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ORIGINAL PAPER

Investigation of rheological synergistic interactions between hydrocolloids and starch in milky cacao beverages model: principal component analyses

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Abstract In this study, effects of different selected starches (tapioca, potato, modified corn) and gums (xanthan gum, guar gum, locust bean gum) on the rheological behaviour of model milky cacao beverages were studied for improvement in the rheological properties of milky cacao beverages which directly affect consumer acceptability of the product. The soluble solids, pH and colour values of the samples were also determined. Milky cacao beverages showed pseudoplastic behaviour. Ostwald de Waele model accurately described the flow behaviour of all beverage samples with high R^2 values very close to unity. K (consistency coefficient), and n (flow behaviour index) values were found to between 5.5–170.64 mPa s, 0.387–0.999, respectively. Principal component analysis was successfully performed to classify the milky cacao beverages including different starch and gum combinations. The results of the present study highlighted that selection of optimum starch and gum combination is very important for production of the product with desired quality.

Keywords Milky cacao beverages · Starch · Gum · Rheology · PCA

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Introduction

Gums and starch are used in many food products for different purposes such as thickeners, stabilizers, gelling agents and texture modifiers [1]. They are high molecular weight hydrophilic biopolymers. They are also widely used in the food industry to provide enhanced viscosity, gelling, thickening, stabilization of emulsion, water and oil binding, and manufacturing of the product with desired sensory attributes. In addition, gums can change the rheological characteristics of starches [2–4]. The rheological and physical properties, and therefore, the consumer acceptance of the final product are affected by the type of gums and starches in the formulation, and therefore, their types and concentrations should be adjusted considering rheological properties of the samples [5–9]. Determination of suitable starch/gum combination is very crucial for the product quality. Selection and addition of the suitable gum can protect deformation of starch granules against shear during cooking, improving texture/rheology of the product [10]. Some starch–gum combinations should be considered, or proposed to be used, in high-moisture food products because gum and starch polymer molecules are both polymolecular and polydisperse. Huang [11] reported that changes in gelatinization enthalpies were mixed in the article studied the effects of the two gums on five starches and generally good interactions can cause variations in the final physical and rheological properties. Sudhakar et al. [12] defend that guaran molecules being more extended and LBG polysaccharide molecules being more coiled, allowing the former to hydrogen bond to amylose molecules (AM) when studied differences in the effects of guar gum and LBG on starches. Aftermore examination about molecular structures of guaran and LBG, results showed that guaran molecules are indeed more extended than LBG molecules so this situation brings about less interaction of LBG molecules with AM molecules [13]. Shi and BeMiller [14] found that there is a iota-type carrageenan in the reaction setting with corn starch and little effect on the viscosity. These all interaction between gums and starch may be different and important; generally, good interactions can cause variations in the final physical and rheological properties of the formulated products and in their consumer acceptance. The quality of the food is highly affected by the synergistic behaviour between the starch and gums. In particular, the apparent viscosity and consistency of the product could be affected by gum and starch combination used in the formulation. It is important that determination of the optimum synergy interaction between gum and starch in product is important for lowering cost of the product and producing better quality of product.

Dairy based beverages such as milky beverages, hot chocolate, salep, kefir, ayran for direct consumption are common in Turkey and other countries. Since instant products are prepared easily in a very short time by adding powdered ingredients into liquid, they are one of the most popular dairy products throughout the world [15]. Sugar, cocoa powder, milk, whey powder, starch, flavour, salt and gums are ingredients of milky cacao beverages. Their nutritional, fluidity, sensory characteristics are very important subjects for several groups of consumers like young and elder people [6, 16]. Milky cacao beverages are the most popular ones. Either liquid or semi-solid the instant products are convenient by requiring very little time and effort for reconstitution or cooking for consumption [17]. It should be necessary to observe interaction of gums and starches in model foods to determine optimum quality and cost of the product formulation. For this aim, it is required to study with many samples since there are many different types of gums and starches be used in the product formulation. In order to eliminate difficulties regarding with interpreting of the results obtained from analysis of many samples, chemometric approaches are generally used in the food industry.

Chemometric approach is a widely used method combination of mathematic and statistics to interpret large numbers of chemical data [18]. Principal component analysis (PCA) is one of the mostly preferred chemometric method used in the food industry. PCA can be provided beneficial information for explaining similarities and differences in the data set [19], which could provide maximum required information from data obtained [20].

