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Research article

Evaluation of yam (*Dioscorea rotundata*) mucilage as a stabilizer in the production of mango nectar

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ABSTRACT

Instability in fruit drinks is a phenomenon that affects sensory and physical-chemical properties, which consumers perceive as lack of quality. Yam mucilage was evaluated as a stabilizer in the production of mango nectar. In addition, physicochemical characteristics, physical and rheological stability were determined. A completely randomized design with factorial arrangement (2 × 4) was utilized. The factors were the concentration of the stabilizers, and the yam mucilage:carboxymethylcellulose ratio. Results showed that physicochemical properties comply with Colombian regulations and, as the proportion of carboxymethylcellulose decreased in the mucilage:CMC ratio, the absolute value of zeta potential decreased. Rheologically, mango nectar exhibit overall shear-thinning (pseudoplastic) and thixotropic properties. Results indicate that yam mucilage should be used in a mixture with other hydrocolloids.

1. Introduction

Nectar is a product made with fruit juice, pulp or concentrate. According to Colombian Resolution 7992 (Ministry of Health, Colombia, 1991), the minimum percentage of fruit or pulp and soluble solids contributed by fruit to the nectar are related. These should be liquid, free of extraneous matter and strange flavors, have a uniform color, and the characteristic odor of the raw material that is being used (ICONTEC, 2007; Parraga, 2012).

The maximum percentage of stabilizers, alone or in mixtures, for the elaboration of nectar is 0.15% (ICONTEC, 2007; Ministry of Health, Colombia, 1991). Nectars preferred by consumers are those made from tropical fruits, especially when they are rich in micronutrients; therefore, fruits such as mango (*Mangifera indica L.*) which is one of the most consumed in the world are preferred (Morales and Rodríguez, 2009; Rico et al., 2012).

Mango pulp has a significant concentration of bioactive compounds such as vitamin A (essential for maintenance of epithelial tissues of the skin and mucous membranes), as well as compounds with high antioxidant activity, including vitamin C, vitamin E, polyphenols, carotenes, among others (Sumaya et al., 2012).

In addition, trends towards the consumption of healthy products are reflected in the use of natural additives. Some of the most important additives to preserve sensory and physical-chemical quality of food are stabilizers in food matrices such as nectar (Andrade et al., 2015; Cuichan, 2013; Jouki et al., 2014). Similarly, consumers of food products are becoming increasingly aware of the importance of replacing non-natural products, hence the growing interest in the consumption of natural fresh fruits and tropical fruit drinks in preference to synthetic soft drinks and dairy products. Also, consumers currently prefer nectars made with ingredients obtained naturally or minimally processed, such as stabilizers that play a key role in ensuring good sensory properties (Machado et al., 2013; Sousa et al., 2010; Sumaya et al., 2012).

Mucilage is a colloidal, lipophilic liquid system and a hydrogel that provides unique functional and rheological properties to products in which it is used due to the viscosity of its gel; thus, its use allows liquid foods to thicken and modifies the food texture. The systems to which it is added do not flocculate; it reduces the superficial and interfacial tension. Therefore, it can be applied in the manufacture of jellies, jams, bakery products, in the pharmaceutical industry, for the elaboration of beverages, and as a stabilizing agent in emulsions in ice cream industry (Andrade et al., 2015; Contreras-Padilla et al., 2016; Njintang et al., 2014; Tavares et al., 2011).

To avoid phase separation in nectars, commercial stabilizers such as pectin, natural gums such as guar gum, xanthan gum, and modified cellulose such as carboxymethylcellulose are used (Genovese and Lozano, 2001; Vera, 2011). Due to its weak gel characteristics and high

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Table 1. Experimental design for the tests of mango nectar.

Treatment	Concentration of stabilizers (%)	Ratio of stabilizers (mucilage: CMC)
T1	0.01	20:80
T2	0.01	50:50
T3	0.01	80:20
T4	0.01	100:0
T5	0.03	20:80
T6	0.03	50:50
T7	0.03	80:20
T8	0.03	100:0

Table 2. Physicochemical characterization of mango nectar.

