0.5} = K_{OM} + K_M \cdot \gamma^n$ (4)

Where τ is the shear stress (Pa); τ_0 is the yield stress (Pa); γ is the shear rate (s^{-1}); n is the flow behavior index (dimensionless); K is the consistency index ($Pa \cdot s^n$); K_{OC} is the Casson yield stress ($Pa^{1/2}$); K_C is the Casson plastic viscosity ($Pa^{1/2} \cdot s^{1/2}$); K_{OM} is the square root of the yield stress ($Pa^{1/2}$); and K_M is the consistency index ($Pa^{1/2} \cdot s^n$). The software *Statistica* 7.0 (Statsoft, USA) was used for calculations.

2.8 Sensory evaluation

The sensory evaluation of fermented beverages (stored at 5 °C) was conducted one week after production by an untrained panel of 50 assessors (12 males, 38 females) aged 18-35 years. The tasting panel consisted of students recruited from the Federal University of Paraíba (João Pessoa, Brazil). The assessors were asked to evaluate the color, appearance, aroma, texture, taste and overall acceptability of each sample based on a 9 point hedonic scale (9 = like extremely; 5 = neither like nor dislike; 1 = dislike extremely). The analysis was performed in individual booths and the samples were served in plastic cups and were coded with three-digit numbers. Ambient-temperature water was available for panel members to rinse their palates between samples. Crackers were also supplied to aid in removing any carryover between samples [18]. Three sessions of analysis were performed, with up to four samples served at each session. Before sensory evaluation, all samples were microbiologically evaluated to determine the number of total coliforms and thermotolerant coliforms per milliliter (MPN mL^{-1}) and the total counts of mesophilic aerobic bacteria (CFU mL^{-1}) and of yeasts and molds (CFU mL^{-1}), following the methodologies recommended by the American Public Health Association [19]. Ethics approval was obtained from the Research Ethics Committee of the Federal University of Paraíba (Ethics approval number: 383.500/2013).

2.9 Statistical analysis

The regression coefficients for linear, quadratic, and interaction terms were determined by multiple linear regression (MLR). The significance of each regression coefficient was judged statistically by computing the t-value from pure error obtained from the replicates at the central point of this experiment. Analysis of variance (ANOVA) was used to validate the model. The regression coefficients were then used to generate response surfaces. All calculations and graphics were performed using the software *Statistica*®, version 7.0 (Statsoft, USA). A difference was considered statistically significant when $p < 0.05$.

III. RESULTS AND DISCUSSION

3.1 Technological properties

The technological properties of fermented beverages such as pH, acidity, WHC and SI are important parameters that influence the quality of the product [6,20]. Based on a CCD, the effects of independent variables (WSSE and inulin) on the technological properties of yogurt-like beverages prepared with caprine milk were evaluated. The responses obtained from the 11 assays are shown in Table 2.

pH and acidity: Zajsek and Gorsek [21] established that acidity attributes (pH and titratable acidity) are important factors that can strongly affect the quality of fermented products like yogurt. The variables WSSE content and inulin concentration, at the levels studied, did not have any influence ($p > 0.05$) on the acidity or pH of the yogurt-like beverages. Our results for inulin concentration are in agreement with previous studies in which the addition of inulin during the preparation of yogurt-like beverages did not influence the pH and acidity of the products [22,23]. With respect to the use of WSSE in the manufacture of yogurt-like beverages, Park *et al.* [9] developed fermented beverages that were produced from mixtures of WSSE and bovine skim milk and observed that the different proportions of milk/soymilk did not result in significant differences in the acidity of the products.

