RESEARCH ARTICLE

Milk solids replacement with chickpea flour in a yogurt system and their impact on their physicochemical, rheological, and microstructural properties during storage

Angel Humberto Cabrera-Ramírez[1] iD; Diana Morales-Koelliker[2] iD; Victoria Guadalupe Aguilar-Raymundo[3,*] iD

[1] Instituto Politécnico Nacional. Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada. Cerro Blanco 141, Colinas del Cimatario. CP. 76090 Santiago de Querétaro, Oro. Mexico.
[2] Facultad de Nutrición. Universidad Popular Autónoma de Estado de Puebla. 21 Sur, 1103, Barrio de Santiago, CP. 72410. Puebla. Mexico.
[3] Programa Académico de Ingeniería Agroindustrial. Universidad Politécnica de Pénjamo. Carretera Irapuato - La Piedad km 44, C.P.36921. Predio el Derramadero, Pénjamo. Mexico.

* Corresponding author: **vaguilar@uppenjamo.edu.mx** (V. G. Aguilar-Raymundo).

Abstract

Yogurt is one of the most widely consumed foods around the world, with a tendency to add several ingredients with functional properties. The incorporation of legume flours in food systems has been a growing trend in recent years. Therefore, this study evaluated the effect of the addition of chickpea flour on the physicochemical, rheological, and microstructural properties of yogurt. Different levels of chickpea flour (1, 2, and 3%) were added to yogurt and the evolution of systems were monitored on days 1, 8, 15, and 22 of storage. Results for pH (4.61 – 4.75), titratable acidity (0.58% - 0.72%) and density (1048 - 1139 kg/m^3) showed no significant differences ($p > 0.05$), while higher concentrations of the flour resulted in lower levels of syneresis (15.90% - 23.73%). The flow properties confirmed the non-Newtonian behavior in the systems, fitting the two Power Law and Herschel-Bulkley models, thus establishing a relationship between the experimental data and the variables under study. The microstructure analysis showed that a higher concentration of chickpea flour increases the porosity of the system. Finally, the results suggest that it is highly recommended to replace milk solids with chickpea flour, thereby maintaining the properties and stability of the product.

Keywords: yogurt; chickpea flour; physicochemical; rheological; properties; microstructure.

1. Introduction

The addition of vegetable proteins has been a critical element in the formulation of healthy foods, emphasizing alternative high-protein ingredients. In the last decade, the use of legumes as a new substitute for meat and animal tissues has increased by 46% (**Global CAGR, 2017**). In 2019, Innova Market Insight, a global research company specializing in the food and beverage industry, reported average annual growth of 9% in the use of vegetable proteins where cereals and legumes were the main ingredients. In particular, the chickpea (*Cicer arietinum* L.) predominated with a 21.9% increase in its incorporation into foods compared to other legumes such as lentils (*Lens esculenta*), common beans (*Phaseolus vulgaris*), and faba beans (*Vicia faba*), representing 12.3%, 6.5%, and 6.2%, respectively.

The total area dedicated to chickpea planting and harvest in Mexico in January 2020 was 976,124 ha, which translates into the production of 4190 tons with a yield of 0.88 ton/ha according to the Servicio de Información Agroalimentaria y Pesquera (**SIAP 2020**), with the Sinaloa state as the leading producer. The chickpea presents a unique nutritional composition with the pericarp or husk rich in phenolic compounds as a food ingredient. The cotyledon has a high concentration of protein and micronutrients (**Knights & Hobson 2016**).

Furthermore, it has a high starch content and is also a good source of soluble dietary fiber due to the lignin, pectin, and hemicellulose content (3% - 7%). The fat content in chickpea ranges from 2.9% to 8.8% and is distributed in polyunsaturated fatty acids (62% - 67%), monounsaturated fatty acids (19% - 26%), and saturated fats (12% - 14%). Protein content on a dry basis range from 17 to 22%. However, it could increase to 28.9% if dehusked, showing a better protein quality (especially from essential amino acids) than other legumes such as beans or green beans (Oomah et al., 2011; Jukanti et al., 2012).

Recent studies have shown that the partial replacement of some components in food systems improves the quality of the product. Hickisch et al. (2016) used *Lupinus* to obtain a base (milk type) supplemented with 2% lupine protein, 4% glucose, and 4% coconut oil.

Fermentation was completed after 10 hours, obtaining a pH of 4.5 and syneresis of 2.2% - 20%, thereby showing that lupine proteins are the suitable raw material for producing an alternative plant-based yogurt. Sarker et al. (2020) incorporated dark red kidney bean (*Phaseolus vulgaris* L.) protein hydrolysates inhibiting the growth of oxidizing substances in plain yogurt and evaluated them for three days. The results of the study indicate that red kidney bean protein hydrolysates may be used as a potential antioxidant and food additive.

