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Technological and sensory feasibility of enrichment of low-sugar mango jams with curcumin encapsulated in lipid microparticles

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Abstract

This study aimed to evaluate the feasibility of producing low-sugar mango jams enriched with curcumin-loaded lipid microparticles (CLM). The jams were incorporated with babacu oil and tristearin lipid microparticles encapsulating curcumin, using tween 80 and span 60 as surfactants. The jams were characterized by physicochemical and sensory tests along 30 days of storage, and the results revealed CLM incorporation had only a small influence on the macroscopic homogeneity and pH of the jams. Up to 4 g/100 g of incorporation of CLM, the color intensity and colorimetric stability of the jams were enhanced. The incorporation of CLM led to the jams to be classified, rheologically, as emulsion filled gels, and the small deformation rheology tests revealed the CLM acted as active fillers. However, the incorporation of 10 g CLM/100 g jam led to a non-reproducibility of the data obtained for frequency sweep experiments. Sensory evaluation (affective tests) indicated a high acceptation of the curcumin enriched mango jams, in terms of flavor, odor, spreadability, texture and color, both at the beginning and end of the storage period of 30 days.

Keywords: solid lipid particles; curcuminoids; jams; emulsion filled gels.

Practical Application: The study shows an interesting and industrially feasible alternative to increase the nutritional value of the mango jam.

1 Introduction

The growing demand for healthy and nutritional products has been a continuous challenge for the food industry. Among the alternatives that can be explored in order to increase the nutritional value of foods is their enrichment with bioactive compounds, such as curcumin (Borrin et al., 2016). Curcumin is a phenolic compound with recognized antioxidant properties and several biological activities, including anti-hypertensive, anti-cancer, anti-inflammatory and neuroprotetive (Adaramoye et al., 2009). Its low toxicity and strong yellow color are interesting for the replacement of artificial yellow dyes, largely associated to allergies (Stevens et al., 2015). The incorporation of curcumin in food products, however, can be limited by its hydrophobicity, high sensitivity to light, and strong spicy flavor. Such characteristics may hinder the incorporation of curcumin in aqueous media and decrease the sensory quality of the products (Prasad et al., 2014). To overcome these drawbacks the encapsulation of the curcumin in lipid matrices can be used, including lipid particles, in which the lipid core is formed by solid lipids at room temperature (La Torre & Pinho, 2015).

Lipid particles are can also be incorporated in gelled matrices, originating structures denominated as emulsion filled gels (EFG). EFG are complex biopolymer systems consisting of dispersed lipid droplets or particles entrapped in a gelled matrix, whose rheological and breakdown properties are strongly affected by the properties of the components (gel matrix and lipid droplets) and interactions among them (Lorenzo et al., 2013; Oliver et al., 2015). Several gelled food products, including yogurt, cheeses, dairy desserts and jams are classified as EFG (Oliver et al., 2015).

Fruit jams are defined as intermediate moisture foods produced by boiling fruits pulp with other ingredients, especially sucrose, pectin and organic acids (Javanmard et al., 2012). Their popularity is due to their low cost, accessibility and pleasant organoleptic characteristics (Tomruk et al., 2016). Among the fruits used for jam production are the mangoes, known for presenting a strong yellow color, a sweet and pleasant flavor, and for being a good source of vitamins and minerals (Basu et al., 2011; Javanmard et al., 2012; Sanchez-Riano et al., 2018; Costa et al., 2019). Attractive colors are important quality criteria for jams, as it is generally the first sensory parameter evaluated by the consumers, strongly affecting their behavior (Javanmard & Endan, 2010). In some fruit jams, however, the natural pigments which confer the characteristic color of the products are unstable and susceptible to degradation during processing and storage. Such drawback requires the need of colorants incorporation to ensure products with stronger colors for longer storage periods and, consequently, higher market potential (Javanmard & Endan, 2010).

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In this context, considering the importance of a strong yellow color for mango jams and the interest in the development of food products with improved nutritional characteristics, the aims of thist study were to evaluate the feasibility of producing low-sugar mango jams incorporated with different amounts of curcumin-loaded lipid microparticles, evaluating their physicochemical characteristics and their sensory acceptability. A strong point in this study is that the techniques here used to produce the lipid microparticles and the mango jam are totally feasible to be used by the food industry.

2 Materials and methods

2.1 Materials

Lipid microparticles were produced using babacu oil (*Orbygnia speciosa*, Jacy Fragrâncias, Santa Bárbara d´Oeste, SP, Brazil), tristearin, span 80, tween 60 and curcumin from Sigma (St Louis, MO, USA), xanthan gum (Grindsted Xanthan 80, Du Pont, Cotia, SP, Brazil) and deionized water (Direct-Q3, Millipore, Billerica, MA, USA). The jams were produced using Tommy mangoes (*Mangifera indica* L) bought in a local market, refined sugar and pectin 105 (CPKelco, Limeira, SP, Brazil). All other chemicals were reagent grade.