In the present study, three different gums (xanthan, guar and locust bean gum) and starches (modified corn, tapioca and potato) were used in the milky cacao beverages. Totally, 36 different samples were prepared with different combination of the gums and starches and their physicochemical (pH, colour properties (*L*, *a* and *b*) and rheological properties were determined. PCA was performed for classification of the samples based on the obtained data to determine alternative combinations, which is very important in many aspects.

Materials and methods

Sugar (sucrose), milk, whey powder (Maybi Food Co, Turkey), cacao (Ulker, Turkey), starches (PS, TS, and MCS) (Cargill, Co, USA), chocolate powder (Melodi Co, Turkey), chocolate flavour (Givaudan Flavour Co, Switzerland), sodium chloride and gums (guar, xanthan and locust been gum) (TIC Gum Co, USA) were used.

The preparation of the model milky cacao beverage samples

Twelve grams sucrose, 180 mL milk, 2 g whey powder, 6 g cacao, 0.50 g starch, 0.2 g gum, 0.25 g powdered chocolate, 0.1 g chocolate flavour and 0.025 g salt were mixed. Thirty-six powder mixtures including different gum and starch combinations were prepared. Starch and gum combinations in the model formulations are shown in Table 1. During the preparation of the milky cacao beverage, powdered ingredients were slowly added to prevent agglomeration into 180 mL of boiled milk in crucible. The crucible was stirred constantly with a magnetic stirrer (Yelowline, Germany) at 80 °C for 15 min. Then, the prepared milky cacao beverage was cooled to 60 °C at a room temperature.

The soluble solids, pH and colour values

The soluble solid content (Brix) of the samples was determined using automatic refractometer (Reichert AR 700, USA) at room temperature, and the results were expressed as °Brix at 25 °C. The pH values of the samples were determined by a pH meter at 25 °C (WTW-Inolab Level 3 Terminal, Weilheim, Germany). The colour values (*L*, *a* and *b* values) of the samples were measured using colourimeter (Lovibond RT Series Reflectance Tintometer, England).

Rheological measurements

The rheological properties of the samples were determined using a strain-/stress-controlled rheometer (Thermo-Haake, Rheostress 1, Germany) equipped with a temperature control unit (Haake, Karlsruhe K15, Germany) and a parallel-plate (radius = 35 mm) configuration and a gap of 0.5 mm between the upper and lower plates. The measurements were taken within the shear rate changed between 0.1 and

Table 1 Brix, pH, colour (*L, a, b*) values of milky cacao beverages including different starch and gum combination