Raza et al. (2021) evaluation of effects of ball-milled roasted chickpea powder on physicochemical, rheological, and sensorial properties of yogurt supplemented with RC levels of 1 - 5 g/100 mL. Results showed a gradual decline in the pH of pre-inoculated samples with corresponding increases in powder concentration from 1 to 5 g/100 mL. Kaur Sidhu et al. (2020) evaluated the fortification of yogurt with chickpea flour (0%, 1%, 2.5%, 5% w/v) with *Lactobacillus acidophilus* LA5 and *Bifidobacterium* BB12, observed that chickpea flour contributed to the viability of microorganisms (10^6 CFU/g) during storage and the syneresis of the yogurt improved.

The focus of these studies is on fortifying or enriching yogurt; however, few studies consider partial or total substitution of any component of the formulation. Previously, the partial substitution of fluid milk with chickpea extract was studied, which resulted in a yogurt-type, and maintained its characteristics like natural yogurt (Aguilar-Raymundo & Vélez-Ruiz, 2019).

Fermented milk products are an excellent vehicle for encouraging the intake of chickpeas. Therefore, the objective of this work was to replace milk solids with chickpea flour and to determine its physicochemical and microstructural properties during storage.

2. Materials and methods

Raw materials

Kabul type chickpea seeds (*Cicer arietinum* L) Blanco Sinaloa variety, 2017 harvest, were provided by the "Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias" (INIFAP) Celaya, Mexico. Whole ultra-pasteurized milk (Alpura®, Mexico) was used as well as powdered semi-skimmed milk (Svelty Nestlé®, Mexico)

and lactic cultures (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. bulgaricus (YO-MIX 883 LYO 500 DCU, Danisco, USA Inc. Madison, WI, USA).

Raw chickpea flour

To obtain the flours, 100 g of chickpea seeds were passed through a hand grain mill (Estrella brand, Mexico), and subsequently sieved with the US No. 60 sieve (ASTM sieve #60, size 250 μm). The flours were stored in resealable bags at room temperature (27 °C) until use.

Yogurt system preparation

For the yogurt preparation was using methodology describe by Tamime & Robinson (1999), chickpea flour was added to the commercial milk at 1, 2 and 3 g/100 mL milk. Consequently, it was pasteurized for 20 minutes at 90 ºC and then cooled down to 42 ºC before being inoculated with lactic cultures (0.2%). The fermentation conditions were 4.5 h ± 0.5 at 42 ºC. The yogurt systems were prepared following the same methodology as the control, adding 1% to 3% of chickpea flour. All yogurt systems and the control were distributed in several lots of 250 mL and stored at refrigeration temperature (4 ºC) until analysis on days 1, 8, 15, and 22.

Physicochemical analysis of yogurt

The pH was measured with a potentiometer (HANNA, H198107 Romania), previously calibrated at room temperature (27 °C). Acidity was quantified by titration of 9 mL sample using phenolphthalein and NaOH (0.1N) (method 16.026) (AOAC, 2000). The density was determined with a gravimetric method using a grease pycnometer (Fisher brand, Ontario, Canada). The color of the yogurt was measured using a CR-410 colorimeter (Konica Minolta Sensing, Inc., Osaka, Japan) previously calibrated with a white mosaic (Y = 86.6, x = 0.3168, y = 0.3242), and the values of the L*, a*, b* parameters were expressed on the CIE Lab scale. Subsequently, the net color change (*DE*) was calculated using the following equation (Eq. 1).

$$\Delta E = \sqrt{(L_i - L_0)^2 + (a_i - a_0)^2 + (b_i - b_0)^2} \qquad \text{(Eq. 1)}$$

Where L_i, a_i, and b_i are the values of the systems during storage and L_0, a_0, and b_0 are the initial values of the samples.

The syneresis of the systems was determined by centrifuging. Samples of 10 g were taken and placed in 50 mL conical tubes and centrifuged at 176 g for 20 min at 10 °C (Rojas-Castro et al., 2007). The syneresis calculation was determined using the following equation (Eq. 2).

$$\text{Synéresis (\%)} = \frac{Supernatant\ weight}{Sample\ weight} * 100 \quad \text{(Eq. 2)}$$

Rheological measurements

Using the Brookfield DV-II + Pro Digital Viscometer (Brookfield Engineering Laboratories Inc., Middleboro, MA, USA), the flow properties in yogurt systems were measured. Samples were placed in a 300 mL container, and the LV-64 probe was used (Brookfield, 2011). Shear stress (t) and shear rate (g) were obtained from the readings of 5, 10, 20, 50, and 100 rpm at a temperature of 20 °C. Two mathematical models were used to describe the behaviour of foods: Power Law (PL) (Eq. 3) and Herschel-Bulkley (HB) (Eq. 4).

$$\text{LP: } \tau = K\dot{\gamma}^n \qquad \text{(Eq. 3)}$$

$$\text{HB: } \tau = \tau_0 + K\dot{\gamma}^n \qquad \text{(Eq. 4)}$$

Where τ represents the shear stress (Pa), while K represents the consistency coefficient (Pa·s^n); γ represents the shear rate (1/s); n the flow rate (dimensionless); and τ_0 represents the yield stress (Pa).