2.2 Production of curcumin-loaded lipid microparticles

The production of curcumin-loaded lipid microparticles (CLM) was carried out according to Geremias-Andrade et al. (2017). Lipid phase (tristearin and babacu oil, 1.2 and 2.8 g/100 g, respectively) were melted at 80 °C with span 80 (1.4 g/100 g) and curcumin was added (0.03 g/100 g). Tween 60 (0.6 g/100 g) dispersed in water, at 80 °C, was poured into the melted lipid and the mixture was stirred for 5 min, at 18,000 rpm (T25, IKA, Staufen, Germany). Xanthan gum was added (0.1 g/100 g) as thickener. The samples, produced in triplicate, were stored under refrigeration.

2.3 Production of low-sugar mango jams

For the production of the jams, the mangoes were selected, sanitized, manually peeled and diced. The mango cubes had the fibers removed in a fruit stripper. The soluble solids (SS) content of the mango pulp was measured (portable refratometer ITRF95, Instrutemp, São Paulo, SP, Brazil) and, afterwards, the pulp was cooked. The value of SS content was used to calculate the pectin and sugar contents, in the ratio 3 parts of sugar:7 parts of pulp, conferring the low-sugar classification according to the Brazilian legislation (Brasil, 1978). The jam was cooking in a pan under low heat and intense manual stirring, until the final product reached approximately 38 °BRIX. Sugar and pectin were slowly incorporated to the product troughout the cooking process. Afterwards, the hot product was packed in glass bottles, which were inverted in order to promote sterilization by hot filling. CLM were incorporated to the jams in different concentrations: control (without CLM); 1% (w/w), 2% (w/w), 4% (w/w) and 10% (w/w). The products were stored at 7 °C.

2.4 Determination of pH and colorimetric parameters

The values of pH of the mango jams were measured during storage using pHmetrer (Ultrabasic UB-10, Denver Instrument, Denver, CO, USA). The colorimetric parameters of the tristimulus colour system (L*a*b*) were obtained by reflectance, using an illuminator D65 with the observer at 10° in a colorimeter Miniscan XE (Hunterlab, Reston, VA, USA). The values of Chroma (C^*_{ab}), hue angle (H^*_{ab}) and total color difference (TCD) were calculated. For TCD calculation the reference was the colorimetric data obtained on the first day of storage of the jams.

2.5 Rheological measurements of mango jam

Shear sweep tests, strain sweep tests and frequency sweep tests were performed in a rheometer (AR2000 Advanced Rheometer, TA Instruments, New Castle, DE, USA) using parallel plate geometry (60 mm diameter, 1 mm gap). All samples were analyzed at a controlled temperature of 10 °C, and a relaxation period of 2 min was applied in order to equilibrate the samples and eliminate stresses resulted from the loading process. Flow curves were obtained by registering shear stress while the shear rate was increased from 0.01 to 100 s^{-1} and the experimental data were fitted to a Herschel–Bulkley (HB) model, using the *Rheology Advantage Data Analysis* V.5.3.1 software (TA Instruments, New Castle, DE, USA), according to Equation 1.

$$\tau = \tau_0 + K\dot{\gamma}^n \quad (1)$$

where τ is shear stress (Pa); τ_0 is yield stress (Pa); K is consistency index ($Pa.s^n$); n is flow index; and $\dot{\gamma}$ is shear rate (s^{-1}).

Frequency sweep tests were subsequently performed using a strain amplitude of 0.5% (within the LVR, previously determined), in an angular frequency range of 0.01–10 Hz, and the results were analyzed by Power Law model, using the *Rheology Advantage Data Analysis* V.5.3.1 software (TA Instruments, New Castle, DE, USA), according to the Equations 2 and 3.

$$G' = K'.\omega^{n'} \quad (2)$$

$$G'' = K''.\omega^{n''} \quad (3)$$

where, G' is the storage modulus; G" is the lost modulus; K' and K" are power law constants; n' and n" are frequency exponents; and ω is the angular frequency.

2.6 Sensory evaluation of mango jams

This research was approved by the Ethics Research Committee from the Faculty of Animal Science and Food Engineering (FZEA) – University of São Paulo (USP, Brazil) (code CAAE 65891817.0.0000.5421), and the 120 non-trained participants signed a Term of Consent. Sensory affective tests were performed on the samples within 1 and 30 days of storage. The panelists were asked to indicate how much they liked or disliked the mango jams based on the attributes spreadability, odor, taste and color, according to a 9-point hedonic scale. Also, a purchase intent test was applied to the panelists. All samples were microbiologically tested before sensory tests (aerobic bacterias count, total coliforms, presence of *Staphylococcus coagulase*, yeast and mould count).