Gum	Starch	Brix	pH	Colour properties		
				L	*a*	*B*
XG	TS	9.47 ± 0.05	8.35 ± 0.00	14.57 ± 0.13	11.18 ± 0.08	13.97 ± 0.09
	MCS	9.66 ± 0.19	8.29 ± 0.02	12.65 ± 0.10	9.97 ± 0.02	11.92 ± 0.04
	PS	9.57 ± 0.29	8.55 ± 0.00	15.43 ± 0.31	11.53 ± 0.06	14.09 ± 0.22
	MCS + TS	9.68 ± 0.08	8.35 ± 0.01	15.46 ± 0.06	9.98 ± 0.03	12.47 ± 0.05
	MCS + PS	9.68 ± 0.10	8.33 ± 0.00	13.69 ± 0.01	9.54 ± 0.04	11.55 ± 0.07
	PS + TS	9.65 ± 0.13	8.36 ± 0.00	15.15 ± 0.12	9.74 ± 0.10	11.41 ± 0.16
GG	TS	10.39 ± 0.16	8.36 ± 0.01	14.01 ± 0.36	9.96 ± 0.14	12.52 ± 0.24
	MCS	10.51 ± 0.25	8.25 ± 0.00	13.56 ± 0.12	9.84 ± 0.01	12.38 ± 0.10
	PS	10.55 ± 0.32	8.53 ± 0.00	14.89 ± 0.11	11.38 ± 0.05	14.25 ± 0.07
	MCS + TS	10.52 ± 0.04	8.33 ± 0.01	13.60 ± 0.11	9.24 ± 0.08	11.46 ± 0.06
	MCS + PS	10.08 ± 0.08	8.33 ± 0.02	14.65 ± 0.08	10.01 ± 0.09	11.64 ± 0.11
	PS + TS	9.65 ± 0.16	8.33 ± 0.00	13.51 ± 0.12	9.14 ± 0.02	10.96 ± 0.02
LBG	TS	9.84 ± 0.07	8.33 ± 0.00	13.87 ± 0.26	10.75 ± 0.17	13.12 ± 0.24
	MCS	9.65 ± 0.09	8.38 ± 0.00	13.65 ± 0.02	10.10 ± 0.06	12.59 ± 0.03
	PS	9.70 ± 0.02	8.52 ± 0.00	14.99 ± 0.09	11.27 ± 0.08	14.22 ± 0.13
	MCS + TS	9.94 ± 0.02	8.30 ± 0.01	14.73 ± 0.03	10.37 ± 0.06	12.51 ± 0.07
	MCS + PS	9.80 ± 0.17	8.30 ± 0.00	15.47 ± 0.93	10.02 ± 0.44	12.11 ± 0.50
	PS + TS	9.76 ± 0.04	8.3 ± 0.01	15.41 ± 0.04	10.03 ± 0.06	12.62 ± 0.09
XG + LBG	TS	9.72 ± 0.13	8.28 ± 0.00	14.28 ± 0.08	8.69 ± 0.06	9.94 ± 0.08
	MCS	9.78 ± 0.05	8.27 ± 0.00	15.58 ± 0.00	10.46 ± 0.01	12.36 ± 0.06
	PS	9.87 ± 0.02	8.11 ± 0.01	12.38 ± 0.14	9.14 ± 0.08	10.87 ± 0.17
	MCS + TS	10.84 ± 0.07	8.25 ± 0.02	14.29 ± 0.05	9.20 ± 0.07	10.24 ± 0.02
	MCS + PS	10.24 ± 0.00	8.52 ± 0.03	13.43 ± 0.14	9.24 ± 0.03	10.12 ± 0.15
	PS + TS	10.17 ± 0.04	8.14 ± 0.02	12.99 ± 0.06	9.23 ± 0.03	10.28 ± 0.05
LBG + GG	TS	9.36 ± 0.16	8.30 ± 0.00	13.69 ± 0.06	10.23 ± 0.0	12.07 ± 0.06
	MCS	9.33 ± 0.49	8.26 ± 0.00	14.95 ± 0.04	10.21 ± 0.0	12.34 ± 0.04
	PS	9.62 ± 0.09	8.26 ± 0.00	14.13 ± 0.01	9.25 ± 0.01	10.93 ± 0.01
	MCS + TS	9.21 ± 0.18	8.22 ± 0.02	14.17 ± 0.08	9.14 ± 0.02	11.38 ± 0.09
	MCS + PS	9.39 ± 0.06	8.26 ± 0.03	14.10 ± 0.02	9.26 ± 0.01	12.33 ± 0.07
	PS + TS	9.08 ± 0.10	8.42 ± 0.02	14.13 ± 0.04	9.74 ± 0.03	12.43 ± 0.03
XG + GG	TS	9.44 ± 0.20	8.28 ± 0.02	15.46 ± 0.07	10.13 ± 0.04	12.34 ± 0.06
	MCS	10.15 ± 0.02	8.27 ± 0.00	14.20 ± 0.05	8.74 ± 0.05	10.41 ± 0.09
	PS	9.92 ± 0.07	8.30 ± 0.03	12.79 ± 0.07	9.55 ± 0.02	11.87 ± 0.05
	MCS + TS	10.10 ± 0.08	8.26 ± 0.02	13.16 ± 0.03	9.52 ± 0.00	11.34 ± 0.05
	MCS + PS	10.38 ± 0.12	8.24 ± 0.03	13.29 ± 0.01	9.25 ± 0.01	11.26 ± 0.02
	PS + TS	9.89 ± 0.06	8.36 ± 0.02	12.87 ± 0.02	9.35 ± 0.01	11.85 ± 0.06

TS tapioca starch, *MCS* modified corn starch, *PS* potato starch, *XG* xanthan gum, *GG* guar gum, *LBG* locust bean gum

300 s^{-1} at constant temperature (58 °C). Generally, milky cacao beverages are consumed at temperatures ranged between 40 and 60 °C, so the rheological measurements of the samples were taken at 58 °C. Each measurement was replicated four times on the same sample. The flow behaviour of the samples was determined using measured data according to Ostwald de Waele (Eq. 1).

$$\sigma = K\gamma^n \quad (1)$$

where σ is the shear stress (Pa), K is the consistency index (Pa s^n), γ is the shear rate (s^{-1}), n is the flow behaviour index (dimensionless).

Principal component analysis

PCA was performed to classify milky cacao beverage samples including different gum and starch combinations with respect to their some physicochemical (pH, colour properties and Brix value) and rheological parameters (*K*, *n* and η_{50}). PCA was achieved using 2008 XLSTAT Software (XLSTAT, USA). Moreover, correlations among the corresponding parameters were determined using Pearson correlation carried out with XLSTAT Software.