Evaluation of yogurt microstructure

Because of equipment limitations, only two systems (yogurt with 2 and 3% chickpea flour) previously were freeze-dried were tested after eight storage days. The microstructure evaluation was carried out using a scanning electron microscope (SEM) (Phenom Pro Phenom-World BV, The Netherlands) conditioned to work in a low vacuum module, with the electron beam adjusted to 5 kV. Samples were placed on carbon tape and mounted on an aluminum plate for observation at 1250x and 7500x. Using the Phenom Image viewer v1.0.0 software, the measurements of the empty spaces in the yogurt matrix were carried out (**Cabrera-Ramírez et al., 2020**).

Statistical analysis

The systems were analyzed after preparation on days 1, 8, 15, and 22 of storage. The response variables identified as physicochemical, and flow properties were statistically examined with the Minitab software (v.16; Minitab Inc., State College, PA, USA). Statistical analysis was performed using an analysis of variance (ANOVA), while a Tukey test was applied for multiple comparisons of the mean values.

3. Results and discussion

Physicochemical characteristics of yogurt systems

The physicochemical characteristics of yogurt samples added with chickpea flour (var. Blanco Sinaloa) and control (YC) are shown in **Table 1**. Nevertheless, all samples show a slight decrease in pH values over the storage period, with the lowest values occurring after 22 days, ranging from 4.64 to 4.75. According to the Food

and Drug Administration (**FDA, 2017**), yogurt should have a pH of 4.6 or lower and is acceptable up to 4.2, meaning that the yogurt systems generated in this study are within the established guidelines. Previous studies have shown that pulses ingredients tended to keep the pH and acidity of yogurt systems without adverse effects over their properties (**Zare et al., 2012**; **Raza et al., 2021**).

The titratable acidity was expressed as the production of lactic acid. A significant increase ($p > 0.05$) between days 1 and 22 of storage was observed, ranging from 0.58 to 0.72% for systems with chickpea flour, while control ranged from 0.46 to 0.72%. Regarding density, no significant differences ($p < 0.05$) were observed with the control or between treatments, showing an average density of 1079.5 ± 24.45 kg/m^3.

Syneresis provides the measurement of released serum or whey from yogurt samples. Syneresis has been reported as an undesirable characteristic of yogurt. The percentage of syneresis showed that both the storage time and the formulation was statistically different ($p < 0.05$). Data showed a tendency to decrease syneresis in samples of yogurt with added chickpea flour. The yogurt added with 3% of chickpea flour showed the lowest value with 15.90 ± 3.46 % on the first day, increasing to 19.29 ± 0.35% after 21 days of storage. **Brennan & Tudorica (2008)** indicated that the syneresis of yogurt is affected by the fat content in the milk used to make yogurt. The fat globules could reduce the aggregation of casein, improving the network and creating a more compact structure. The data obtained in this study show a tendency towards a decrease in the percentage of syneresis depending on chickpea flour concentration. Therefore, the macromolecules such as protein, fats, and starch present in the chickpea flour may be acting as a stabilizing agent in the yogurt matrix, allowing better diffusion and water holding capacity (WHC). Other authors concluded that the reduction in the percentage of syneresis is attributed to the amount of fiber dietary present in the flours and increases the WHC (**Barkallah et al., 2017**; **Öztürk et al., 2018**).

Table 1

Physicochemical characteristics of the yoghurt systems partially substituted by chickpea flour (var. Blanco Sinaloa)

System	Days	pH	Titratable Acidity (%)	ρ (kg/m^3)	Syneresis (%)
YC	1	4.67 ± 0.05[aA]	0.46 ± 0.09[aA]	1066 ± 0.01[aA]	31.39 ± 8.64[aA]
	8	4.67 ± 0.05[abA]	0.70 ± 0.03[aAB]	1048 ± 0.02[aA]	35.70 ± 1.11[bA]
	15	4.67 ± 0.04[bAB]	0.70 ± 0.03[aAB]	1082 ± 0.01[aA]	35.76 ± 0.95[bA]
	22	4.61 ± 0.05[bB]	0.72 ± 0.00[aB]	1096 ± 0.02[aA]	36.76 ± 0.11[cA]
YCF1	1	4.67 ± 0.03[aA]	0.60 ± 0.06[aA]	1066 ± 0.00[aA]	21.35 ± 0.21[aA]
	8	4.67 ± 0.04[abA]	0.58 ± 0.06[aAB]	1063 ± 0.00[aA]	22.10 ± 0.70[bA]
	15	4.67 ± 0.03[bAB]	0.64 ± 0.09[aAB]	1109 ± 0.01[aA]	22.40 ± 0.70[bA]
	22	4.64 ± 0.02[bB]	0.68 ± 0.03[aB]	1116 ± 0.02[aA]	23.73 ± 0.05[cA]
YCF2	1	4.69 ± 0.02[aA]	0.64 ± 0.09[aA]	1073 ± 0.00[aA]	20.60 ± 0.45[aA]
	8	4.69 ± 0.01[abA]	0.62 ± 0.12[aAB]	1059 ± 0.01[aA]	21.50 ± 0.10[bA]
	15	4.70 ± 0.02[bAB]	0.64 ± 0.13[aAB]	1087 ± 0.04[aA]	21.70 ± 0.26[bA]
	22	4.64 ± 0.005[bB]	0.62 ± 0.06[aB]	1063 ± 0.00[aA]	22.26 ± 0.15[cA]
YCF3	1	4.70 ± 0.01[aA]	0.64 ± 0.09[aA]	1078 ± 0.00[aA]	15.90 ± 3.46[aA]
	8	4.74 ± 0.05[abA]	0.64 ± 0.09[aAB]	1139 ± 0.05[aA]	18.00 ± 0.26[bA]
	15	4.75 ± 0.04[bAB]	0.70 ± 0.03[aAB]	1078 ± 0.01[aA]	18.26 ± 0.47[bA]
	22	4.67 ± 0.01[bB]	0.72 ± 0.00[aB]	1049 ± 0.01[aA]	19.26 ± 0.35[cA]