2.7 Statistical analyses

Tukey tests were performed to compare the treatment means. The significance level for all tests was 5%, which was calculated using SAS Software version 9.2.

3 Results and discussion

3.1 Stability of pH of mango jams

After the production, the mango jams without lipid microparticles (named control) and jams with CLM (1, 2, 4 and 10 g CLM/100 g jam) were characterized in terms of pH over 30 days of storage (data not shown). This type of evaluation is important, as the pH act in flavor promotion and also in preservation of fruit juices and derived products (Akhtar et al., 2010; Safdar et al., 2012). Besides, the pH of jams may also affect the hardness of the products, interfering on their sensory properties (Basu & Shivhare, 2010).

The control jam, as well as the jams incorporated with 1% and 10% CLM, presented pH values approximately 3.5 and samples with 2% and 4% CLM presented slightly higher pH values, ranging between 3.55 and 3.60. The pH decreased between days 1 and 15 of storage to values lower than 3.50 to control jams, 1% and 10% CLM, and pH values lower than 3.60 to 2% and 4% CLM. It was probably related to the formation of free acids and to pectin hydrolysis (Muhammad et al., 2008). On the other hand, for all formulations tested, pH increased after 30 days, to values lower than 3.55 (control, 1% and 10% CLM jams) and 3.70 (2% and 4% jams). This is probably related to the degradation of organic acids, due to reactions with pigments (Cano & Marin, 1992).

The obtained values of pH were like the ones verified by Safdar et al. (2012), who investigated the suitability of different mango varieties for jams and also studied the storage stability of the systems at room temperature. The mango jams evaluated by these authors had pH ranging between 3.52 to 3.64. Kansci et al. (2008), investigated the biochemical and physicochemical properties of four mango varieties and quality characteristics of their jams, and verified pH values of the obtained jams ranged from 2.85 for Keitt jam to 3.10 for Améliorée, lower than that obtained in the present work. According to the author these differences in acidities verified may be due to organic acids or other compounds of the raw pulp. Lal et al. (1998) suggested that a good quality jam can be obtained with values of pH between 2.8 and 3.5, which is close to the values obtained for the mango jams evaluated in the present work during the first 15 days of storage.

3.2 Colorimetric stability of mango jams

The colorimetric parameters of the CIE Lab system (L*, a*, b*) of jams were measured in different days of storage

Table 1. Colorimetric parameters of mango jams produced with different amounts of curcumin-loaded lipid microparticles along 30 days of storage.