SI: Syneresis, an undesirable property in yogurt products, is the effect of liquid separating from the yogurt curds [24]. The syneresis index was influenced ($p < 0.05$) by the content of WSSE, where a linear effect of this variable was observed. The concentration of inulin, at the levels studied, did not influence the syneresis index ($p > 0.05$) but did influence ($p < 0.05$) the interaction between the independent variables. The results show that the higher the WSSE content, within the levels studied, the lower the syneresis index of yogurt-like beverages. The adjusted regression model built to evaluate the syneresis index (SI), for use with codified variable levels, is presented in Eq. 5. The model revealed a determination coefficient of 0.976, explaining 97.6% of the variability in the experimental data. A response surface was generated from this regression model (Fig. 1).

$$SI = 43.37 - 7.33X_1 - 1.44X_1X_2 \quad (5)$$

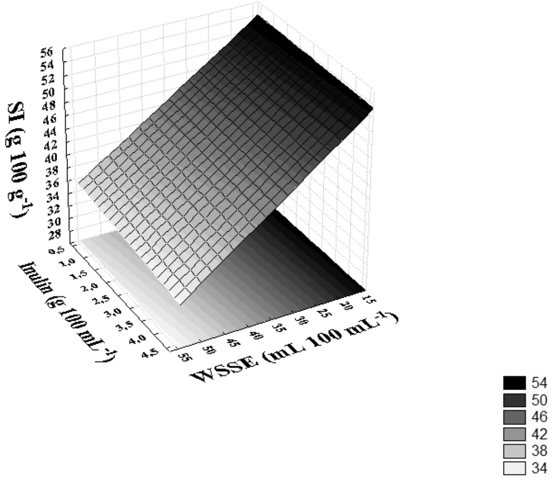

Fig. 1. Response surface for the syneresis index (g 100 g^{-1}) of the yogurt-like beverages as a function of their water-soluble soy extract content (mL 100 mL^{-1}) and inulin concentration (g 100 mL^{-1}).

Park *et al.* [9] observed that yogurt prepared from a mixture of bovine skim milk and WSSE exhibited a lower syneresis index than yogurts prepared from bovine milk alone, also verifying that yogurt prepared from equal proportions of bovine milk and WSSE had the smallest syneresis indices. Harwarker and Kalab [25] reported that the microstructure of yogurt consists of chains and clusters of casein molecules, and the susceptibility of yogurt to syneresis is closely related to the space between casein clusters. Based on the aforementioned result, the incorporation of WSSE into the substrate may have filled the spaces between casein clusters in the caprine milk gel and reinforced the gel network, reducing the syneresis index of the product.

Inulin has a high water retention capacity due to its molecular structure and promotes an increase in the amount of total solids when used as a supplement during the manufacture of yogurt products. Thus, inulin may contribute to the reduction in SI [10]. However, according to the adjusted model we obtained, an effect was only observed on the interaction between the independent variables. In agreement with this result, Guven *et al.* [23] observed that the addition of inulin to yogurt made from bovine milk did not influence the natural release of whey from the curds of the product.

Table 2. Evaluation of the technological properties of yogurt-like beverages

Assay	Responses			
	pH	Acidity (g 100 g^{-1} lactic acid)	Syneresis (g 100 g^{-1})	WHC (g 100 g^{-1})
1	4.15 ± 0.02	0.80 ± 0.02	48.97 ± 0.20	62.39 ± 0.80
2	4.23 ± 0.01	0.71 ± 0.02	37.13 ± 1.73	88.11 ± 2.49
3	4.18 ± 0.01	0.78 ± 0.02	50.42 ± 1.34	54.84 ± 2.19
4	4.38 ± 0.00	0.69 ± 0.02	32.82 ± 0.46	90.12 ± 1.79
5	4.14 ± 0.00	0.77 ± 0.01	53.65 ± 0.63	54.65 ± 3.41
6	4.27 ± 0.01	0.64 ± 0.01	32.99 ± 0.22	94.98 ± 0.26
7	4.33 ± 0.00	0.66 ± 0.02	44.49 ± 1.44	65.64 ± 1.46
8	4.25 ± 0.01	0.69 ± 0.02	44.72 ± 1.84	71.33 ± 3.02
9	4.19 ± 0.00	0.76 ± 0.01	44.41 ± 0.32	68.97 ± 4.84
10	4.25 ± 0.01	0.79 ± 0.03	43.61 ± 0.72	70.72 ± 4.83
11	4.27 ± 0.01	0.72 ± 0.04	43.87 ± 0.91	68.13 ± 1.61

Values are expressed as mean ± standard deviation of triplicate determinations.

