Research Article
Open Access
CrossMark

Characterization of a Mexican hot sauce (from "chile de arbol") and changes through storage

Abstract

Due to the importance of hot sauces as a complementary food and as non-Newtonian fluid, a characterization of this item was completed. The study was divided into three stages, firstly, four commercial sauces were analyzed on physicochemical, microbial and flow properties to have a framework of accepted products by human consumers. Subsequently, a group of twelve sauces, was prepared to determine the same and other properties influenced by formulation, and from the obtained information, a third or storage study of eight elaborated sauces was carried out, measuring the same characteristics, also influenced by formulation, sanitization treatment, temperature and storing time. Finally, three items, two studied and selected sauces were prepared in order to develop a sensorial assessment and to generate a complete vision, comparing with a commercial one, the two selected sauces resulted with better acceptation that the commercial hot sauce.

Keywords: hot sauce, physicochemical properties, characterization, and stability storage

Volume 12 Issue 1 - 2024

Yanaina Chávez Ugalde,[1] Jorge F Vélez-Ruiz[1,2]

[1]Departamento de Ingeniería Química e Ingeniería en Alimentos, Universidad de las Américas Puebla, Mexico
[2]Food Network Consultores, Instituto de Diseño e Innovación Tecnológica, Mexico

Correspondence: Jorge F Vélez-Ruiz, Departamento de Ingeniería Química e Ingeniería en Alimentos Universidad de las Américas Puebla, San Andrés Cholula, Puebla, C.P. 72810. Mexico, Tel +222.2370117, Email jorgef.velez@udlap.mx

Received: November 23, 2023 | **Published:** January 09, 2024

Introduction

Hot sauce is a particular food, in which the presence of capsaicin and other ingredients dispersed in water, contribute to its properties. It is a spicy item or salsa, elaborated with chili, vinegar, tomato, onion, and other herbs. Hot sauce consumption has been increasing and importance in Mexico, Latin America and around the world. Then, the formulation and characteristics of hot sauce, preparation, manufacturing process, and effect of constituents and process variables, are very important, due to the influence on their properties and on consumer acceptance. The hot sauce frequently, is used to give an extra of flavor in foods, fortunately it also contributes with good nutrients and health benefits, due to food ingredients, antioxidants and capsaicin in particular.

The presence of water content, with the ingredients dispersed in it, are influenced in their properties by the formulation, elaboration process, and by supplied energy that favors the small droplets formation;[1] in it, the chili is the most important one. This food item is characterized by low content of carbohydrates, fats, and proteins, with presence of fiber, minerals, vitamins, and capsaicin, producing an acidic food. For instance, although the sauces have important differences from country to country, Dong-Jin et al.[2] reported a water content of 95.66%, fiber of 0.42%, capsaicin content of 4.28 mg, and a pH of 3.26.

There exists limited information on this type of foods, physicochemical and sensory properties such as color, density, phases separation, viscosity, flow properties, and consumer preferences. These properties and others, need to be measured, characterized, and studied in order to have, a complete panorama and to control the manufacturing process, as well as to know the influence of ingredients, formulation variables and process parameters. Gamonpilas et al.,[3] conducted a rheological study of hot sauce, finding a strong shear thinning response, that was fitted to the Herschel-Bulkley model, in which the presence of total solids and starch were related to yield stress. More recently, Ulyarti et al.,[4] reported ranges of 3.78 to 4.00 for color (in which 5 was for red color), 37 to 243 poises for initial viscosity, and 0 to 5.84% for phases separation, among other characteristics, for a chili sauce influenced by the starch concentration. Even though, there exist a gamma of hot sauces with a wide variety of characteristics, around the world.

Thus, the objectives of this research were three, first: to standardize the formulation stage of the Mexican sauce; second: to study and analyze the effect of process variables, and third: to observe the behavior of some selected sauce items through storage.

Materials and methods

In order to achieve the proposed objectives, we applied standard methods and used the next materials in a work of several months.