Statistical analysis

All the analyses were performed in triplicate, and data were reported as mean ± SD. Statistical analyses were performed using by the Statistical Package for the Social Sciences (SPSS) 17.0.1 statistical package programme.

Results and discussion

The soluble solids, pH and colour properties of the milky cacao beverages samples

As shown in Table 1, the soluble solid values of the milky cacao beverages containing different starch and gum combinations were in the range of 9.44–10.84 °Brix. It was seen that starch and gum type and their interaction cause significant ($p < 0.05$) differences in the Brix values. Generally, it was observed that the using of XG and LBG gum combination with MCS + PS starch combination had the highest value of 10.84 °Brix. Then, this value was followed by the samples including GG with TS, MCS, PS, MCS + TS, and on the other hand, XG and GG combination was high Brix value when using with MCS, MCS + TS and MCS + PS in formulation. Yanes et al. [6] studied commercial chocolate milk beverages, and they found that Brix values changed between 16.25 and 18.40. Dogan et al. [16] pointed out that the Brix values of instant hot chocolate changed from 9.66 to 10.42 °Brix. In the another study conducted by Dogan et al. [16], Brix values of the hot chocolate beverages were reported to between 9.45 and 10.79 °Brix. Variation between Brix values of the samples might be resulted from type of ingredients, especially starch and gum, and their concentrations in the formula. Moreover, preparation method of the sample could also important factor influencing Brix value.

The pH values of the milky cacao beverages containing different starch/gum combinations were varied between 8.11 and 8.55 at 25 °C (Table 1). The lowest pH values of samples were observed in XG + LBG gum combination with PS and PS + TS. The highest value of pH was 8.55 in the sample containing XG with PS in milky cacao beverages formulation. The pH is also affected ($p < 0.05$) by starch type, gum type and their combination. This may have resulted from the structure of starch or gum and their interactions. Mishra and Rai [21] studied morphology and functional properties of CS, PS and TS. They found that the pH values of PS had the highest pH which was followed by CS and TS, respectively [21]. The pH values of the hot chocolate beverage including different starch gum combinations and gum combinations changed between 8.06–8.33 and 8.29–8.57, 7.83–9.79, respectively [16, 22, 23]. The present findings are in accordance with the previous ones.

As shown in Table 1, *L*, *a* and *b* values of the samples changed between 12.65–15.58, 8.69–11.53 and 9.94–13.97, respectively. The usage of different starch and gum types slightly affected colour properties of the samples. Dogan et al. [16] pointed out that *L*, *a* and *b* values of hot chocolate samples produced by different cocoa combination varied between 8.88–15.67, 7.81–10.78 and 6.55–12.83, respectively, and the differences between the colour values in study might be resulted from the chemical composition, especially polyphenol type and concentrations of the cocoa used in the formula [23]. In another study, *L, a* and *b* values of cocoa beverage powder formulated with crystal sugar changed between 46.86–50.37, 11.46–11.95 and 14.15–14.69, respectively [24]. These results were found as higher than those of our study, which might have resulted from formulation of the product, especially type and concentration of ingredients.

The rheological behaviour of the samples

Shear rate versus shear stress data obtained from rheological measurements for the milky cacao beverages are shown in Fig. 1. As shown in the figure, the apparent viscosity of all beverages decreased with the increasing shear rate, indicating shear thinning behaviour of the samples, which could be also understood from the *n* values of the samples. *n* values lower than 1 indicated shear thinning behaviour of the samples [24]. Table 2 shows the rheological parameters of Ostwald de Waele model. *K*, *n* and R^2 values for Ostwald model were in the range of 5.513–170.646 mPa s^n, 0.387–0.9999, 0.9750–0.9997, respectively. The effects of starch and gum types and their interactions on *K* and *n* values of beverages were found to be significant. XG + LBG and MCS + TS combination had the highest *K,* and lowest *K* value was obtained in the milky cacao beverages sample containing LBG + GG and PS + TS combination. The apparent viscosity of the milky cacao beverages samples at 50 s^{-1}, η_{50}, accepted as shear rate in the mouth [25], and it ranged between 4.704 and 27.336 mPa s, as shown in Table 2. Rheological properties of commercial chocolate milk beverages were studied by Yanes et al. [6], and chocolate drink from cupuassu was studied by Da Silva Lannes and Medeiros [15]. Glicerina et al. [26] studied rheological and microstructural properties of dark, milk and white chocolate. Results showed that apparent viscosity was 9.62, 1.55 and 0.59 Pa s, respectively.