WHC: High WHC is an important characteristic of fermented beverages like yogurt because consumers tend to reject the presence of exudates in these products [6]. As observed for SI, inulin did not exhibit any influence ($p > 0.05$) on the WHC of yogurt-like beverages. The effect of interaction between the independent variables was also not observed ($p > 0.05$). The WHC of fermented beverages was influenced ($p < 0.05$) by the addition of water-soluble soy extract, where linear and quadratic effects were observed. The adjusted model built to analyze WHC with coded variable values is shown in Eq. 6.

$$WHC = 69.42 + 14.75X_1 + 3.28X_2^2 \quad (6)$$

The model presented a determination coefficient of 0.967, explaining 96.7% of the experimental data variability, suggesting that this model can be used for predictive purposes. A response surface was generated from this regression model, enabling the visualization of the variation in WHC as a function of the independent variables (Fig. 2). The results show that, the higher the WSSE content used, the greater the WHC of fermented beverages made from caprine milk. Wu *et al.* [24] showed that the WHC is related to the capacity of proteins within the yogurt structure to retain water. Thus, our WHC results may be related to the technological properties of soy proteins.

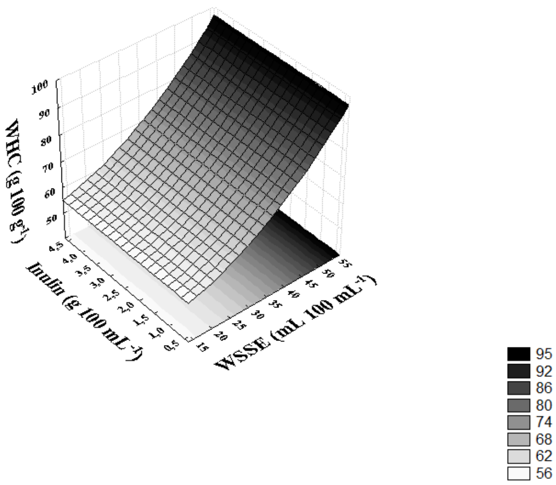

Fig. 2. Response surface for the WHC (g 100 g^{-1}) of the yogurt-like beverages as a function of their water-soluble soy extract content (mL 100 mL^{-1}) and inulin concentration (g 100 mL^{-1}).

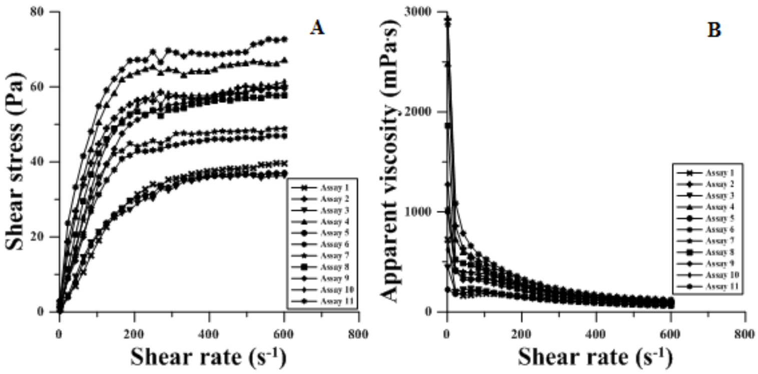

Fig. 3. Rheological behavior of the fermented beverages: (A) Ascending flow curves (shear stress (Pa) *versus* shear rate (s^{-1}). (B) Ascending flow curves (apparent viscosity (mPa·s) *versus* shear rate (s^{-1}).