Materials

Glacial acetic acid was taken from the laboratory of Food Engineering (Universidad de las Américas Puebla, Cholula, Puebla). Whereas the other ingredients (chili, cinnamon, cumin, marjoram, pepper, and salt) were acquired in a local supermarket.

Four commercial Mexican sauces ("Búfalo", "Don Carlos", "Tampico" and "Valentina") were bought in a local supermarket; they were analyzed to have a reference frame.

Methods

Elaboration process

Powder ingredients, such chili, cinnamon, cumin, marjoram, pepper and salt, were weighted and manually mixed with a stainless-steel spoon. The garlic was cooked at 70°C, cooled (5 min) and, also weighted. Then the garlic was added to one liter of water, placed in a commercial blender, Waring 7010G (Dynamics Corp, Conn., USA), mixing both; subsequently the powder mix was incorporated, and after 30-45 s, the glacial acetic acid was added, mixing all ingredients during 20 s. The sauce items were placed in glass containers at room temperature (25°, not lights), until samples were taken for analysis and determinations.

Physicochemical determinations

Acidity was quantified by titration using NaOH (0.1N), when a pH of 8.3 was reached, as indicator. This is an accepted method by the Mexican norm,[5] in which the next relationship was used to quantify it, and expressed as acetic acid:

$$\text{Acidity}\left(\%\right) = \frac{\text{Volume x Normality of NaOH}\left(\text{mL}\right)\ \text{x}0.06}{\text{Sample volume}\left(\text{mL}\right)} x100 \quad \text{(Eq 1)}$$

pH was measured with a digital potentiometer, Hanna H198107 (Hanna Instruments Ltd., Smithfield, RI, USA), previously calibrated with buffers of pH 4.0 and pH 7.0; by immersion of the electrode in the sample.

Color was measured with a Gardner Color System 05 colorimeter (Hunter Labs, Reston VA, USA), previously calibrated with the references, white and black plates, having standardized reflectance, and using a tristimulus scale. The differences for samples, were evaluated using L*, a* and b* CIELAB color parameters, as well as the net change of color by using equation 2,[6] 10 g of sauce sample were placed in quartz cells.

$$\Delta E = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2} \qquad \text{(Eq 2)}$$

Where: ΔE is the net change of color, ΔL* is the luminosity parameter change, Δa* is the red parameter change, and Δb* is the yellow parameter change.

Density was determined following a gravimetric method, by using Grease pycnometers and taking water as reference, it was expressed in kg/m^3.

Moisture was quantified by weight loss through evaporation of water, introducing samples into an oven at 110°C for 24 hours, according to the method 17.007.12.[7]

Stability or Phase separation was measured by centrifugation of 25 mL of sauce at 2000 rpm (192.3 g), for 1 min, by using a Centrifuge Instrument (Fisher Scientific International, Massachusetts, USA), and applying the next relation (equation 3) for the evaluation of the percentage of stability (ST).[8] In which high percentages was taken as a good stability or negative separation of the dispersed elements.

$$ST = \left(Supernatant\ volume / Initial\ volume\right)\ x\ 100 \qquad \text{(Eq 3)}$$

Water activity measurement was carried out using a commercial instrument (Decagon CX-1 model, Pullman, WA, USA), previously standardized with activated carbon (a_w 0.530) and distilled water (a_w 1.000).

Rheological characterization

Measurements for flow response of sauce items were carried out in a digital Brookfield viscometer (DV-III, Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA). The viscometer was adjusted to zero, a spindle LV (with a specific torque), and the small sample cell (20 mL) were set in the instrument.