Physicochemical properties	Concentration of stabilizers (%)	Ratio of stabilizers (mucilage: CMC)			
		20:80	50:50	80:20	100:0
pH	0.01	3.71 ± 0.02^{bA}	3.72 ± 0.02^{bA}	3.68 ± 0.01^{bA}	3.70 ± 0.01^{bA}
	0.03	3.74 ± 0.01^{aA}	3.75 ± 0.03^{aA}	3.77 ± 0.01^{aA}	3.74 ± 0.02^{aA}
TSS (° Brix)	0.01	12.45 ± 0.02^{aA}	12.04 ± 0.08^{aB}	12.09 ± 0.01^{aB}	12.05 ± 0.02^{aB}
	0.03	11.94 ± 0.08^{bA}	12.05 ± 0.02^{aA}	11.95 ± 0.08^{bA}	12.04 ± 0.01^{aA}
AT (% citric acid)	0.01	1.21 ± 0.02^{aA}	1.29 ± 0.02^{aA}	1.24 ± 0.01^{aA}	1.25 ± 0.01^{aA}
	0.03	1.28 ± 0.01^{aA}	1.24 ± 0.03^{aA}	1.28 ± 0.01^{aA}	1.26 ± 0.02^{aA}

Averages with different lowercase letters in the same column and with different capital letters in the same row indicate a statistically significant difference according to the Tukey test ($p \leq 0.05$).

Table 3. Zeta potential and sedimentation index on the tenth day of mango nectar.

Properties	Concentration of stabilizers	Ratio of stabilizers (mucilage: CMC)			
		20:80	50:50	80:20	100:0
Zeta potential	0.01	-16 ± 1.59^{aA}	-15.77 ± 0.08^{aA}	-8.2 ± 0.55^{aB}	-9.5 ± 0.31^{aB}
	0.03	-12.7 ± 0.46^{aA}	-13 ± 1.40^{aA}	-10.6 ± 0.27^{aB}	-7±1.04^{aB}
Sedimentation index, %	0.01	6.1 ± 0.70^{aA}	7.0 ± 0.14^{aA}	5.10 ± 0.07^{aA}	10.5 ± 0.74^{aA}
	0.03	5.6 ± 0.28^{aA}	14.2 ± 0.21^{aA}	6.3 ± 0.33^{aA}	11.6 ± 0.54^{aA}

Means with different lowercase letters in the same column and with different uppercase letters in the same row indicate statistically significant difference with the Tukey test ($p \leq 0.05$).

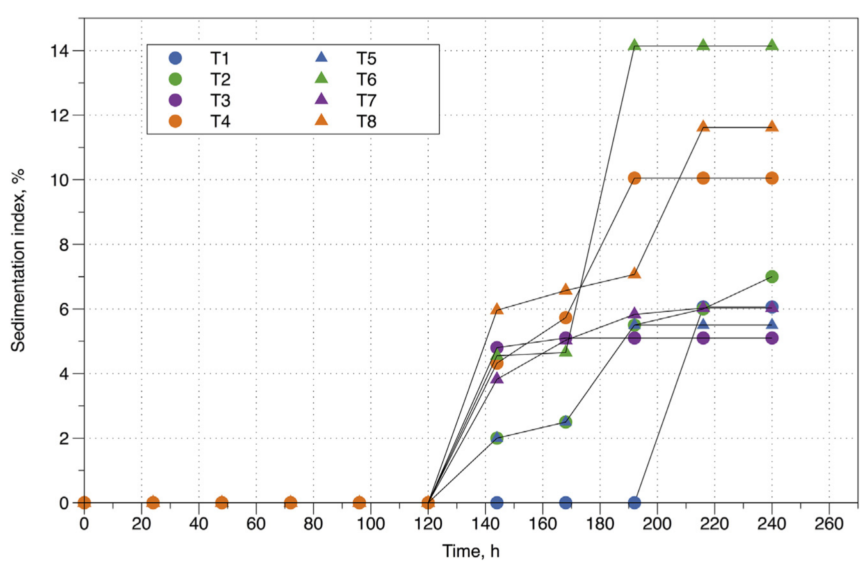
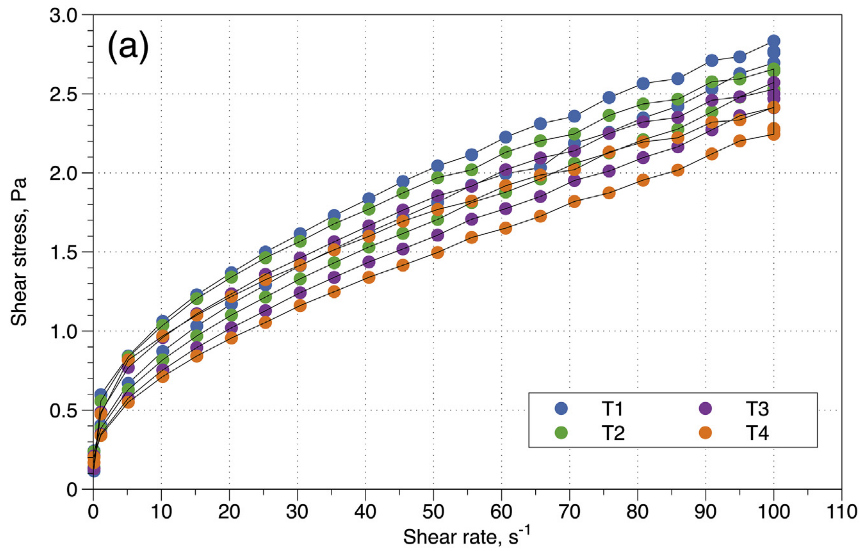