3.2 Rheological behavior

Two types of plots were generated to demonstrate the flow behavior (upward cycles) of yogurt-like beverages, i.e., a flow curve ($\tau = f(\gamma)$) and a viscosity curve (Apparent viscosity (η) = $f(\gamma)$) (Fig. 3A and B)). All samples exhibited pseudoplastic behavior. Time-dependent viscosity was also demonstrated by the fact that the up- and down-flow curves were not coincident with the lower shear stress values at shear rate down cycles, indicating that yogurt-like beverages present thixotropic behavior (Fig. 4).

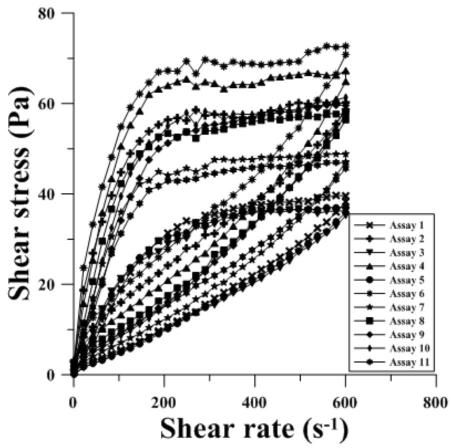

Fig. 4. Thixotropic behavior: hysteresis effect between up and down cycles.

This thixotropic effect occurs as a result of structural breakdown and can be estimated by considering the area of the hysteresis loop between the two curves [26]. Similar results have been reported for dairy fermented beverages [27-29] and for fermented beverages made from WSSE [6]. According to Mohameed *et al.* [30], the interactions present in a network of curds include electrostatic and hydrophobic forces that are considered weak bonds. Thus, the shear rate applied may result in the breakdown of these bonds, leading to the hysteresis effect observed. Rheograms of the samples displayed several oscillations that can be explained by the presence of beads formed by the agglutination of denatured whey proteins and casein micelles, the formation of which has been well explained by Sodini *et al.* [31]. The formation of these aggregates is a typical problem in fermented dairy beverages, influencing product appearance and acceptance.

3.3 Rheological modeling

Due to the pseudoplastic behavior of the samples, the shear rate appears to be an important variable to be considered in addition to the stipulated variables in our experimental design (inulin and WSSE contents). However, if a constitutive model is considered to accurately describe the influence of the shear rate on the viscosity of a system, this difficulty can be overcome by analyzing the effect of the studied variables on the rheological behavior of the samples in terms of its effect on the parameters of this constitutive model [32].

The models of Herschel-Bulkley and Mizrahi-Berk showed high goodness of fitting for all samples tested (Table 3). However, these rheological models exhibited negative yield stress values (τ_0 and K_{OM}), which are meaningless physically [33] and were thus considered inadequate to represent the rheological behavior of the samples. Oliveira *et al.* [26] evaluated the rheological behavior of fermented dairy beverages using the Herschel-Bulkley model and also observed negative yield stress values. However, it should be noted that controlled stress rheology could have provided a more sensitive measurement of yield stress than controlled rate rheology because the variable of primary interest could have been more carefully controlled. In the controlled stress approach, it is possible to gradually increase the stress applied to the material and detect the point at which movement (yield) first occurs [11]. The Casson model did not exhibit negative values for yield stress, but the determination coefficients in this model were lower than those found using the Ostwald-de-Waelle model. Therefore, as has been observed in many studies of fermented dairy beverages and fermented soymilk beverages, the model of Ostwald-de-Waelle (Power law) best fit the experimental data [9,26,34]. The power law model explained between 84.52% and 93.27% of the variation in the experimental data, meaning that this model can be used to explain the rheological behavior of the yogurt-like beverages analyzed.

3.4 Effect of the variables of interest on the consistency index (*K*) and the flow behavior index (n)

From our rheological modeling results, the Ostwald-de-Waelle model was chosen to describe the rheological behavior of the products. The rheological parameters of consistency index (*K*) and flow behavior index (n) were obtained for up and down cycles (Table 4). Higher values of the consistency index were observed in the ascending curves, where pseudoplastic behavior occurred ($n < 1$). The descending curves exhibited increased flow behavior index values for all samples, and dilatant behavior ($n > 1$) was observed in several samples. This dilatant behavior in the descending curves was also observed by Penna *et al.* [35] in commercial fermented dairy beverages.