Values represent the mean ± standard deviation of three independent experiments. Different capital letters per column indicate a statistical difference ($p < 0.05$) and Tukey tests. Lower case letters per column show statistical difference between formulations. Capital letters show statistical difference between storage time. YC: yogurt control; YCF1: yogurt with 1% chickpea flour; YCF2: yogurt with 2% chickpea flour; YCF3: yogurt with 3% chickpea flour.
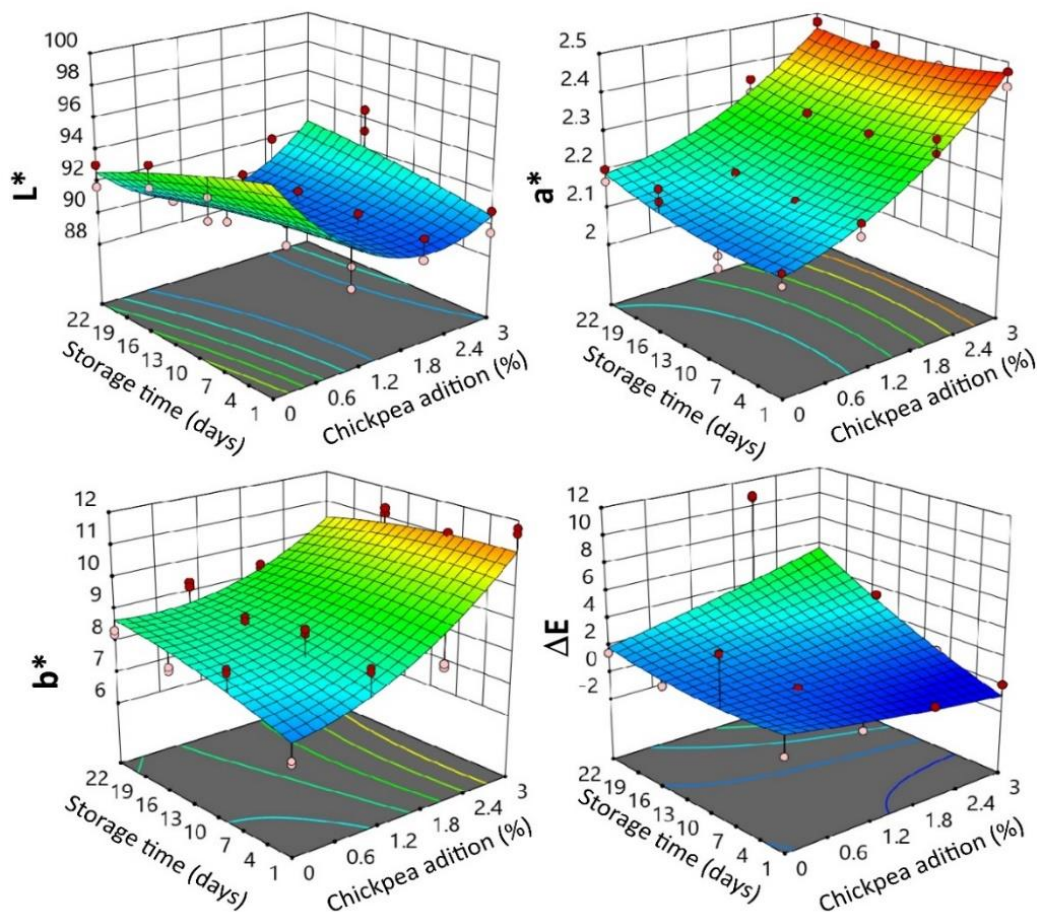
Figure 1. Colour parameters (L*, a*, and b*) and the net colour change (*DE*) as a function of formulation and storage time. Red dots represent the mean of three independent experiments, while the vertical lines show the standard deviation of each mean value. The colour gradient (blue to red) represents low to high values, respectively.