The measuring parameters were determined with the three relationships (Equations 4 to 6) given by the manufacturer[9]: In which from the rotation speed and torque, the shear rate (γ) and shear stress (τ), angular velocity (ω) as fundamental parameters were computed:

$$\gamma = \frac{2\omega R_c^2}{R_c^2 - R_b^2} \qquad \text{(Eq 4)}$$

$$\omega = \left(\frac{2\pi}{60}\right)N \qquad \text{(Eq 5)}$$

$$\tau = \frac{M}{2\pi R_b^2 L} \qquad \text{(Eq 6)}$$

Where: γ is the shear rate (s^{-1}), ω is the angular velocity of the spindle (rad/s), R_c is the internal container radius (0.9525 cm), R_b is the spindle radius (cm), N is the velocity of the spindle (rpm), τ is the shear stress (N/m^2), M is the experimental torque (6.737×10^{-5} x instrument reading in percentage (N·m), and L is the effective length of the spindle (cm).

In this work, two flow models were used to fit the experimental data; the Power Law and Herschel-Bulkley fittings, both models are expressed by equations 7 and 8.[10,11]

$$\tau = K\gamma^n \qquad \text{(Eq 7)}$$

$$\tau = \tau_o + K\gamma^n \qquad \text{(Eq 8)}$$

Where: τ is the shear stress (Pa), K is the consistency coefficient ($Pa \cdot s^n$), γ is the shear rate (s^{-1}), n is the flow behavior index (dimensionless), and τ_o is the yield stress (Pa).

Additionally, in order to know the best fitting when both models were applied, two goodness relationships were used. The percentage of mean relative error (PEM, Eq. 9) and the square root of the mean error (RMSE, Eq. 10).[12]

$$PEM = \frac{100}{n}\sum_{i=1}^{n}\left(\frac{\left|\tau_{exp} - \tau_{pred}\right|}{\tau_{exp}}\right) \qquad \text{(Eq 9)}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\tau_{exp} - \tau_{pred}\right)^2\right]^{\frac{1}{2}} \qquad \text{(Eq 10)}$$

Where: *n* is the number of determinations, τ_{exp}: is the experimental shear stress (Pa), and τ_{pred}: is the predicted shear stress, by the model (Pa).

Microbiological count

The hot sauce samples were tested for aerobic bacteria, fungi, and yeast, by following the correspondent Mexican norms.[13] These analyses were performed by preparing serial dilutions in peptone water (0.1% w/v) and plating the samples in duplicate. The samples were aerobically incubated for 48 h at 35°C or 120 h at 35°C (yeast and fungi) before enumeration.

Sensorial analysis

Sensory analysis of the selected samples was carried out with 20 non-trained panel, and applying a structured hedonic scale.[14] Thus, in order to determine the global acceptance of the hot sauce, the sensory evaluation of selected items by an untrained panel, was based on affective tests by using a 9-point hedonic scale, 1 for dislike extremely and 9 for like extremely.[14] The group of panellists worked individually, with 3 samples per session.

Statistical analysis

The analysis of properties, acidity, color parameters, density, and pH, were done in triplicate. All data were subjected to analysis of variance and Tukey test to determine significant differences between the studied systems, with a confidence level of 95%, using the MINITAB software v.16® (Minitab Inc., State College, PA, USA).

Research evolution

In order to complete the study, first: four commercial brands of Mexican sauce were characterized to have a frame of properties from this type of food items. Experimentally, the formulation of the prepared sauces was standardized; and their more important properties were measured, characterized and analyzed; finally, a stability analysis was completed.

Results and discussion

Commercial characterization and frame

As a result of the commercial exploration, four brands from the commercial sauces, were selected, they are identified as:

i) "Don Carlos" brand, a "gourmet" sauce prepared with tree chili.

ii) "Tampico" brand, an extra spicy sauce.

iii) "Valentina" brand, a spicy sauce.

iv) "Bufalo" brand, classic spicy sauce.

Physicochemical determinations

The properties measured in the four commercial items, were those previously mentioned.