For the ascending curves, the consistency index (K_1) and the flow behavior index (n_1) were linearly influenced ($p < 0.05$) by the WSSE content. The results showed that higher levels of WSSE were correlated with increases in the consistency index values and decreases in the flow behavior index values. The inulin content did not influence ($p > 0.05$) these rheological parameters. In agreement with this result, Aryana and McGrew [27] evaluated probiotic yogurts and observed that the inulin content did not influence the viscosity of these products. Inulin has a limited effect on viscosity and its influence will depend on the content and type (standard or high performance) of inulin used [36,37].

Table 3. Rheological modeling of the fermented beverages, according to the experimental data of the ascending curves after 1 day of storage (5°C).

Assay	Rheological model													
	Casson: $\tau^{0.5} = K_{OC} + K_C \cdot \gamma^{0.5}$			Ostwald-de-Waelle: $\tau = K \cdot \gamma^n$			Mizrahi-Berk: $\tau^{0.5} = K_{OM} + K_M \cdot \gamma^n$				Herschel-Bulkley: $\tau = \tau_0 + K \cdot \gamma^n$			
	K_{OC}	K_C	R^2	K	n	R^2	K_{OM}	K_M	n	R^2	τ_0	K	n	R^2
1	2.779	0.161	0.87	2.716	0.434	0.92	-11.717	11.750	0.069	0.95	- 11.904	8.066	0.300	0.94
2	5.014	0.131	0.72	13.270	0.248	0.88	-16.407	19.296	0.037	0.91	- 139.63	139.515	0.059	0.93
3	2.985	0.142	0.85	3.486	0.382	0.93	-11.862	12.481	0.059	0.96	- 15.095	11.958	0.238	0.95
4	5.200	0.143	0.68	13.806	0.261	0.85	-17.681	20.489	0.039	0.88	- 157.56	154.82	0.061	0.90
5	2.982	0.145	0.89	3.442	0.388	0.92	-12.455	12.975	0.058	0.94	- 16.305	12.509	0.236	0.94
6	5.545	0.140	0.71	16.500	0.242	0.88	-16.462	19.759	0.039	0.91	- 162.65	163.49	0.059	0.93
7	4.238	0.132	0.72	8.712	0.284	0.87	-15.016	17.068	0.042	0.90	- 72.587	69.379	0.092	0.91
8	4.615	0.142	0.73	10.409	0.281	0.88	-16.426	18.703	0.041	0.90	-78.781	75.919	0.096	0.92
9	3.949	0.176	0.81	6.276	0.367	0.90	-15.039	16.027	0.057	0.93	- 27.956	22.884	0.218	0.92
10	4.347	0.162	0.75	8.378	0.324	0.87	-20.394	21.933	0.041	0.90	- 50.013	44.525	0.149	0.91
11	3.959	0.137	0.76	7.196	0.308	0.88	-15.134	16.794	0.044	0.91	- 42.502	39.300	0.135	0.92

Table 4. Rheological parameters of the fermented beverages obtained from the Power law model.

Assay	Ostwald-de-Waelle: $\tau = K \cdot \gamma^n$					
	Ascending curve			Descending curve		
	K (Pa·s^n)	n	R^2	K (Pa·s^n)	n	R^2
1	2.716	0.434	0.923	0.020	1.177	0.995
2	13.270	0.248	0.882	0.434	0.756	0.982
3	3.486	0.382	0.933	0.023	1.142	0.995
4	13.806	0.261	0.845	0.094	1.010	0.977
5	3.442	0.388	0.915	0.019	1.178	0.997
6	16.500	0.242	0.878	0.401	0.795	0.975
7	8.731	0.284	0.864	0.019	1.216	0.988
8	10.409	0.282	0.875	0.065	1.050	0.988
9	6.276	0.367	0.900	0.031	1.171	0.991
10	8.378	0.324	0.872	0.025	1.205	0.992
11	7.196	0.308	0.884	0.091	0.963	0.989