Figure 1. Sedimentation index behavior in mango nectar during 10 days of storage at room temperature 24 °C.



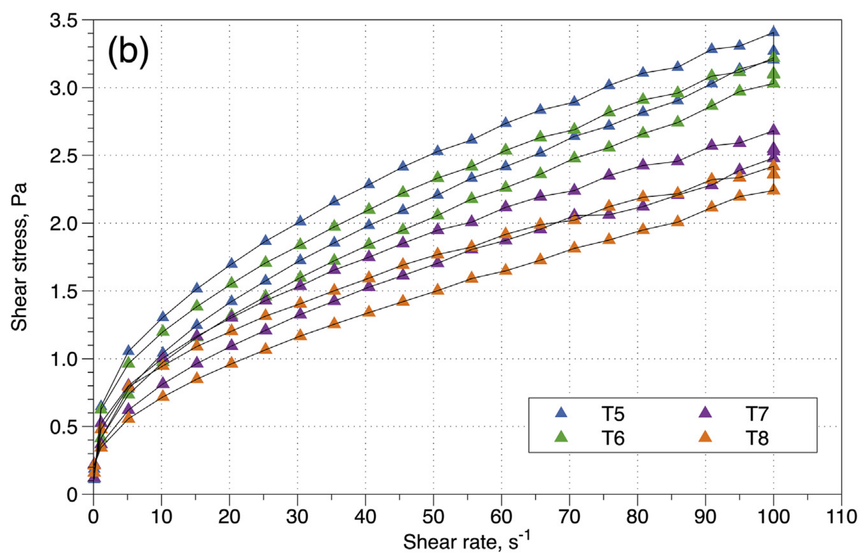


Figure 2. Flow behavior of mango nectar stabilized with mixtures of yam mucilage. (a) Concentration of stabilizers, 0.01% (b) Concentration of stabilizers, 0.03%.

pseudoplasticity, the mucilage could replace these commercial stabilizers. Thus, the objective of this research was to evaluate yam mucilage as a stabilizer in the production of mango nectar.

2. Materials and methods

2.1. Raw material and extraction of yam mucilage

Yam (*Dioscorea rotundata*) was acquired from the market square of the city of Sincelejo (Sucre-Colombia). Extraction of mucilage was done by the bubbling method, using a continuous pilot-scale equipment (University of Sucre, Colombia). It operates with a yam: water ratio of 1: 8, and whose basis is flotation in the presence of air as medium for separation. Liquid mucilage was dried in a vacuum freeze dryer (Freezone, Labconco, USA) for 60 h, and for this purpose, it was first frozen at -50 °C after which the sample was macerated for later use (Pérez et al., 2015; Tavares et al., 2011).