The apparent viscosity of GG and LBG with starches was between 6.16–11.50, 4.70–7.92 mPa s, respectively.

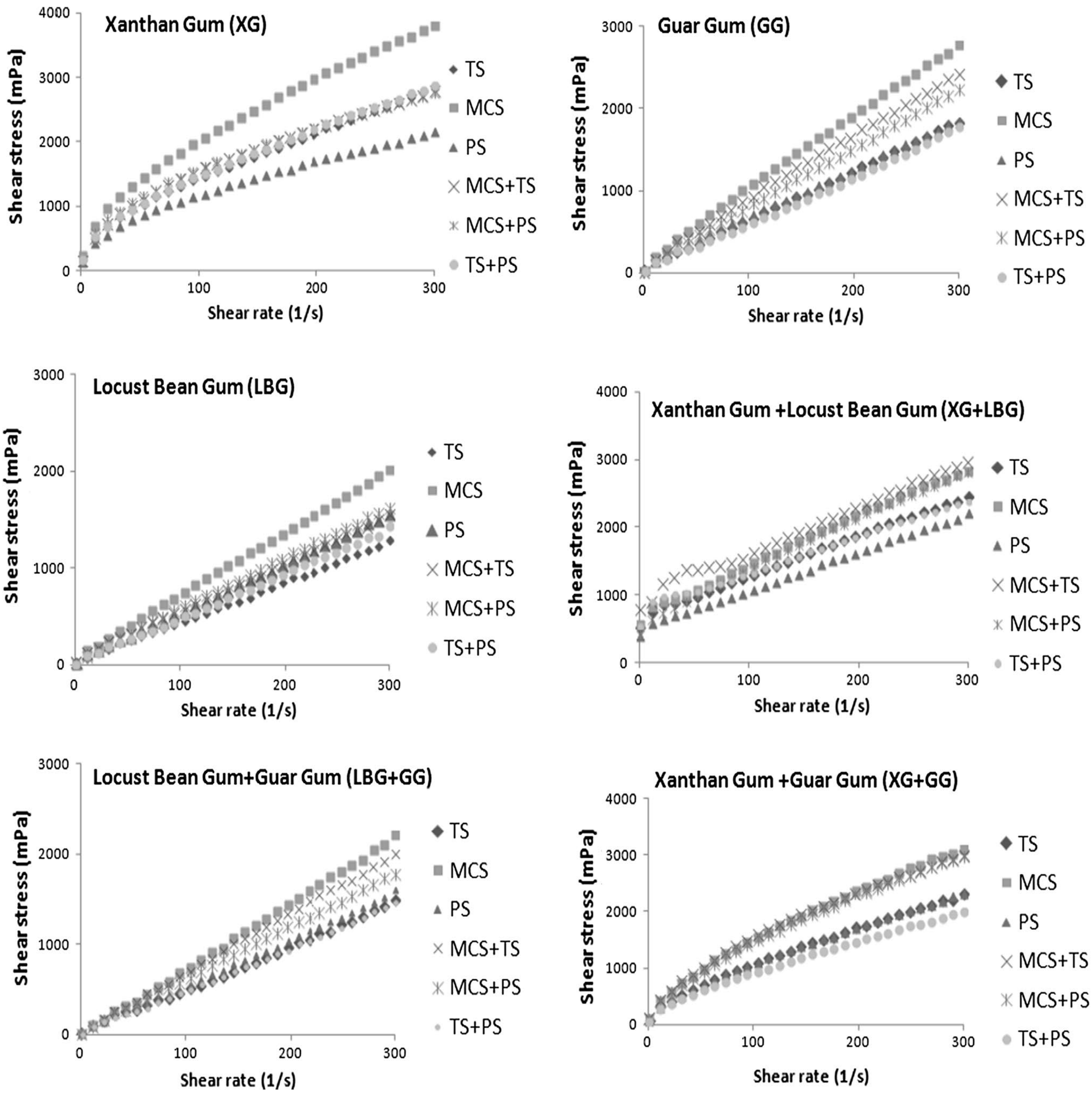

Fig. 1 Flow behaviour of the milky cacao beverages including different starch and gum in the formulation

On the other hand, gum combinations with starches, the best combination was found as XG + LBG and XG + GG with starches. These values were changed between 11.96 and 24.60 mPa s. Generally, while the XG + LBG and XG with different starch combination had high viscosity values, other combinations had low viscosity values. Starch and gum interactions could result in different rheological behaviour [25], because the gum contains different galactomannans or sometimes a unique galactomannan. Sometimes the gum can be used with the starch, one that produces a solution of lower viscosity and vice versa when a gum that produces a solution of higher viscosity than an equivalent amount of starch [27].