The influence of WSSE on the consistency index (K_1) of the fermented beverages (ascending curves) was explained by an adjusted regression model. The regression model used with codified variable levels is presented in Eq. 7. The model showed a determination coefficient of 0.924, explaining 92.4% of the variability in the experimental data, suggesting that this model can be used for predictive purposes. A response surface was generated from this regression model, where the influence of the WSSE on the consistency index can be observed (Fig. 5). The response surface generated indicates that higher WSSE contents are correlated with higher consistency index values. The consistency index is linearly correlated with viscosity [34], and this result can be explained by the functional properties of soy proteins that allow the formation of a gel network structure with semisolid characteristics [38].

$$K_1 = 8.56 + 4.92 \cdot X_1 \qquad (7)$$

The adjusted regression model used with coded variable values to analyze the flow behavior index (n_1) in the ascending curves is shown in Eq. 8. The model presented a determination coefficient of 0.798, explaining 79.8% of the variability in the experimental data. A response surface was generated from this regression model, enabling the visualization of the variation in flow behavior index values as a function of the levels of the independent variables (Fig. 6). Increased WSSE content was correlated with lower flow behavior index values. Thus, the shear-thinning effect is correlated with WSSE content, and the partial substitution of caprine milk for WSSE increased the pseudoplasticity of the yogurt-like beverages. Penna *et al.* [35] evaluated commercial fermented dairy beverages and observed that lactic beverages with high consistency index values and high pseudoplasticity were found to be well accepted by the consumers.

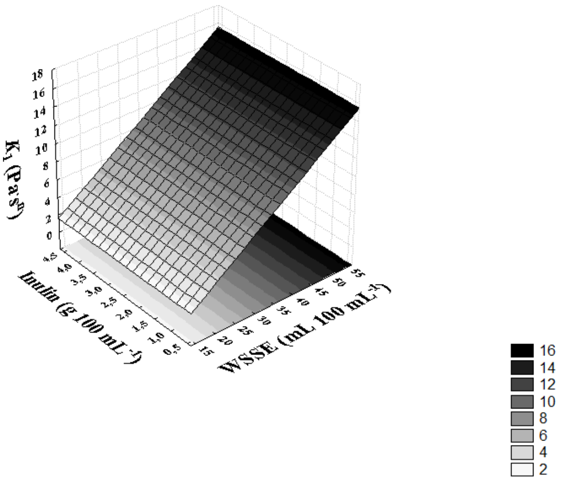

Fig. 5. Response surface for the consistency index (Pa·s^n) of the yogurt-like beverages as a function of their water-soluble soy extract content (mL 100 mL^{-1}) and inulin concentration (g 100 mL^{-1}). Ascending curves.

In the descending curves, WSSE content influenced ($p < 0.05$) the consistency index values, and linear and quadratic effects were observed. Although inulin did not influence ($p > 0.05$) this response variable, an interaction effect between the independent variables was observed. In the down cycles, neither linear nor quadratic fits described the variation in the flow behavior index values as a function of the WSSE content and the inulin concentration of the yogurt-like beverages.

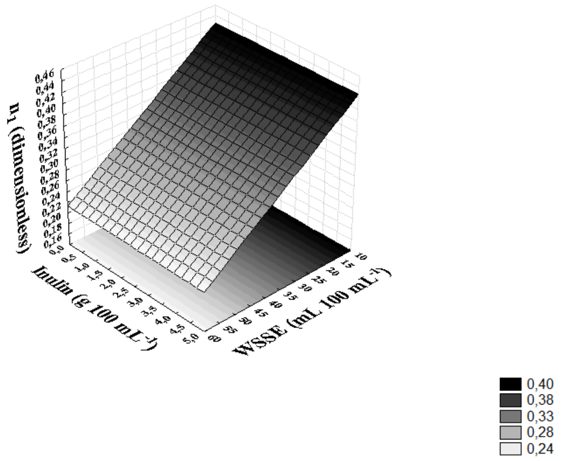

Fig. 6. Response surface for the flow behavior index (dimensionless) of the yogurt-like beverages as a function of their water-soluble soy extract content (mL 100 mL^{-1}) and inulin concentration (g 100 mL^{-1}). Ascending curves.