2.2. Elaboration of mango nectar

The fresh mangos (*Mangifera indica* var. Tommy Atkins) were acquired in a local market in Sincelejo (Colombia). The fruits were selected with commercial maturity, uniform in size, free of pests, and no mechanical damage. The pulp was extracted by means of an industrial fruit pulper provided with a sieve of 1.6 mm mesh size (DF-300 Javar, Colombia). Mango pulp was subjected to physicochemical analyzes such as: titratable acidity expressed in citric acid equivalence (AOAC 942.15, 2012); the pH was measured directly with a pH meter (Metrohm, Switzerland) based on the AOAC procedure 981.12 (2012); and the content of total soluble solids (TSS) was determined using a digital refractometer (Atago, Japan), according to AOAC procedure 983.17 (2012), expressed in °Brix. Bell Chem Internacional S.A. supplied food additives used such as ascorbic acid, citric acid, carboxymethylcellulose (CMC), benzoate, and sugar (sucrose).

Mango nectar was formulated to contain mango pulp 20 % and 12°Brix by adding required quantity of sugar and water to the fruit pulp. The ingredients were mixed and finally, the acidulant (citric acid), antioxidant (ascorbic acid), stabilizers (yam mucilage and CMC), and preservatives (potassium sorbate) were added. This mixture was subjected to pasteurization and packed in plastic containers (Parraga, 2012; Ministry of Health, Colombia, 1991).

Table 4. Rheological parameters and hysteresis of power law model in mango nectar.

Rheological, statistic parameters, and hysteresis		Concentration of stabilizers	Ratio of stabilizers (mucilage: CMC)			
			20:80	50:50	80:20	100: 0
Ascent	n	0.01	0.42 ± 0.027^{aA}	0.410 ± 0.012^{aA}	0.433 ± 0.001^{aA}	0.402 ± 0.003^{aA}
		0.03	0.419 ± 0.000^{aA}	0.433 ± 0.004^{aA}	0.429 ± 0.003^{aA}	0.409 ± 0.008^{aA}
	K (Pa·s^n)	0.01	0.40 ± 0.045^{bA}	0.39 ± 0.026^{aA}	0.342 ± 0.007^{aA}	0.370 ± 0.014^{aA}
		0.03	0.491 ± 0.002^{aA}	0.43 ± 0.011^{aAB}	0.365 ± 0.007^{aBC}	0.360 ± 0.017^{aC}
	R^2 aj.	0.01	0.98	0.99	0.99	0.99
		0.03	0.98	0.98	0.99	0.99
Descent	n	0.01	0.498 ± 0.002^{aB}	0.499 ± 0.003^{aB}	0.517 ± 0.001^{aA}	0.512 ± 0.003^{aA}
		0.03	0.496 ± 0.001^{aB}	0.505 ± 0.001^{aB}	0.503 ± 0.004^{aA}	0.504 ± 0.005^{aA}
	K (Pa·s^n)	0.01	0.26 ± 0.02^{bA}	0.248 ± 0.007^{bA}	0.217 ± 0.008^{bB}	0.207 ± 0.003^{aB}
		0.03	0.32 ± 0.003^{aA}	0.29 ± 0.001^{aB}	0.242 ± 0.006^{aC}	0.214 ± 0.007^{aD}
	R^2 aj.	0.01	0.97	0.97	0.97	0.97
		0.03	0.99	0.98	0.97	0.96
Hysteresis, %		0.01	0.01	10.1 ± 0.31^{aA}	11.8 ± 0.71^{aA}	11.9 ± 0.42^{aA}
		0.03	0.03	11.6 ± 0.14^{aA}	10.7 ± 0.11^{aA}	11.09 ± 0.01^{aA}

Averages with different lowercase letters in the same column and with different capital letters in the same row indicate a statistically significant difference according to the Tukey test ($p \leq 0.05$).