As shown in Table 2, the best results of consistency coefficient value was observed in sample including XG+LBG and starches combinations is MCS+TS (170.64 mPa.s), secondly better result is in MCS+PS (168.67 mPa.s), alternatively the third good result is in MCS (159.45 mPa.s) for XG. In this section, general trend was found in favour of using the MCS starch and XG in milky cacao beverages

Table 2 Rheological parameters of the model milky cacao beverages including different starch/gum combination

Gum	Starch	Ostwald de Waele parameters			
		K (mPa s^n)	n	R^2	η_{50} (mPa s)
XG	TS	103.33 ± 0.00	0.576 ± 0.005	0.9977	19.63 ± 0.00
	MCS	159.45 ± 0.00	0.554 ± 0.010	0.9992	27.33 ± 0.00
	PS	114.44 ± 0.00	0.511 ± 0.002	0.9988	16.66 ± 0.00
	MCS + TS	145.58 ± 0.00	0.515 ± 0.009	0.9997	23.80 ± 0.00
	MCS + PS	168.67 ± 0.00	0.487 ± 0.018	0.9994	23.53 ± 0.00
	PS + TS	108.76 ± 0.00	0.570 ± 0.012	0.9981	20.03 ± 0.00
GG	TS	8.55 ± 0.00	0.940 ± 0.022	0.9986	6.49 ± 0.00
	MCS	19.09 ± 0.00	0.875 ± 0.031	0.9996	11.50 ± 0.00
	PS	12.13 ± 0.00	0.889 ± 0.024	0.9992	7.86 ± 0.00
	MCS + TS	15.76 ± 0.00	0.862 ± 0.018	0.9994	9.23 ± 0.00
	MCS + PS	14.53 ± 0.00	0.885 ± 0.024	0.9991	9.14 ± 0.00
	PS + TS	6.45 ± 0.00	0.981 ± 0.012	0.9983	6.16 ± 0.00
LBG	TS	5.74 ± 0.001	0.941 ± 0.021	0.9984	4.70 ± 0.00
	MCS	11.26 ± 0.00	0.908 ± 0.021	0.9994	7.91 ± 0.00
	PS	11.43 ± 0.00	0.943 ± 0.021	0.9991	5.60 ± 0.00
	MCS + TS	10.42 ± 0.00	0.877 ± 0.020	0.9987	6.51 ± 0.00
	MCS + PS	10.76 ± 0.00	0.870 ± 0.040	0.9990	6.48 ± 0.00
	PS + TS	6.20 ± 0.00	0.950 ± 0.053	0.9987	5.33 ± 0.00
XG + LBG	TS	155.83 ± 0.03	0.476 ± 0.031	0.9774	18.90 ± 0.00
	MCS	142.82 ± 0.00	0.518 ± 0.005	0.9804	20.63 ± 0.00
	PS	106.96 ± 0.02	0.541 ± 0.054	0.9795	15.60 ± 0.00
	MCS + TS	170.64 ± 0.04	0.387 ± 0.029	0.9393	24.60 ± 0.00
	MCS + PS	102.84 ± 0.02	0.575 ± 0.036	0.9916	19.10 ± 0.00
	PS + TS	141.73 ± 0.00	0.486 ± 0.009	0.9750	20.36 ± 0.00
LBG + GG	TS	6.02 ± 0.00	0.963 ± 0.014	0.9978	5.35 ± 0.00
	MCS	7.22 ± 0.00	0.999 ± 0.020	0.9996	6.99 ± 0.00
	PS	6.63 ± 0.00	0.959 ± 0.032	0.9990	5.65 ± 0.00
	MCS + TS	8.21 ± 0.00	0.953 ± 0.014	0.9994	6.94 ± 0.00
	MCS + PS	7.55 ± 0.00	0.957 ± 0.013	0.9993	6.06 ± 0.00
	PS + TS	5.51 ± 0.00	0.977 ± 0.009	0.9986	5.23 ± 0.00
XG + GG	TS	48.33 ± 0.00	0.674 ± 0.028	0.9990	13.40 ± 0.00
	MCS	78.44 ± 0.00	0.645 ± 0.023	0.9995	18.96 ± 0.00
	PS	47.99 ± 0.00	0.679 ± 0.027	0.9995	13.46 ± 0.00
	MCS + TS	97.25 ± 0.00	0.600 ± 0.009	0.9997	19.33 ± 0.00
	MCS + PS	75.66 ± 0.00	0.644 ± 0.011	0.9996	17.80 ± 0.00
	PS + TS	42.40 ± 0.00	0.673 ± 0.015	0.9984	11.96 ± 0.00