$$n_1 = 0.320 - 0.064 \cdot X_1 \quad (8)$$

The adjusted regression model used with coded variable values to analyze the consistency index (K_2) in the descending curves is presented in Eq. 9. The determination coefficient of this model was 0.861, explaining 86.1% of the variability in the experimental data. A response surface was generated from this regression model, demonstrating the linear increase in the consistency index as a function of increased WSSE content (Fig. 7).

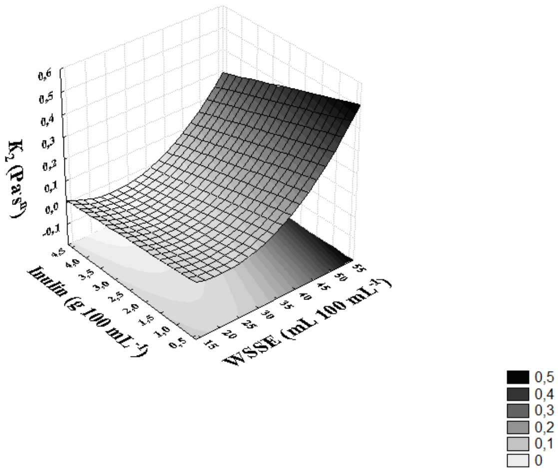

Fig. 7. Response surface for the consistency index (Pa·s^n) of the yogurt-like beverages as a function of their water-soluble soy extract content (mL 100 mL^{-1}) and inulin concentration (g 100 mL^{-1}). Descending curves.

$$K_2 = 0.0496 + 0.128 \cdot X_1 + 0.084 \cdot X_1^2 - 0.086 \cdot X_1 \cdot X_2 \quad (9)$$

3.5 Sensory properties

The evaluation of sensory properties is a crucial step for the development of attractive and well-accepted food products [39]. The final consumer response to a product is based on the perception of different attributes that constitute its sensory quality, and the perceived sensations depend on the intensity and interactions among these attributes [40]. The responses obtained from the 11 assays showed that the yogurt-like beverages achieved good sensory acceptability and exhibited good textures (Table 5).

It was not possible to obtain a linear or quadratic fit to describe the effect of the independent variables on the following sensory attributes: appearance, color, aroma, texture and taste. Only the overall acceptability of the yogurt-like beverages was influenced ($p < 0.05$) by the independent variables. Linear and quadratic effects were observed for the WSSE content, whereas linear effect was observed for the inulin content. The adjusted quadratic model ($R^2 = 0.849$) used with codified independent variable values to analyze overall acceptability is presented in Eq. 10. A response surface was generated from this model (Fig. 8).

$$\text{Overall acceptability} = 6.64 - 0.19X_1 - 0.18X_1^2 + 0.25X_2 \quad (10)$$

The results showed that an increase in the concentration of inulin was correlated with an improvement in the overall acceptability of the product. Rinaldoni *et al.* [6] observed that an increase in the concentration of inulin in fermented beverages made from WSSE increased the sweetness and creaminess of the products, and the best overall acceptability was achieved in beverages prepared with an inulin concentration of 5 g 100 mL^{-1}. High WSSE contents were correlated with a lower overall acceptability in yogurt-like beverages. According to Park *et al.* [9], this negative effect is likely related to the "beany flavor" of soy, which limits its incorporation into food products in Western countries. However, the response surface for overall acceptability (Fig. 8) indicates that better results were obtained using a WSSE content ranging from 20 to 35 (mL 100 mL^{-1}), possibly due to the contribution of water-soluble soy extract to the consistency of yogurt-like beverages.