2.3. Analysis of mango nectar

2.3.1. Sedimentation index

The separation phase percentage was determined by sedimentation stability using the methodology proposed by Fasolin and Da Cunha (2012). The mango nectars were transferred to graduated 25 mL tubes, stored at 24 ± 2 °C and measured for 10 days. The sedimentation height was measured on a millimeter scale at regular intervals of 24 h. Sedimentation index (SI) was calculated using following equation (Eq. (1)).

$$SI(\%) = \frac{H_t}{H_0} \times 100\% \tag{1}$$

Ht - the sedimented height after a time t

H_0 - the initial height at time t_0.

2.3.2. Zeta potential

The measurement of zeta potential was made by electrophoresis using a Zeta Meter 3.0+ (Zeta-Meter Inc., USA), following the methodology proposed by Genovese and Lozano (2001). Samples were diluted with distilled water at a ratio of (1:10) to reduce the concentration of particles. The study was carried out at room temperature (25 °C) and triplicate readings were made for each formulation.

2.3.3. Rheological measurements

For the determination of the flow behavior (stationary test), 10 mL of mango nectar was taken and placed in the MCR 302 rheometer (Anton Paar, Austria) with a concentric cylinder accessory (CC24-38036, which has internal radius 1.2 cm and external radius of 1.25 cm) by varying the shear gradient on a continuous ramp from 0.1 to 100 s^{-1} ascending and then descending from 100 to 0.1 s^{-1}. The maximum shear gradient (100 s^{-1}) was maintained for 2 min. Measurements were made in duplicate at a temperature of 25 °C. The experimental values of the flow curves were adjusted to rheological models of power law (Eq. (2)), Bingham (Eq. (3)) and Herschel-Bulkley (Eq. (4)) (Chien et al., 2013).

$$\sigma = K\dot{\gamma}^n \tag{2}$$

$$\sigma = \sigma_0 + K\dot{\gamma} \tag{3}$$

$$\sigma = \sigma_0 + K\dot{\gamma}^n \tag{4}$$

Where,

σ - shear stress (Pa)

$\dot{\gamma}$ - shear rate (s^{-1})

n - flow behavior index

K - consistency coefficient (Pa · s^n)

σ_0 - yield stress (Pa).

2.4. Experimental design

A completely randomized design with 2 × 4 factorial arrangement was utilized. The factors were the concentration of stabilizers (0.01 and 0.03%) and the yam mucilage:carboxymethylcellulose ratio (20:80, 50:50, 80:20 and 100:0) (Table 1). The separation phase percentage, Z potential, titratable acidity, pH, total soluble solids, rheological parameters were named dependent variables. All measurements were performed at triplicate.

2.5. Statistical analysis

Analysis of variance (ANOVA) of the two factors and interactions were applied to the different sets of data. Least significant differences were calculated by the Tukey test at the 5% significance level. Statistical analysis was performed using the R-studio software (version 1.1.442, 2018).

3. Results and discussion

3.1. Physicochemical characterization of mango pulp

In the physicochemical characterization of Tommy Atkins mango (*Mangifera indica L.*) pulp total soluble solids content of 15.36 ± 0.14 °Brix, an acidity of 0.15 ± 0.02%, and a pH of 3.77 ± 0.05 were measured at a temperature between 24 and 25 °C with a pulp yield of 65%. These values meet the specifications of Colombian regulations (ICONTEC, 1994). These values are also within reported range of values for different mango varieties (Quintero et al., 2013) and close to those of Tommy Atkins variety reported by Ramírez et al. (2010) and Sabato et al. (2009).

3.2. Characterization of mango nectar

Physicochemical properties (pH, total soluble solids and titratable acidity) of mango nectar treatments are shown in Table 2. The pH was between 3.68 and 3.77, soluble solids between 11.94 and 12.45ºBrix, and titratable acidity was between 1.21 and 1.29%. These values comply with Colombian regulations (ICONTEC, 1994).

Statistical analysis showed that only the concentration of stabilizers significantly ($p < 0.001$) affected pH but did not affect the acidity. An increase in the concentration of the stabilizers (0.01–0.03%) resulted in an increase in the pH. Similar results have been reported for goldenberry nectar added with carnitine (Cuichan, 2013), and mixed mango and cherry nectar when guar gum was used (Lozano et al., 2016). Differences in pH can be due to hydrocolloids' encapsulating properties, therefore they can trap substances such as pigments and organic acids from mango pulp to mask pH in beverages (Nwaokoro and Akanbi, 2015).