Acidity determination ranged from 2.44 to 4.62%, in which Valentina sauce has the lowest acidity, and Bufalo brand was the most acid. This parameter was high in three items, because 3%, as been cited as an expected value. Comparison of these determinations, indicated a significant difference between samples, 2.44 ($\pm$ 0.03) for Valentina, 3.26 ($\pm$ 0.03) for Don Carlos, 3.51 ($\pm$ 0.04) for Tampico, and 4.62 ($\pm$ 0.08) for Bufalo sauces.

pH as related with acidity, showed the next values range, 2.66 to 3.33, with the lowest value for Tampico and highest value for Valentina. Three pH determinations (2.69 $\pm$ 0.01 for Tampico, 3.11 $\pm$ 0.01 for Bufalo, and 3.17 $\pm$ 0.04 for Don Carlos sauces) exhibited lower values than the pH of 3.26, reported by Dong-Jin et al.[2] Only one of the sauces (Valentina item) had a higher pH, 3.33 $\pm$ 0.04. This property did not show significant difference between the four brands.

Color parameters ranged from 19.01 to 27.46 for L*, 14.40 to 20.48 for a*, and 11.39 to 17.10 for b*, exhibiting low luminosity, light yellow colors, in which the red tone is characteristic of these food items. The luminosity was the only one parameter with significant difference, the other two-color parameters did not show a significant difference between the four sauce items.

Density was in a range of 1038.59 to 1107.09 kg/m^3, with the Tampico one, being the lightest of the four samples, whereas the Bufalo sauce was the most dense, due to a higher concentration and density of the ingredients, dispersed in the water solvent. There was not a significant difference in this physical property for Tampico (1038.59 $\pm$ 13.84 kg/m^3) and Valentina (1048.13 $\pm$ 8.57 kg/m^3) brands, but Don Carlos (1079.59 $\pm$ 3.61 kg/m^3) and Bufalo (1107-09 $\pm$ 2.11 kg/m^3) were statistically different.

For separation phases, the four brand sauces showed a very high stability of the ingredients, resulting 97% for Don Carlos and 100% for the other three items.

Moisture was not correlated to density, that is a frequent relationship, it exhibited a range of 83.33 to 92.92%, with lower content for Valentina brand and higher for Tampico sauce. The determined range of these four sauces is close to those reported by Mckee et al.,[15] who reported a range of 88.3 to 91.1% for commercial chili sauces. ANOVA results indicated a significant difference between the four commercial items, for this property.

Finally, for the water activity measurement in which high contents of moisture was characterized, a range of 0.952 to 0.974 was measured. This parameter ensures a good stability of food items, but do not eliminate the possibility for growth of microorganisms, then other preservative components must be incorporated.

Microbiologic determinations

Almost all determinations, aerobic-mesophilic bacteria, molds and yeasts, were under the Mexican norms,[13] with < 10 UFC/mL; with exception of the Valentina and Bufalo sauces for bacteria counts, in which 760 UFC/mL for the first, and 26500 UFC/mL for the second, were determined, being this last count out of the norm.

Flow characterization

The four sauce items exhibited a non-Newtonian nature, when they were subjected to viscometric determinations. In two of them the best fitting was with the Power Law, whereas the other two were better fitted by the Herschel-Bulkley model. Tampico sauce had a n of 0.35 ($\pm$ 0.02) and a K of 2.86 ($\pm$ 0.09) Pa s^n, Valentina sauce showed a n of 0.27 ($\pm$ 0.01) and a K of 5.16 ($\pm$ 0.02) Pa s^n, being more viscous and non-Newtonian than the first. On the other side, Bufalo sauce exhibited a n of 0.35 ($\pm$ 0.03), a K of 3.95 ($\pm$ 0.14) Pa s^n, and a τ_o of 1.42 ($\pm$ 0.32) Pa, whereas Don Carlos sauce showed a n of 0.55 ($\pm$ 0.06) and a K of 7.31 ($\pm$ 0.34) Pa s^n, and a τ_o of 1.44 ($\pm$ 0.34) Pa, being more consistent and less non-Newtonian, than the other two sauces; the yield stress was similar in both sauces. The four samples exhibited a pseudoplastic behavior, similar to those results obtained and reported by Martinez and Rivera;[16] two of them without yield stress and two with yield stress.