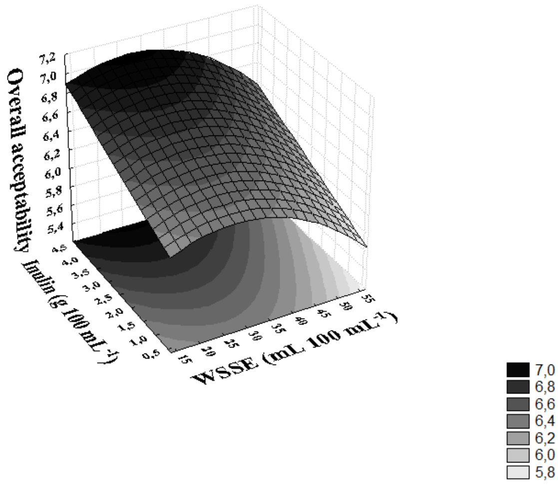

Fig. 8. Response surface for the overall acceptability of the yogurt-like beverages as a function of their water-soluble soy extract content (mL100 mL^{-1}) and inulin concentration (g 100 mL^{-1}).

Table 5. Evaluation of the sensory properties of the yogurt-like beverages

Assay	Responses					
	Appearance	Color	Texture	Aroma	Taste	Overall acceptability
1	6.22 ± 1.54	6.16 ± 1.66	6.82 ± 1.59	4.92 ± 1.70	5.46 ± 2.01	6.41 ± 1.38
2	6.04 ± 1.75	5.74 ± 1.77	6.60 ± 1.64	4.88 ± 1.98	4.56 ± 1.99	6.03 ± 1.40
3	5.92 ± 1.84	5.94 ± 1.75	6.42 ± 1.58	5.10 ± 1.85	6.00 ± 2.09	6.76 ± 1.32
4	6.16 ± 1.75	6.14 ± 1.81	6.68 ± 1.61	5.44 ± 1.69	6.26 ± 1.71	6.81 ± 1.20
5	6.43 ± 1.57	6.18 ± 1.84	6.56 ± 2.03	5.62 ± 2.22	5.61 ± 2.33	6.65 ± 1.70
6	6.77 ± 1.65	6.52 ± 1.61	7.18 ± 1.61	4.90 ± 1.58	5.06 ± 2.21	5.81 ± 1.75
7	6.39 ± 1.41	6.22 ± 1.70	7.08 ± 1.71	5.42 ± 1.96	5.35 ± 2.23	6.32 ± 1.75
8	6.53 ± 1.57	6.37 ± 1.67	7.08 ± 1.74	5.48 ± 2.00	5.67 ± 2.43	6.92 ± 1.80
9	6.14 ± 1.81	6.18 ± 2.01	6.94 ± 1.43	5.02 ± 1.79	6.00 ± 1.87	6.54 ± 1.52
10	5.92 ± 1.74	5.90 ± 1.66	6.68 ± 1.45	5.14 ± 1.70	5.62 ± 2.19	6.62 ± 1.28
11	6.10 ± 1.71	5.94 ± 1.80	6.64 ± 1.41	5.20 ± 1.85	5.82 ± 2.25	6.70 ± 1.39

Values are expressed as mean ± standard deviation.

IV. CONCLUSIONS

Characterizing and understanding the rheological and technological properties of food materials is essential to numerous aspects of food science and technology, including sensorial data and the standardized characterization of innovative products. The addition of WSSE and inulin to yogurt-like beverages made from caprine milk is technically viable, as observed from the rheological, technological and sensory properties of the obtained products, which overcame the technological limitations of caprine milk. From our adjusted models for the response variables studied, we find that yogurt-like beverages made from caprine milk containing 30% (v/v) WSSE supplemented with 4% (w/v) of inulin are technically viable and possess desirable technological and sensory properties. This result demonstrates either the positive effect of inulin on the sensory acceptance of yogurt-like beverages or the positive effect of WSSE on the technological and rheological properties of yogurt-like beverages. Moreover, in these products, the excellent nutritional properties of soybean proteins and lipids combine with the functional properties of inulin, making such products an attractive alternative given the current market demand for food products that provide additional health benefits.

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