TS tapioca starch, *MCS* modified corn starch, *PS* potato starch, *XG* xanthan gum, *GG* guar gum, *LBG* locust bean gum

formulation. The interaction of starches with GG shows that the highest value of *K* was observed when it was used with MCS starch, 19.09 mPa s, MCS + TS, 15.76 mPa s and MCS + PS,14.53 mPa s. On the other hand, it was observed that TS and PS starches have antagonistic effect when using with GG in model. However, it was seen that *K* value of the mixtures of LBG and starches was determined in PS as the highest and MCS, 11.43 and 11.26 mPa s, respectively. Among the starches and gums combinations in milky cacao beverage formulation, MCS + TS with XG + LBG combination was found to have the highest *K*, 170.64 mPa s; especially, the synergistic effects were observed in the TS, MCS as the individual using with XG + LBG combination. LBG + GG combination and their interactions with starches showed synergistic effect for MCS + TS and MCS + PS, 8.21 and 7.55 mPa s, respectively. In the other side, PS + TS showed antagonistic interaction (5.51 mPa s). MCS and TS combination

Table 3 Correlation coefficients between the parameters of the milky cacao beverages

	K	*n*	η_{50}	Brix	pH	*L*	*a*	*b*
K	**1**							
n	−0.916	**1**						
***η*50**	0.908	−0.943	**1**					
Brix	0.271	−0.247	0.238	**1**				
pH	−0.161	0.130	−0.146	−0.012	**1**			
L	−0.075	0.117	−0.148	−0.233	0.336	**1**		
a	−0.203	0.181	−0.202	−0.154	0.580	0.512	**1**	
b	−0.389	0.352	−0.356	−0.240	0.545	0.455	0.918	**1**

with XG + GG showed to higher *K* (97.25 mPa s) value than other starches and their combinations. However, it was found that the combination of PS + TS with XG + GG was showed antagonistic effect, as 42.40 mPa s, so it may not be considered this using combination in formula of milky cacao beverage as optimum quality preference.

All these interactions between gums and starches may be affected by intermolecular associations in media. Therefore, we observed to good synergistic relationships between gums and starches in model milky cacao beverage. The literature gives to us some important keys of this mechanism of synergistic interaction between starches and gums. Network of starch and gum copolymers is idea about a synergistic effect between starch and gum polymer molecules [28]. Michniewicz and Jankiewicz [29] reported that water-soluble pentosans were formed with complexes of starch polymer molecules. There are two effects: (1) interaction between leached amylose (AM) and low molecular weight (MW) amylopectin (AP) molecules and gum molecules and (2) forces exerted on granules in the shear field are much larger than those encountered in starch–water suspensions of equal starch concentration due to the thickening effect of the gums might be responsible the synergistic increase in paste viscosity affected by gums. The result showed that the work required to move swollen granules past each other was magnified in more viscous media, and viscosity increases were not the result of a specific interaction between the starch and the gum [27].

Classification of milky cacao beverages including different gum and starch combination

After determination of physicochemical and rheological properties of the milky cacao beverages, principal component analysis was performed to classify the beverages. Table 3 shows the eigenvalues and their contribution of the variance percentage of the principal components. As shown in table, eigenvalues of the PCs ranged between 3.644 and 0.051. When considering Kaiser's rule, only two first and second PCs could be described the variance of the data set in the present study since their eigenvalues were found