Characterization of fresh prepared sauce systems

Systems preparation

The sauces prepared in our labs, to be studied at this part of the work, were a total of twelve systems (S1 to S12). These systems included: one natural sauce without additives (S1), two system with sodium benzoate (SB) at 0.01 and 0.05 levels (% w/w, S2, S3), three systems with xanthan gum (XG) at 0.20, 0.40 and 0.60 (% w/w, S4, S5, S6), and six systems with the combination of both additives, at 0.20 XG-0.01SB, 0.20 XG-0.05 SB, at 0.40 XG-0.01SB, 0.40 XG-0.05 SB, at 0.60 XG-0.01SB, 0.60 XG-0.05 SB (%w/w, S7, S8, S9, S10, S11, S12).

Physicochemical characteristics of the systems

The physicochemical characteristics for the prepared twelve sauces, were determined at different times, at 0 (fresh), 1 and 2 weeks, they are expressed at Tables 1–3.

Density, of the studied sauce systems, were in the range of the commercial items (1038.59 to 1107.09 kg/m^3); as well as the pH, with values closer to the high pH (3.33) of the commercial ones. A similar situation was observed for the moisture, but it is not the case of the water activity (Table 1), the commercial sauces exhibited a lower activity, that could be attributed to presence of ingredients trapping the water.

As expected, color parameters (Table 2) were very similar to those of commercial sauces, exhibiting low luminosity, with values higher than 22.2 in prepared systems; lower a* determinations, closer to the low values of commercial items, indicating a lower presence of the red color, whereas the yellow color of the prepared sauces was in the range of commercial ones, and also, with low presence of the yellow tone. Additionally, as a good indicator, the net change of color showed very low magnitudes, with a range of 0.45 to 6.32 (Table 3), being the lowest calculation in the first week for system 5, and the highest evaluation for the second week in the system 3. Six magnitudes of this computed parameter were higher in the second week, as expected. Statistical evaluations indicated a non- significant variation with respect to time.

Whereas the stability of solids in prepared sauces (Table 3) was higher than 61%, and the determinations were very similar at the two weeks, concluding that the increase in stability may be related to the gum incorporation, in which the phase stability increased from 61-65% up to 91-100%, being of 100% in six of the seven systems added with xanthan gum, at the first week, and in four of them in the second week. This positive effect was significant statistically, and attributed to an available tridimensional network, formed for this gum.[17]

Table 1 Physicochemical properties of prepared sauce systems measured at time 0

Sauce system	Density (kg/m³)	Moisture (%)	Water activity	pH
S1	1049.32 ± 3.2	86.6 ± 1.53	0.988	3.4
S2	1060.54 ± 8.5	82.3 ± 6.71	0.981	3.3
S3	1044.03 ± 3.1	84.8 ± 5.84	0.985	3.4
S4	1046.43 ± 3.3	90.5 ± 1.29	0.982	3.4
S5	1048.10 ± 6.9	89.3 ± 0.33	0.998	3.4
S6	1054.62 ± 3.3	88.4 ± 1.37	0.991	3.3
S7	1044.03 ± 3.2	88.2 ± 0.09	0.982	3.4
S8	1050.55 ± 5.5	88.7 ± 0.11	0.978	3.4
S9	1047.52 ± 3.0	90.8 ± 0.33	0.977	3.4
S10	1057.07 ± 2.3	91.1 ± 0.42	0.979	3.4
S11	1049.92 ± 5.9	91.8 ± 2.79	0.982	3.3
S12	1063.59 ± 3.1	90.3 ± 0.07	0.983	3.3

Table 2 Color parameters of prepared sauce systems measured at three times (fresh, first and second weeks)