Jam	Storage (d)	L*	a*	b*	Chroma	Hue
Control	1	$22.4^{cD} \pm 0.24$	$-0.48^{cA} \pm 0.08$	$21.5^{aC} \pm 0.58$	$21.6^{aC} \pm 0.58$	$91.28^{aA} \pm 0.19$
	7	$24.1^{bD} \pm 0.18$	$-0.06^{abA} \pm 0.19$	$16.5^{cD} \pm 0.34$	$16.5^{cD} \pm 0.34$	$135^{aA} \pm 89$
	15	$28.2^{aC} \pm 0.40$	$-0.40^{bcA} \pm 0.22$	$17.7^{cE} \pm 0.66$	$17.7^{cE} \pm 0.66$	$91.3^{aB} \pm 0.66$
	30	$24.7^{bD} \pm 0.34$	$0.05^{aA} \pm 0.22$	$20.1^{bC} \pm 0.83$	$20.1^{bC} \pm 0.83$	$179^{aA} \pm 103$
1% CLM	1	$26.1^{bC} \pm 0.27$	$-0.68^{bAB} \pm 0.18$	$19.5^{bC} \pm 0.93$	$19.6^{bC} \pm 1.12$	$92.1^{aA} \pm 0.52$
	7	$24.1^{cD} \pm 0.61$	$-0.24^{aAB} \pm 0.13$	$21.9^{abB} \pm 1.36$	$21.9^{abB} \pm 1.36$	$90.7^{bcA} \pm 0.35$
	15	$27.6^{aC} \pm 0.64$	$-0.54^{bAB} \pm 0.12$	$23.6^{aC} \pm 0.76$	$23.6^{aC} \pm 0.76$	$91.3^{abB} \pm 0.28$
	30	$26.0^{bC} \pm 0.65$	$-0.14^{aA} \pm 0.05$	$23.3^{aBC} \pm 2.03$	$23.3^{aBC} \pm 2.03$	$90.4^{cA} \pm 0.12$
2% CLM	1	$26.7^{bBC} \pm 0.29$	$-0.89^{bBC} \pm 0.08$	$21.9^{abC} \pm 0.68$	$21.9^{abC} \pm 0.68$	$92.3^{aA} \pm 0.21$
	7	$26.9^{bC} \pm 0.28$	$-0.37^{aBC} \pm 0.11$	$19.4^{bC} \pm 0.76$	$19.42^{bC} \pm 0.93$	$91.1^{bcA} \pm 0.40$
	15	$32.1^{aB} \pm 0.48$	$-0.55^{abAB} \pm 0.13$	$19.9^{abD} \pm 0.69$	$19.93^{abD} \pm 0.69$	$91.6^{abAB} \pm 0.36$
	30	$27.2^{bC} \pm 0.50$	$-0.26^{aA} \pm 0.31$	$22.6^{aBC} \pm 2.57$	$22.62^{aBC} \pm 2.58$	$90.6^{cA} \pm 0.72$
4% CLM	1	$28.2^{cB} \pm 1.9$	$-1.15^{bC} \pm 0.16$	$25.7^{aB} \pm 2.83$	$25.7^{aB} \pm 2.83$	$92.6^{aA} \pm 0.08$
	7	$29.0^{bcB} \pm 0.18$	$-0.58^{aC} \pm 0.08$	$21.9^{bB} \pm 0.48$	$21.9^{bB} \pm 0.48$	$91.5^{bA} \pm 0.23$
	15	$32.4^{aB} \pm 0.70$	$-0.82^{aB} \pm 0.14$	$26.0^{aB} \pm 1.41$	$26.0^{aB} \pm 1.41$	$91.8^{bAB} \pm 0.38$
	30	$30.85^{abB} \pm 0.78$	$-0.71^{aB} \pm 0.16$	$24.8^{abB} \pm 1.07$	$24.8^{abB} \pm 1.07$	$91.6^{bA} \pm 0.38$
10% CLM	1	$30.73^{dA} \pm 0.47$	$-1.74^{cD} \pm 0.10$	$37.4^{aA} \pm 1.16$	$28.7^{aA} \pm 18.64$	$136^{aA} \pm 87$
	7	$32.53^{cA} \pm 0.40$	$-1.01^{aD} \pm 0.12$	$29.5^{cA} \pm 0.31$	$29.5^{cA} \pm 0.34$	$91.9^{aA} \pm 0.20$
	15	$37.48^{aA} \pm 0.22$	$-1.37^{bC} \pm 0.15$	$32.7^{bA} \pm 0.42$	$32.8^{bA} \pm 0.50$	$92.3^{aA} \pm 0.15$
	30	$33.70^{bA} \pm 0.29$	$-1.25^{abC} \pm 0.19$	$36.9^{aA} \pm 0.39$	$36.9^{aA} \pm 0.38$	$91.9^{aA} \pm 0.30$

Averages of samples produced with different formulations, at the same day of storage, followed by the same capital letters in the same column do not differ at 5% significance by Tukey test, and averages of samples produced with the same formulation, at different days of storage, followed by the same lowercase letters in the same column do not differ at 5% significance by Tukey test.

and the results are shown in Table 1. The evaluation of these parameters is frequently used for an indirect measurement of pigment content of products for being an effective, simple and quick method (Pathare et al., 2013).

The colorimetric results obtained in the first day of storage showed the incorporation of CLM resulted in higher values of L*, and lower values of a*. Regarding the values of b*, the samples without CLM did not present significant ($p>0.05$) differences in comparison to the jams produced with 1% and 2% CLM incorporation, however, presented lower values in comparison to the jams with higher concentrations of CLM (4% and 10% CLM) (Pathare et al., 2013).

As expected, these alterations verified in the primary colorimetric values of the jams resulting from the incorporation of CLM, have also affected the parameteres Chroma (C*ab) and Hue angle (H*ab). Chroma was significantly higher for jams produced with 4% and 10% CLM, indicating that, at these concentrations, the incorporation of CLM increased the color intensity (Pathare et al., 2013). On the other hand, the incorporation of CLM have only affected the values of H*ab, which is a qualitative attribute of color, at 10% CLM.

Through the evaluation of the colorimetric parameters of the samples at different days of storage, it was verified that control jam showed increase in L* and a*, and decreases in b* and Chroma over the 30 days of storage. Although this formulation has also presented increases in H*ab during the storage period, the deviations associated to these values were high, indicating that oxidative processes of the natural pigments of the product were probably taking place heterogeneously in the sample.

The color variations were much lower for jams with 1%, 2% and 4% CLM. Hue angle values for these three formulations presented small decreases throughout the storage period, however all formulations had values ranging between 90.34 and 92.55, expected for systems with a yellow color (represented by Hue angle 90°), characteristic of products derived from mangoes (Pathare et al., 2013).