Color of the yogurt systems

Figure 1 shows the colour parameters L*, a*, and b* and the net color change (*DE*) of the yogurt systems. No statistical differences (*p < 0.05*) were observed for the brightness (L*), in which, regardless of the treatment and storage time, the samples showed high values for brightness, ranging from 88,74 to 97,27, showing a bright white coloration. The statistical analysis showed a significant difference (*p < 0.05*) between the formulations for parameters a* and b*, where parameter a* values ranged from 2.08 to 2.44, with a tendency towards a red coloration. In contrast, parameter b* presented values from 6.75 to 11.15, with a yellow coloration tendency. No statistical differences were observed regarding the net color change (*p < 0.05*), showing a tendency to increase as a storage time function and chickpea flour concentration. The color of yogurt is commonly associated with consumer acceptance and marketing.

Rheological properties

The flow parameters obtained from the Power Law and Herschel-Bulkley equations are shown in Table 2. Regarding the goodness-of-fit tests, it can be observed that the yogurt systems present a better fit to the Power Law. All yogurt systems had values of $n < 1$, which denotes

their non-Newtonian nature. Depending on the nature and the structural characteristics of the matrix, yogurt presents a non-Newtonian character of pseudoplastic type with a high dependence on time (Ares et al., 2007), which is consistent with the data obtained in this study. The consistency coefficient (K) in the LP and HB models showed values ranging from 2.42 to 4.62 Pa·s^n, decreasing this parameter in most systems between days 1 and 15. However, in the systems incorporated with chickpea flour, an increase in this parameter was observed for time (YCF3).

Several studies have evaluated the rheological characteristics of yogurt systems. Macedo & Ramírez & Vélez-Ruiz (2015) elaborated a yogurt enriched with microcapsules containing omega-3 fatty acids. The authors observed similar behavior in the flow parameters, showing an increase in the K_{HB} (0.53 to 1.17 Pa·s^n) and K_{LP} (3 to 39.19 Pa·s^n) values.

Evaluation of yogurt microstructure

Figure 2 shows the microstructure of the different yogurt systems observed through the scanning electron microscope at 1250x and 7500x. It is noteworthy to observe that at a depth of 1250x, the systems show a similar matrix. However, after magnifying at 7500x, all samples showed the

presence of the lactic cultures, namely *Streptococcus thermophilus*, which was identified in all samples. The yogurt system added with 2% chickpea flour showed a higher amount of fat globules embedded in the casein matrix and a compact casein matrix. On the other hand, this treatment (2%) showed lower thermal stability of the fat globules, which tended to melt quickly because of the electron beam. Regarding the yogurt added with 3% chickpea flour, it can be observed that it has a relatively more porous matrix than the yogurt added with 2% chickpea flour. This system shows a lower incidence of fat globules embedded in the casein matrix, so it was less susceptible to the electron beam. The starch contained in chickpea flour may be interacting with the fat globules, allowing the formation of a more homogeneous matrix. It has been reported that amylose chains can form interactions with lipids under certain processing conditions, leading to the formation of amylose-lipid complexes (Vu et al., 2017).

As shown in the magnification at 7500x (Figure 2), regardless of the treatments, all samples clearly showed the presence of the casein matrix. However, a variation in the size of the empty spaces in the matrix was observed. No significant differences were observed ($p < 0.05$) in the size of the empty spaces in the yogurt matrix, where the yogurt added with 2% of chickpea flour presented the smallest size with 635.5 ± 116.8 nm. In contrast, yogurt with 3% chickpea flour showed larger spaces in the casein matrix, with an average of 649.1 ± 111.0 nm. These data indicate a higher porosity, which could affect water retention capacity, thus decreasing the syneresis of the material, which is consistent with the data shown in Table 1. Furthermore, this characteristic directly affected the rheological properties, resulting in higher consistency coefficient (K) values after 22 days, regardless of the mathematical model.

In summary, the incorporation of chickpea flour helped to improve the characteristics of the yogurt matrix, generating a more porous matrix (larger internal spaces). The change in porosity positively impacted the physical attributes dependent on water diffusions, such as the percentage of syneresis and the rheological properties.

The relationship between physicochemical and rheological characteristics of yogurt systems

To determine the relationship between the significant variables studied and the common characteristics, a principal component analysis (PCA) was performed, shown in Figure 3. The first three components describe 80.71% of the total variability in the data, with the first component describing 39.69% of the variability in the data, the second component 26.97%, while the third component represents the remaining 14.06%. The variables that contributed positively to the first component were titratable acidity, net color change (*DE*), and consistency coefficients for both rheological models, whereas brightness (L*), percentage of syneresis, and pH contributed negatively to this component (Figure 3b). On the other hand, the second component was positively affected by the percentage of syneresis, brightness (L*), net color change (*DE*), and the Power Law consistency coefficient.