Sauce system	Fresh			First week			Second week		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
S1	23.19	15.06	13.46	25.27	15.86	13.84	23.55	14.15	13.18
S2	22.74	14.88	13.31	24.45	15.68	13.36	22.88	14.07	12.6
S3	29.74	15.82	14.52	25.58	16.43	14.49	23.73	14.37	13.19
S4	25.16	16.13	14.69	28.17	16.79	15.82	26.2	14.92	14.44
S5	25.09	15.31	14.34	25.16	15.75	14.34	23.18	14.02	13.03
S6	25.54	15.52	14.53	26.75	16.62	15.68	24.01	14.62	13.43
S7	23.77	15.65	13.57	22.94	14.37	13.03	23.55	14.15	13.18
S8	24.44	15.55	14.27	23.91	14.61	13.53	22.88	14.07	12.6
S9	24.23	15.88	14.1	23.27	14.31	13.16	23.73	14.37	13.19
S10	24.83	15.92	14.39	24.24	14.46	13.42	26.2	14.92	14.44
S11	26.81	15.89	15.6	26.17	15.24	14.56	23.18	14.02	13.03
S12	26.06	15.89	15.39	24.9	15.1	13.92	24.01	14.62	13.43

Table 3 Physicochemical properties (net change of color and phase stability) of prepared sauce systems measured at two time (first and second weeks)

System	Net change of color (Dimensionless)		Phase stability (%)	
	First week	Second week	First week	Second week
S1	2.26	1.02	61.0 ± 1.41	61 ± 1.41
S2	1.89	1.09	93.0 ± 0.71	91.0 ± 1.41
S3	4.2	6.32	100.0 ± 0	97.0 ± 1.41
S4	3.28	1.61	100.0 ± 0	100 ± 0
S5	0.45	2.65	64.0 ± 0.71	64.0 ± 0-01
S6	2	2.09	65.0 ± 1.40	63.0 ± 1.41
S7	1.62	1.57	95.0 ± 1.39	91.0 ± 1.40
S8	1.31	2.72	95.0 ± 1.41	93.0 ± 1.38
S9	2.06	1.59	100.0 ± 0	100 ± 0
S10	1.85	1.7	100.0 ± 0	99.0 ± 0
S11	1.38	4.83	100.0 ± 0	100 ± 0
S12	2.04	3.11	100.0 ± 0	100 ± 0

Microbiological determinations

The microbiological tests were carried out by duplicate, on prepared fresh sauces, finding high counts for aerobic-mesophilic bacteria, with counts that ranged from 280 000 to 4480 000 UFC/mL; being more contaminated the system S1, whereas the less contaminated was the system S2, all prepared sauces were higher in bacteria count that indicated by the Mexican norm 093 (5000 CFU/mL).

Therefore, it can be concluded, the studied sauce systems were not prepared in aseptic conditions, then these sauces would be rejected from a microbiological point of view; the high degree of

Citation: Ugalde YC, Vélez-Ruiz JF. Characterization of a Mexican hot sauce (from "chile de arbol") and changes through storage. *MOJ Food Process Technol.* 2024;12(1):12–20. DOI: 10.15406/mojfpt.2024.12.00293

contamination was attributed to the inclusion of powder chilly and spicy, that were acquired at a local market, in which both ingredients were placed in sacks on the ground.

Rheological properties

With respect to flow behavior, the prepared sauce systems exhibited a non-Newtonian nature, as expected, with a clear shear thinning or pseudoplastic trend, meanly attributed to the gum presence in systems with it. Although the rest of the sauces, also showed this behavior, influenced by all the solid ingredients. When the twelve sample systems were subjected to fitting with the two mentioned flow models, only three of them were better fitted by the Herschel-Bulkley (S4, S11 and S12), and those with higher content of xanthan gum, consequently showed a yield stress of 4.68 and 4.0 Pa, respectively. Flow properties for the twelve prepared sauces, are included in Table 4.