Even though for jams produced with 10% CLM incorporation the values of b* were statistically the same ($p>0.05$) at the 1st and 30th day of storage, these systems presented increases in L* and a*, and higher variations in Chroma and Hue angle, in comparison to the jams incorporated with lower amounts of CLM. Besides, it is important to highlight the higher deviations associated to the values of Hue angle and Chroma of jams produced with 10% CLM, especially at the first day of storage, which may be considered an indicative that this concentration of CLM was not feasible for the production of completely homogeneous jams.

It is also important to emphazise that the jams incorporated with CLM presented a much higher colorimetric stability than the control jam. Such fact is likely to be due to the antioxant characteristics of curcumin, which may have acted retarding the oxidative processes of the natural pigments present in the mango pulp. The colorimetric tests showed the jams had a more intense and stable color, up to a concentration of 4% CLM.

3.3 Rheological characterization of mango jams

The frequency sweep tests of mango jams were carried out on different days of storage and the obtained results are shown in Figure 1. All formulations presented G' higher than G", indicating a dominant contribution of the elastic component to the viscoelasticity of these gel-like systems (Basu et al., 2011). Jams may be defined as physical gels of pectin in pulp–sucrose–acid, formed by a combination of noncovalent contributions (*e.g.* hydrophobic and hydrogen bonding interactions), which presents certain degrees of elasticity (Basu et al., 2011), as verified in Figure 2.

Through the comparison of the rheological characteristics of the different jams on their first day of storage, it was verified that the jams produced with 1%, 4% and 10% CLM presented similar strength to the control. On the other hand, samples produced with 2% CLM were stronger, as they presented higher values of both moduli. These behaviors were evidenced through the Power Law parameters available in Table 2, as the jams with 2% CLM presented significantly higher ($p<0.05$) values of both, K' and K", in comparison to the other formulations, which presented statistically equal values ($p>0.05$) among them. Besides, the higher the CLM concentration, the lower the values of n', indicating the presence of the microparticles reduced the frequency dependence of G'. However, only samples with 2% and 10% CLM presented lower values of n" in comparison to the control, presenting G" with lower frequency dependence.

Although the rheological properties of jams have already been investigated to elucidate the effects of acidity, amount of and type of pectin, content of fruit pulp content, amount and type of sugar, and process temperature to the characteristics of the final products (Basu et al., 2011, 2013; Basu & Shivhare, 2010, 2013), studies regarding the effect of solid lipid particles incorporation to these products are not found in the literature.

On the other hand, rheological behavior of EFG, here represented by the jams incorporated with CLM, are largely reported, as rheological tests are recognized as powerful tools for the understanding of the structural organization of these gelled systems (Lorenzo et al., 2013). According to the literature, the particles may be classified as active or inactive fillers in EFG depending on the effect of their incorporation to the systems. Active fillers may increase or decrease gels strength, whereas inactive fillers always decrease the force of the gels (Oliver et al., 2015).

Therefore, the results obtained in the present work indicates that the CLM were active fillers in the jams, as they increased the strength of the systems with 2% CLM, and did not change the strength of EFG with 1%, 4% and 10% CLM. Considering pectin forms a network of fibrils in water, these results indicated that the presence of 2% CLM was probably beneficial to the self-association of pectin chains into gel junctions (Basu et al., 2011).

The comparison of the properties of the systems in different days of storage indicated the presence of CLM did not affect the rheological stability of the jams, for all formulations, including the control, presented a good rheological stability until the 10th day of storage, followed by a decrease of G' (also verified through the decreases of K' in Table 2) between days 10 and 20. Besides, in the same period, the frequency dependence of G' increased for all formulations, as verified through the values of n' (Table 2).