In contrast, the pH, the consistency coefficient for the Herschel-Bulkley model (K_{HB}), and the titratable acidity negatively affected the second component. Finally, the variables that positively influenced the third component were the titratable acidity and the syneresis percentage. At the same time, the consistency coefficients (K_{HB} and K_{PL}), the net colour change (*DE*), and brightness (L*) contributed negatively to this component.

As shown in Figure 3c, the data were grouped according to storage time (days). A low separation existed within the treatments at 1, 8, and 15 days (purple, blue, and yellow, respectively). These yogurts systems showed common characteristics such as a higher pH than samples stored for 22 days. Furthermore, these samples showed a low DE, as well as a low titratable acidity. On the other hand, the treatments stored for 22 days (red group) were grouped and separated from the other systems, characterized by presenting the highest net color change values (*DE*) and a higher percentage of titratable acidity. Likewise, these yogurts systems showed a tendency to have the highest consistency coefficients for both mathematical models.

Table 2
Flow parameters of yogurt systems fitted to Power Law (PL) and Herschel-Bulkley (HB) models

System	Days	PL				HB				
		K (Pa·s^n)	n	RMSE	R^2	t$_0$	K (Pa·s^n)	n	RMSE	R^2
YC	1	4.10	0.64	0.64	0.97	1.77	2.42	0.81	0.80	0.97
	8	4.03	0.66	0.35	1.00	1.44	2.69	0.79	0.49	0.99
	15	4.04	0.67	0.38	0.96	1.43	2.71	0.79	0.51	0.99
	22	4.15	0.67	0.26	1.00	1.38	2.88	0.78	0.38	0.99
YCF1	1	4.05	0.66	0.41	0.98	1.48	2.67	0.80	0.55	0.98
	8	4.03	0.66	0.42	0.99	1.49	2.64	0.80	0.56	0.98
	15	3.92	0.68	0.30	0.97	1.27	2.74	0.80	0.42	0.99
	22	4.24	0.65	0.27	0.95	1.52	2.86	0.77	0.38	0.99
YCF2	1	3.96	0.69	0.38	0.97	1.28	2.78	0.80	0.50	0.99
	8	4.01	0.67	0.43	0.99	1.40	2.71	0.80	0.56	0.98
	15	3.97	0.68	0.34	0.98	1.29	2.78	0.80	0.46	0.99
	22	4.48	0.64	0.28	0.99	1.66	2.98	0.76	0.39	0.99
YCF3	1	4.00	0.66	0.35	0.97	1.43	2.66	0.79	0.49	0.98
	8	4.01	0.68	0.52	0.99	1.39	2.73	0.80	0.57	0.99
	15	3.99	0.68	0.42	0.96	1.38	2.72	0.80	0.55	0.98
	22	4.62	0.62	0.34	0.99	1.78	3.00	0.76	0.45	0.97

YC: yogurt control; YFC1: yogurt with 1% chickpea flour; YFC2: yogurt with 2% chickpea flour; YFC3: yogurt with 3% chickpea flour. PL: power-law; HB: Herschel-Bulkley; K: consistency coefficient; n: flow rate; RMSE: Root Mean Squared Error.
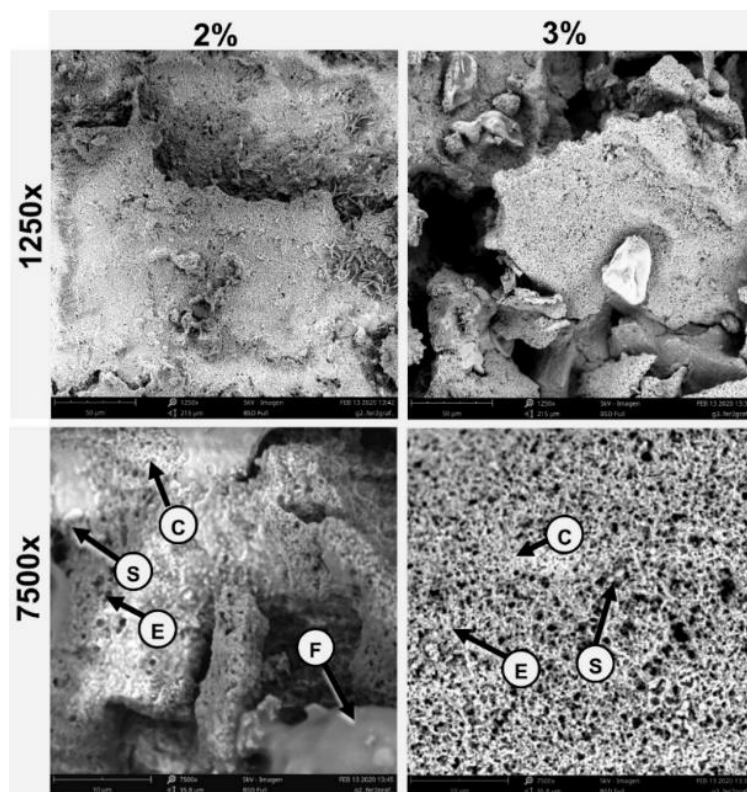
Figure 2. Microstructure of yogurts added with different percentages of chickpeas observed at 1250x and 7500x. C: casein matrix; E: empty space; F: fat globules; S: *Streptococcus thermophilus*.