The concentration of stabilizers, the ratio between stabilizers (mucilage:CMC), and the interaction of the concentration and the stabilizers ratio showed a significant effect on total soluble solids (TSS) content. At a high concentration of stabilizers (0.03%) there was no changes in mango nectar TSS, but at a low concentration of stabilizers (0.01%), an increase in the mucilage:CMC ratios from 20:80 to 50:50 produced a slight decrease in TSS. This is possibly due to the fact that CMC is a hydrocolloid which is difficult to dissolve in liquid solutions, therefore causes lumps to form, so that when its amount decreases in food matrices it produces an increase in soluble solids, as it is a polymer with 99.5% purity (Parraga, 2012; Vera, 2011).

Table 3 shows zeta potential and sedimentation index on the tenth day for mango nectar. Zeta potential was between -15.77 and -7.33 and the sedimentation rate between 5.1 and 14.5%.

According to the statistical analysis, stabilizer ratio significantly affected zeta potential; however, no factor affected the sedimentation index. Low amounts of mucilage in the ratio of stabilizers (mucilage:CMC) causes an increase in the value of zeta potential As the proportion of mucilage in the mix of stabilizers increases, the zeta potential decreases (Table 3). The increase of the value mucilage:CMC ratios in 20:80 and 50:50 is possibly due to hydrocolloids interaction. These are anionic water-soluble polymers that form very viscous solutions in low proportions and they are highly electronegative hydrocolloids. When these hydrocolloids are added to the mango nectar, they interact with the pectins surrounding the carbohydrates and proteins, causing negative values in zeta potential (Andrade et al., 2015; Cuichan, 2013; Genovese and Lozano, 2001; Hajmohammadi et al., 2016; Milani and Maleki, 2012).

According to Hajmohammadi et al. (2016) and Bhattacharjee (2016) the colloidal stability can be determined taking into account the zeta potential, according to the following classification: very unstable (±0–10), relatively stable (±10–20), moderately stable (±20–30), and highly stable (±30–40). In general terms, treatments with a lower amount of mucilage in the ratio of stabilizers classify as relatively stable, and those with only 100% yam mucilage and 80% mucilage can be classified as very unstable. Therefore, using yam mucilage as a stabilizer, it should be mixed with other hydrocolloids up to 50:50. Studies show zeta potential values of between -15.73 and -17 for mango juices (Zhou et al., 2017). In addition, there is better stability with CMC than with xanthan gum and pectin with values close to 67 (Ibrahim et al., 2011). In the same way, when comparing the stability of beverages with CMC, pectin, carrageenan or a mixture of these hydrocolloids a better synergistic effect is produced with pectin-CMC mixture (Abedi et al., 2014).

Figure 1 shows sedimentation index evolution over time (10 days). All treatments showed no difference in the first 120 h (5 days), and then began a sharp increase until the tenth day. This may be due to the viscous consistency of mango pulp (Elbandy et al., 2014), which is why it is advisable to use low concentrations of hydrocolloids (Akkarachaneeyakorn and Tinrat, 2015). The slight sedimentation in mango nectars can be due to the different migration speeds of pulp to the bottom due to the gravitational acceleration, the viscosity of the system and density differences of mango drinks and pulps. Stokes Law shows that the sedimentation rate of particles in nectar is inversely related to its viscosity, and directly related to the difference between the density of disperse phase (solid particles) and density of disperse media (Dak et al., 2007; Sinchaipanit and Kerr, 2007; Nwaokoro and Akanbi, 2015).