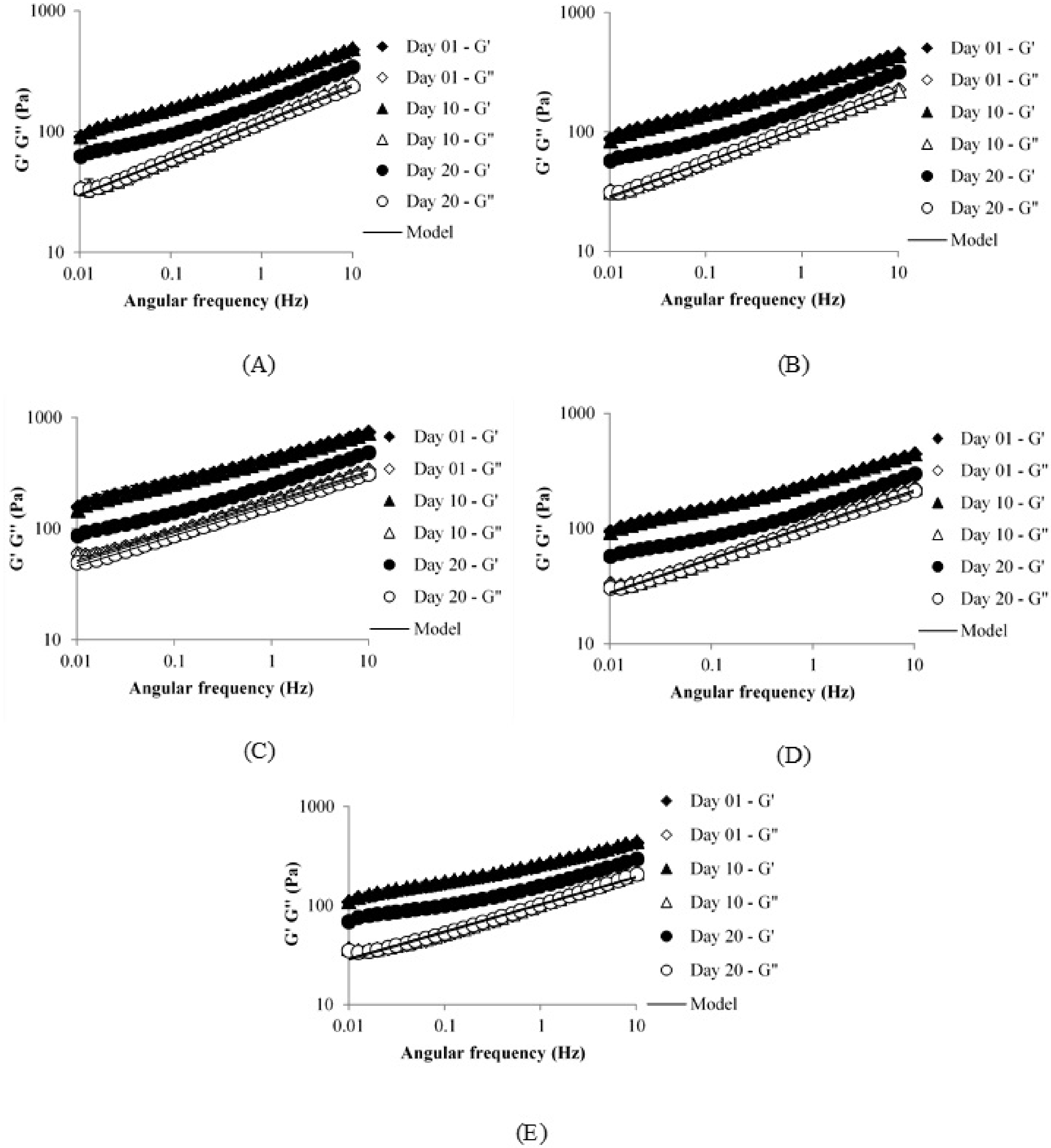
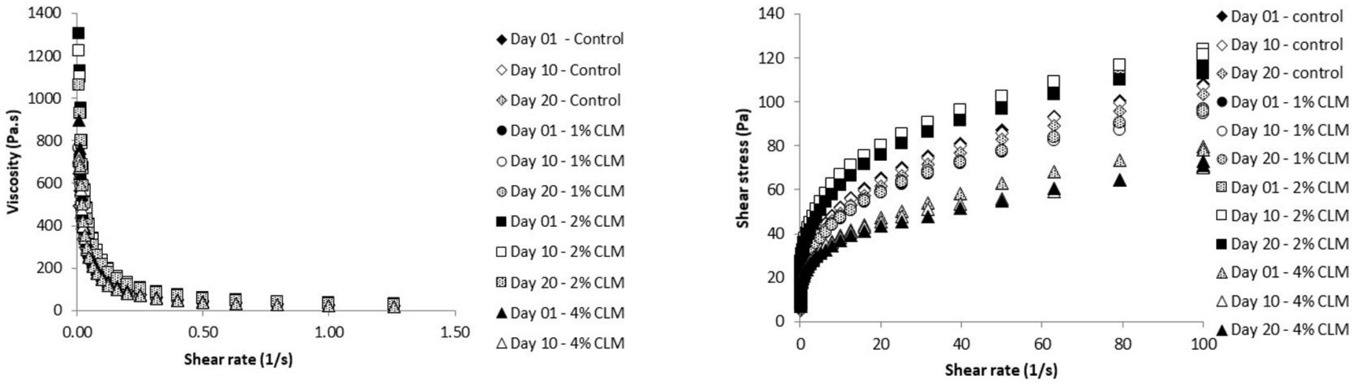


Figure 1. Results of frequency sweep tests of mango jams produced with: no incorporation of CLM (control) (A), 1% CLM (B), 2% CLM (C), 4% CLM (D) and 10% CLM (E), on different days of storage.

Viscosity curves (Figure 2A) of the jams showed similar apparent viscosities, which decreased with increasing shear rate, confirming the non-Newtonian behavior of the samples, also verified and discussed by Basu & Shivhare (2013). These results also revealed that the ageing of the samples did not affect their apparent viscosities up to the 20th day of storage.