a)

Principal Component	Percent	Cumulative Percent
1	39.69	39.69
2	26.97	66.66
3	14.06	80.71
4	11.80	92.51
5	5.98	98.50
6	0.79	99.29
7	0.71	100.00

b)

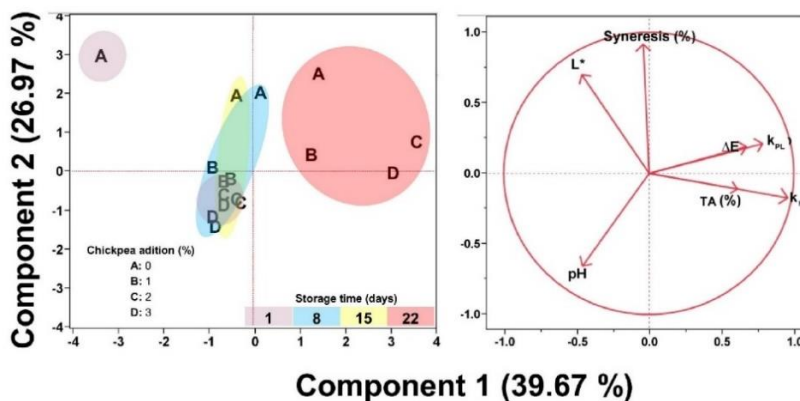| Variable	PC1	PC2	PC3
pH	-0.274	-0.478	-0.044
Syneresis (%)	-0.024	0.668	0.341
TA (%)	0.365	-0.079	0.702
L*	-0.278	0.510	-0.103
ΔE	0.404	0.139	-0.420
K_{PL}	0.471	0.153	-0.426
K_{HB}	0.573	-0.126	0.142

c)

Figure 3. Principal Component Analysis (PCA) for yogurt systems, labeled by chickpea content, and grouped by storage time. a) Values and contribution (%) to the total variation of the studied variables; b) Contribution of each variable to each principal component; c) Scatter and loading plot of the first and second components. L*: brightness; DE: net color change; TA: titratable acidity; K_{HB}: consistency coefficient for the Herschel-Bulkley model; K_{PL}: consistency coefficient for the power-law model.

It is important to highlight that the control treatments (A) showed a tendency to cluster at the top of the graph (Figure 3c), indicating that these samples had the highest values for brightness and the highest syneresis percentages. On the other hand, it was observed that the yogurt systems added with 1%, 2% and 3% of chickpeas were grouped in the lower left quadrant, showing that the addition of chickpea flour results in a homogenization in the characteristics evaluated, remaining even after 15 days of storage. Furthermore, these systems maintained a low percentage of syneresis, a moderate variation in color (*DE*), keeping its consistency (K_{PL}, K_{HB}) for at least 15 days.

4. Conclusions

The addition of chickpea flour binds and stabilizes the yogurt system, obtaining a more porous matrix, leading to improved physicochemical, microstructural, and rheological characteristics. The yogurt systems added with 3% chickpea flour showed the lowest syneresis percentages with 15 to 19% for days 1 and 22. This study showed that it is possible to replace milk solids with the addition of chickpea flour, improving the physicochemical, rheological, and structural characteristics of yogurt. The principal component analysis showed a correlation between the evaluated parameters, showing that yogurts added with chickpea flour improved their physicochemical properties, with a tendency to show the best consistency indexes, lower syneresis percentage, and major color stability. Finally, this study made it possible to reduce solids in a milk system while improved its features and storage stability. Furthermore, this work opens the opportunity to generate a product-oriented to people who care about their dietary habits. Therefore, future work will focus on the sensory and nutritional evaluation of the yogurt system, their glycemic index, and glucose response using a type 2 diabetic model.

ORCID

A. H. Cabrera-Ramírez (ID) https://orcid.org/0000-0002-1148-4202
D. Morales-Koelliker (ID) https://orcid.org/0000-0003-3769-6948
V. G. Aguilar-Raymundo (ID) https://orcid.org/0000-0003-4357-7347

References

Aguilar-Raymundo, V. G., & Vélez-Ruiz, J. F. (2019). Yoghurt-type beverage with partial substitution of milk by a chickpea extract: Effect on physicochemical and flow properties. *International Journal of Dairy Technology, 72*(2), 266 – 274.

A.O.A.C. Association of Official Analytical Chemists. (2000). Official Methods of Analysis. 17th Edition. Gaithersburg, MD. USA.