In Figure 2 (a and b) flow curves of mango nectar are presented. All treatments showed dependence on time, which can be seen in the mismatch between the rise and fall curve. In addition, they presented the characteristic behavior of a pseudoplastic fluid. In the same way it is observed that as mucilage content decreases in ratio and concentration of stabilizers increases, mango nectar offers more resistance to flow. Researchers who have used different hydrocolloids as stabilizers either alone or in mixtures (guar gum, xanthan gum, CMC and pectin) have reported pseudoplastic fluid behavior, showing that viscosity changes depending on the kind of fruit, concentration of pulp, and synergy between hydrocolloids (Abedi et al., 2014; Genovese and Lozano, 2001; Gratao et al., 2007; Lozano et al., 2016; Rodríguez, 2010; Sherafati et al., 2013; Sharoba and Ramadan, 2011).

Experimental data were adjusted to power law models, Bingham and Herschel-Bulckey, which are the most used in food industry and all adequately represented rheological data (R^2 between 91.7 and 99.9%). The model that best represented the rheological data of mango nectar was the power law, with an adjusted determination coefficient (R^2 adjusted) between 98-99%. Flow behavior index of rise and fall curve shows values that oscillate between 0.402 and 0.517 (Table 4), which confirm the pseudoplasticity of mango nectar. Similar results were found in cactus juice (*Opuntia dillenii*) subjected to innovative pasteurization techniques (0.61 and 0.71) (Moussa-Ayoub et al., 2017), mango juice (Zhou et al., 2017) and soursop juice (0,266 y 0,445) at different concentrations of pulp (Gratao et al., 2007).

For ascending and descending curves, the comparison of independent means showed significant difference between treatments, which corroborates time dependence, with a percentage of hysteresis comprised between 10.08 and 14.25% (Table 4). There are similar results reported for mango juice with values between 7.01 and 22.84% (Zhou et al., 2017). In addition, the ascending curve is greater than the descending curve, so mango nectar shows a positive thixotropy, where viscosity decreases with time due to a change of the internal structure when an effort is applied (Mezger, 2006; Quintero et al., 2013; Steffe, 1996). The mismatch between curves has been reported for different products, such as nectars, honey, and pudding (Casanovas et al., 2011).

According to ANOVA, no factor affected the flow behavior index (n) in the ascending curve, but the ratio of stabilizers affected the flow behavior index in descending curve. An increase of mucilage content in the ratio of stabilizers (mucilage:CMC) produced an increase of flow behavior index in descending curve. For consistency coefficient in ascending and descending curves, concentration of stabilizers ($p < 0.01$), ratio of stabilizers ($p < 0.01$), and interaction between concentration and ratio of stabilizers ($p < 0.01$) had significant effects. With the increase of mucilage in the mucilage:CMC ratio there was an increase in the flow behavior index (n) in descending curve. Most pronounced changes in consistency coefficient than in the flow index have been reported in different fruit drinks (Gratao et al., 2007; Moussa-Ayoub et al., 2017; Zhou et al., 2017), also when the amount of mucilage increases in mucilage: CMC ratio, the consistency coefficient decreases. This can be due to the fact that mucilage has less capacity to increase viscosity which is reflected in this parameter. Note the role of thickener and stabilizer of CMC mixtures, which acts as an enhancer of particle-particle interaction causing a better orientation (Dak et al., 2007; Dertli et al., 2016; Ramirez et al., 2010; Sabato et al., 2009).

On the other hand, ANOVA shows that hysteresis percentage was affected by the mucilage:CMC ratio. The increase of mucilage content in the ratio of stabilizers (mucilage:CMC) produced an increase of up to 29% of hysteresis percentage. The highest was found when only mucilage was added as a stabilizer (Table 4), demonstrating the advantages of CMC with respect to yam mucilage as a stabilizer in food matrices such as nectar, because it would require less time to recover its initial viscosity after a time of rest (Razavi and Karazhiyan, 2009; Sharoba and Ramadan, 2011).

4. Conclusion

Mango nectar with addition of stabilizers (yam mucilage and CMC) has a pseudoplastic behavior. According to the zeta potential, it can be classified as relatively stable and has low percentages of sedimentation during 10 days of storage. In addition, the treatment that showed the best consistency was when a ratio of 20:80 mucilage: CMC was used at concentrations of 0.03%, which shows that yam mucilage should be used in a mixture with other hydrocolloids.

Declarations

Author contribution statement

Ermides Lozano: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Jairo Salcedo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ricardo Andrade: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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