The shear stress–shear rate relationship of the jams, shown in Figure 2B, indicated the control jam and the jams with 1%, 2% and 4% CLM could be described by HB model, as the R^2 values ranged between 0.986 and 0.999 (Table 2), which agrees with the literature regarding the properties of jams. On the other hand, although the results of frequency sweep tests for jams



(A) (B)

Figure 2. Viscosity curves (A) and flow curves (B) of mango jams incorporated with different amounts of curcumin-loaded lipid microparticles in different days of storage.

Table 2. Parameters obtained by fitting the frequency sweep data of mango jams produced with different amounts of curcumin-loaded lipid microparticles to Power Law model.

Formulation	Storage (d)	K'	n'	R^2	K"	n"	R^2
	1	263.9^{aB} ± 10.7	0.2330^{bA} ± 0.0004	0.997	117.7^{aB} ± 3.9	0.3010^{aA} ± 0.0052	0.998
Control	10	270.2^{aB} ± 13.6	0.2359^{bA} ± 0.0011	0.997	121.5^{aB} ± 4.1	0.3044^{aA} ± 0.0108	0.997
	20	175.9^{bB} ± 6.49	0.2463^{aA} ± 0.0044	0.986	118.2^{aB} ± 5.7	0.2069^{aA} ± 0.1509	0.999
	1	251.6^{aB} ± 7.35	0.2283^{bA} ± 0.0025	0.997	111.0^{aB} ± 1.6	0.2998^{aA} ± 0.0071	0.998
1% CLM	10	242.0^{aB} ± 11.7	0.2314^{bA} ± 0.0016	0.996	108.1^{aBC} ± 4.4	0.3042^{aA} ± 0.0079	0.999
	20	161.8^{bB} ± 10.9	0.2504^{aA} ± 0.0105	0.086	110.8^{aB} ± 4.5	0.2931^{a} ± 0.0053	0.999
	1	433.5^{aA} ± 34.9	0.2151^{bB} ± 0.0087	0.998	176.8^{aA} ± 15	0.2679^{aB} ± 0.0048	0.996
2% CLM	10	417.9^{aA} ± 18.4	0.2207^{bB} ± 0.0023	0.998	171.6^{aA} ± 7.0	0.2709^{aB} ± 0.0016	0.996
	20	254.6^{bA} ± 13.4	0.2486^{aA} ± 0.0044	0.993	162.5^{aA} ± 5.6	0.2745^{aA} ± 0.0054	0.999
	1	253.2^{aB} ± 11.8	0.2143^{bB} ± 0.0023	0.994	108.9^{aB} ± 4.5	0.2936^{aA} ± 0.0057	0.995
4% CLM	10	252.6^{aB} ± 15.6	0.2197^{bB} ± 0.0023	0.995	108.7^{aBC} ± 5.3	0.2991^{aA} ± 0.0061	0.995
	20	153.7^{bB} ± 11.0	0.2372^{aA} ± 0.0053	0.981	105.3^{aB} ± 5.9	0.2925^{aA} ± 0.0073	0.998
	1	260.1^{aB} ± 11.4	0.1863^{aC} ± 0.0008	0.992	101.1^{aB} ± 3.3	0.2764^{aB} ± 0.0035	0.986
10% CLM	10	270.1^{aB} ± 15.6	0.1902^{aC} ± 0.0050	0.994	104.5^{aC} ± 3.9	0.2774^{aB} ± 0.0061	0.987
	20	164.7^{bB} ± 17.0	0.1991^{aB} ± 0.0073	0.978	103.0^{aB} ± 8.0	0.2741^{aA} ± 0.0117	0.993

Averages of samples produced with different formulations, at the same day of storage, followed by the same capital letters in the same column do not differ at 5% significance by Tukey test, and averages of samples produced with the same formulation, at different days of storage, followed by the same lowercase letters in the same column do not differ at 5% significance by Tukey test.

with 10% CLM were reproducible, reliable flow curves were not obtained for these samples, indicating their high instability. Such instability was probably due to the excess of CLM, already verified and discussed in the section dedicated to colorimetric parameters. According to Javanmard & Endan (2010), it is hard to achieve stability in analyses of fruit jams containing non-uniform particles at very high or very low shear rates, as the shear rates applied may cause breakdown in their structure.

As shown in Table 2, on the first day of storage, the jams with 2% CLM presented higher values of τ_0 and k, even though τ_0 was not statistically different (p>0.05) from the other formulations. Besides, samples with 4% CLM presented lower values of k. The values of *n* were statistically the same (p>0.05) for all formulations tested. The comparison of the HB parameters in different days of storage indicated that all jams presented a high stability along the 20 days of storage evaluated.