Ares, G., Gonçalvez, D., Pérez, C., Reolón, G., Segura, N., Lema, P., & Gámbaro, A. (2007). Influence of gelatin and starch on the instrumental and sensory texture of stirred yogurt. *International Journal Dairy Technology, 60*, 263–269

Barkallah, M., Dammak, M., Louati, I., Hentati, F., Hadrich, B., Mechichi, T., Ayadi, M. A., Fendri, I., Attia, H., & Abdelkafi, S. (2017). Effect of Spirulina platensis fortification on physicochemical, textural, antioxidant and sensory properties of yogurt during fermentation and storage. *LWT, 84*, 323-330.

Brennan, C. S., & Tudorica, C. M. (2008). Carbohydrate-based fat replacers in the modification of the rheological, textural, and sensory quality of yoghurt: comparative study of the utilisation of barley beta-glucan, guar gum and inulin. *International Journal of Food Science Technology, 43*, 824-833

Brookfield U.S.A. (2011). Viscometer handbook, DV II + Pro Operating instructions. Middlebore MA: Brookfield Engineering Laboratories Inc.

Cabrera-Ramírez, A. H., Castro-Campos, F.G., Gaytán-Martínez, M. & Morales-Sánchez, E. (2020). Relationship between the corneous and floury endosperm content and the popped sorghum quality. *Journal of Cereal Science, 95*, 102999.

FDA - Code of Federal Regulations - Title 21 – Yogurt. CFR FDA 1 Apr 2016. Web. 22 Jan 2017.

Global CAGR. (2017). Global Legumes Market Worth. https://prn.to/3awaiRh

Hickisch, A., Beer, R., Vogel, R. F., & Toelstede, S. (2016). Influence of lupin-based milk alternative heat treatment and exopolysaccharide-producing lactic acid bacteria on the physical characteristics of lupin-based yogurt alternatives. *Food Research International, 84*, 180-188.

Jukanti, A. K., Gaur, P. M., Gowda, C. L. L., & Chibbar, R. N. (2012). Nutritional quality and health benefits of chickpea (*Cicer arietinum* L.): a review. *British Journal Nutrition, 108*, S1 S11-S26.

Kaur Sidhu, M., Fengzhi, L., Sharkie, T. P., Ajlouni, S., & Ranadheera, C. S. (2020). Probiotic yogurt fortified with chickpea flour: physico-chemical properties and probiotic survival during storage and simulated gastrointestinal transit. *Foods, 9*(9), 1144.

Knights, E. J., & Hobson, K. B. (2016). Chickpea Overview, in: Reference Module in Food Science. Elsevier.

Macedo y Ramírez, R. C., & Vélez-Ruiz, J. F. (2015). Propiedades fisicoquímicas y de flujo de un yogur asentado enriquecido con microcápsulas que contienen ácidos grasos Omega 3. *Información Tecnológica, 26*(5), 87-96.

Oomah, B. D., Patras, A., Rawson, A., Singh, N., & Campos-Vega, R. (2011). Chemistry of pulses, in: Pulse Foods. Elsevier, pp. 9–55.

Raza, H., Ammer, K., Zaaboul, F., Shoaib, M., Zhao, C. C., et al. (2021). Physicochemical, rheological, and sensory characteristics of yogurt fortified with ball-milled roasted chickpea powder (*Cicer arietinum* L). *Food Science and Technology, 2021*, 1-9.

Rojas-Castro, W. N., Chacón-Villalobos, A., & Pineda-Castro, M. L. (2007). Características del yogurt batido de fresa derivadas de diferentes proporciones de leche de vaca y cabra. *Agronomia Mesoamericana, 18*, 2210-2237.

Sarker, A., Chakraborty, S., & Roy, M. (2020). Dark red kidney bean (*Phaseolus vulgaris* L.) protein hydrolysates inhibit the growth of oxidizing substances in plain yogurt. *Journal of Agriculture and Food Research, 2*, 100062.

SIAP (Servicio de información agroalimentaria y Pesquera). (2020). https://www.gob.mx/siap

Tamime, A. Y., & Robinson, R. K. (1999). Yoghurt – Science and Technology, 2nd edn. Cambridge: Woodhead Publishers, 22 pp.

Öztürk, H. İ., Aydın, S., Sözeri, D., Demirci, T., Sert, D., & Akın, N. (2018). Fortification of set-type yoghurts with *Elaeagnus angustifolia* L. flours: Effects on physicochemical, textural, and microstructural characteristics. *LWT - Food Science and Technology, 90*, 620-626.

Vu, T.H., Bean, S., Hsieh, C. F., & Shi, Y.C. (2017). Changes in protein and starch digestibility in sorghum flour during heat-moisture treatments. *Journal of the Science of Food Agriculture, 97*, 4770-4779.

Zare, F., Champagne, C. P., Simpson, B. K., Orsat, V., & Boye, J. I. (2012). Effect of the addition of pulse ingredients to milk on acid production by probiotic and yoghurt starter cultures. *LWT - Food Science and Technology, 45*, 155-160.