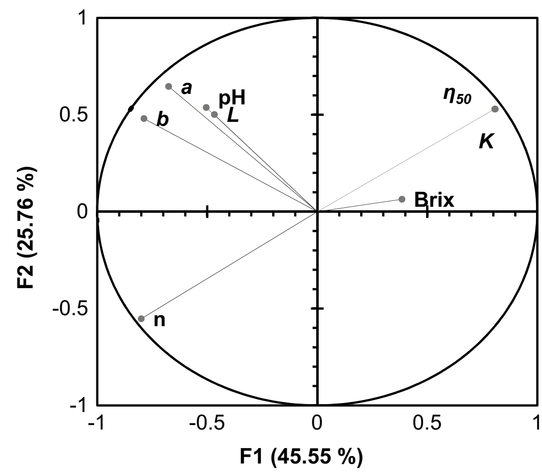

Fig. 2 Plot of the first 2 principal component (PC) loading vectors

as higher than 1.0. As the first PC accounts for 45.554% variability, the second one was 25.761%. Both of them were totally responsible for 71.316% variability, which is adequate for explanation of the data set. Larrigaudiere et al [30] reported that percentage higher than 70% is sufficient for qualitative purposes. The eigenvalue of the PC3 was determined as 0.976, very close to unity; therefore, it could be also accepted together with the other two PCs. By addition of PC3, these 3 PCs explained 83.518 variability in the data set. Explaining the variability of the data set with 3 PC instead of 36 samples is very beneficial in many aspects, which is the reason of why PCA was performed in this study. Loading points of the parameters revealed that all the rheological parameters (*K*, *n* and η_{50}) and *a* and *b* colour parameters explained variability in PC1, and pH and *L* parameters explained in PC2 and Brix explained in the PC3.

Score plots of the PC1 and PC2 are shown in Fig. 2. As seen, colour parameters and pH were on the left-hand upper side of the plot. *K*, η_{50} and Brix values of the chocolate beverages were seen on the right-hand upper side. Correlation coefficients between the analysed parameters as tabulated in Table 4 could be calculated considering cosine of the angel between tow parameters. As shown in the figure, the angle between *K* and

Table 4 Results of PCA using data on the starch and gum composition of the milky cacao beverages

PCs	Eigenvalue	Variability (%)	Cumulative (%)
F1	3.644	45.554	45.554
F2	2.061	25.761	71.316
F3	0.976	12.203	83.518
F4	0.609	7.616	91.135
F5	0.502	6.273	97.407
F6	0.095	1.188	98.595
F7	0.062	0.772	99.367
F8	0.051	0.633	100.000

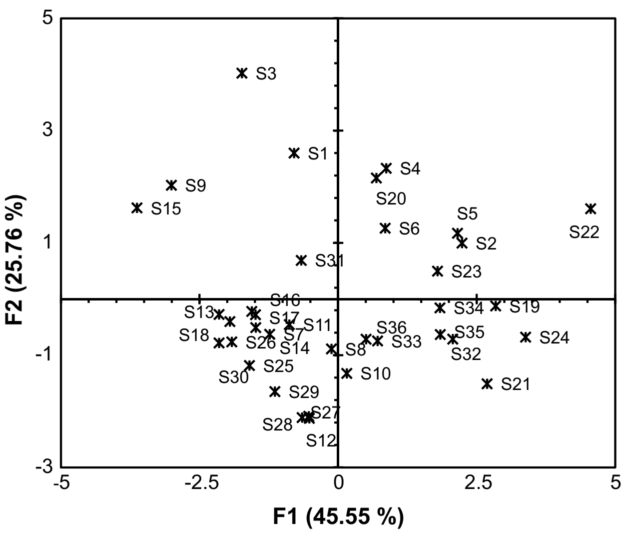

Fig. 3 Plot of the first 2 principal component (PC) score vectors

η_{50} parameters was about 0°; therefore, correlation between them was very close to unity, which was in accordance with the previous studies [31]. Negative correlation between *K* and *n* or η_{50} and *n* was also observed. When considering the fact that colour, pH and Brix value of the samples were found as very close to each other, rheological properties of the samples were predominant factor determining classification. As shown in Fig. 3, samples including XG or XG + LBG in their formulation as a hydrocolloid type were clustered on the upper right side of the figure because of their high *K* and η_{50} values. This classification could provide beneficial information for the food industry for determination of which gum/starch combination could be used in the formulation.

Conclusion

A milky cacao beverage is one of the widely consumed hot beverage type throughout the world. Quality of the end product directly associated with several factors including formulation, type and concentration of the ingredients affects the consumer acceptability of the product. One of the most important quality parameters is related with rheological properties of the product determining consistency mainly associated with starch and gum combination and their concentration in the formula. Therefore, in the present study, different effect of the different starch and gum combinations obtained from three different gums and starches on the rheological and some physicochemical properties of the beverage was investigated. Principal component analysis was successfully performed to ease observation of the results and classification of the samples including different gum and starch combination based on the corresponding parameters. The results of the present study highlighted that rheological properties of the beverage are markedly influenced by starch and gum combination used in the formula; therefore, selection of optimum combination or determination of alternative combinations are very important in many aspects for improving quality of the product and decreasing cost of the product and amount of ingredients added to the formulation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subject.

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