The rheological tests indicated the CLM were active fillers in the jams, as they increased the strength of the systems with 2% CLM and did not change this characteristic in 1% CLM and 4% CLM jams. The incorporation of 10% CLM seemed to be too much, as both colorimetric and rheologically the mango jams were not highly stable.

3.4 Sensory evaluation

Regarding sensory affective tests, the data in Table 3 showed the mango jams incorporated with CLM were well accepted by

Table 3. Average grades assigned by panelists to the attributes of mango jams.

Jam	Odour		Texture		Color		Taste		Spreadability		Global quality	
	Day 1	Day 30	Day 1	Day 30	Day 1	Day 30	Day 1	Day 30	Day 1	Day 30	Day 1	Day 30
Control	7.18 ± 1.5^{Aa}	7.15 ± 1.5^{Aa}	6.53 ± 1.7^{Aa}	6.46 ± 1.8^{Aa}	7.57 ± 1.4^{Aa}	7.45 ± 1.4^{Aa}	7.34 ± 1.5^{Aa}	7.53 ± 1.4^{Aa}	6.24 ± 1.8^{Ba}	5.88 ± 2.9^{Ba}	7.09 ± 1.3^{Aa}	7.08 ± 1.42^{Aa}
1%CLM	7.03 ± 1.6^{Aa}	7.12 ± 1.5^{Aa}	6.96 ± 1.7^{ABa}	6.80 ± 1.7^{ABa}	7.42 ± 1.5^{Aa}	7.44 ± 1.3^{Aa}	7.25 ± 1.6^{Aa}	7.50 ± 1.4^{Aa}	7.13 ± 1.7^{Aa}	6.87 ± 1.7^{Aa}	7.28 ± 1.3^{Aa}	7.24 ± 1.24^{Aa}
2%CLM	7.03 ± 1.5^{Aa}	7.18 ± 1.6^{Aa}	7.17 ± 1.6^{Aa}	7.11 ± 1.5^{Aa}	7.42 ± 1.5^{Aa}	7.33 ± 1.5^{Aa}	7.05 ± 1.8^{Aa}	7.32 ± 1.6^{Aa}	7.29 ± 1.8^{Aa}	7.23 ± 1.7^{Aa}	7.09 ± 1.5^{Aa}	7.37 ± 1.36^{Aa}
4%CLM	7.00 ± 1.5^{Aa}	7.20 ± 1.4^{Aa}	7.34 ± 1.4^{Aa}	7.14 ± 1.5^{Aa}	7.58 ± 1.4^{Aa}	7.63 ± 1.3^{Aa}	7.08 ± 1.7^{Aa}	7.36 ± 1.6^{Aa}	7.62 ± 1.5^{Aa}	7.41 ± 1.5^{Aa}	7.30 ± 1.4^{Aa}	7.51 ± 1.18^{Aa}

Average ± SD. Means with the same uppercase or lowercase letters are not significantly different within the column or same row, respectively (p>0.05) by Tukey'stest (N=120). (for the same attribute).

the panelists in every parameter evaluated. The 10% CLM jam was not tested sensorially, as it was not stable rheologically. In terms of odor, color and taste, the grades were between 7 ("*liked moderately*") and 8 ("*liked very much*") in the hedonic scale, independently of the jam and time of storage. Especifically in relation to the flavor, none of the panelists referred to the spicy flavor typical of curcumin, or to the strong adstringent residual taste typical of polysorbates (tween 60, which was used as surfactant, is polysorbate 60).

As for the time and spreadability, which are closely related characteristics, the lowest grades were given to the control jam. Apparently, the presence of CLM was beneficial to these sensory attributes of the mango jams. Regarding global quality, all the jams were given average grades in the range 7-8, which can be considered as successful in terms of sensory acceptance. Such successful result is confirmed by the fact that only 10% of the panelists said they would not buy the mango jams incorporated with CLM, and 61% stated they would certainly buy them.

Sensorially, the enriched mango jams were extensively accepted, showing once more the proof of concept of the product was successful.

4 Conclusions

The results obtained in the present study indicated the incorporation of CLM did not affect the macroscopic homogeneity of mango jams and presented only a small influence on the pH of these products. The colorimetric tests showed the jams had a more intense and stable color, up to a concentration of 4% CLM. The rheological tests indicated the CLM were active fillers in the jams, as they increased the strength of the systems with 2% CLM and did not change this characteristic in 1% CLM and 4% CLM jams. The incorporation of 10% CLM seemed to be too much, as both colorimetric and rheologically the mango jams were not highly stable. Sensorially, the enriched mango jams were extensively accepted, showing once more the proof of concept of the product was successful. Related to sensory evaluation, in future studies it would be very important to conduct studies based in consumer perception and projective methods.

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