Table 4 Flow properties of prepared sauce systems measured at time 0 (fresh)

System	Power law		Herschel bulkley model		
	n (dimensionless)	K (Pa s^n) (dimensionless)	n	K (Pa s^n)	t_0 (Pa)
S1	0.58 ± 0.19	0.93 ± 0.05			
S2	0.34 ± 0.04	5.93 ± 0.012			
S3	0.26 ± 0.04	8.53 ± 0.08			
S4			0.85 ± 0.14	4.29 ± 0.03	4.68 ± 0.15
S5	0.26 ± 0.05	0.22 ± 0.03			
S6	0.11 ± 0.01	0.25 ± 0.03			
S7	0.39 ± 0.03	2.69 ± 0.05			
S8	0.36 ± 0.06	4.11 ± 0.21			
S9	0.25 ± 0.04	6.64 ± 0.12			
S10	0.27 ± 0.04	7.18 ± 0.16			
S11			0.42 ± 0.04	6.22 ± 0.79	4.00 ± 0.76
S12			0.42 ± 0.09	6.00 ± 0.65	4.00 ± 0.16

The pseudoplastic response in hot sauces was also mentioned by Sikora et al.[18] The flow behavior index of the twelve sauces, ranged from 0.11 to 0.85, in which the lowest value corresponded to system S6 and the highest one, was for S4. An increase in the consistency coefficient was observed with the gum incorporation, with a quantified range of 0.22 to 8.53 Pa s^n, also reported by Taherian et al.[17] And as it was mentioned, only the systems with 0.60% (w/w) of gum, S6, S11 and S12, exhibited yield stress.

The ANOVA results indicated, that the consistency coefficient was significantly influenced by the benzoate, gum and the interaction of both. Whereas the flow index, only had a significant effect from the chemical preservative, and from the xanthan gum, but not from the interaction of both ingredients. As it is known, these flow parameters are very important for handle of fluids in a production plant, for instance, for agitation energy, for friction losses through pipes, and also for pumping needs, among others.

Once the prepared sauce systems were studied and characterized, and as it was expected, they were similar to the commercial items, showing light differences. Then the next stage was done, in order to achieve a complete work and to get, an overall characterization of Mexican sauces.

Stability of selected sauce systems

Systems preparation

In order, to complete this research, and taking the results and information from previous systems, a new group of sauce systems was prepared, combining two levels of benzoate, a stable quantity of gum and other two factors: a sanitization treatment and the storage temperature. The specific characteristics of the eight sauce systems (T1 to T8), are presented in Table 5. The applied treatment was given by a local Industry ("Procesadora Verduzco", S.A de C.V.) at Cholula, Puebla; it consisted of the injection of a gas mix of ethylene oxide and CO_2 (30-70%) at 30°C, through 24 hours, injecting the gases to the open bags containing the spices and chilies, inside of a sanitization chamber.

Table 5 Prepared sauce systems for stability study

System	Sodium benzoate (% w/w)	Xanthan gum treatment (% w/w)	Applied storage	Temperature (°C)
T1	0.05	0.4	None	Room (20-26)
T2	0.1	0.4	None	Room (20-26)
T3	0.05	0.4	None	High (45)
T4	0.1	0.4	None	High (45)
T5	0.05	0.4	Given	Room (20-26)
T6	0.1	0.4	Given	Room (20-26)
T7	0.05	0.4	Given	High (45)
T8	0.1	0.4	Given	High (45)

Physicochemical characteristics of the stored systems

The results of determinations and observations, corresponding to this third stage, through a month of storage for the new group of eight prepared systems, are presented next.

The acidity varied as a function of the systems composition and storage time, then the results are included in Table 6. In general, there was low variation in acidity, between the fresh sauces and the last week of storage, in which the statistical analysis indicated that two factors were significant on this property, one was the ethylene oxide, and second was the storage time.

Something similar happened with the pH, showing low variation, but with a more observable decreasing trend, as expected, due to biochemical changes. This property and its evolution through storage is included in Table 7. All systems exhibited a pH that is in according with the Mexican norm,[19] with a pH range of 3.27 to 3.335. The ANOVA results expressed that, in addition to the treatment and storage time, as significant factors, the sodium benzoate was incorporated as a third factor.

With respect to color, the stored sauce systems presented magnitudes similar to the commercial and prepared systems, also with low values in net change of color through storage. The measured color parameters and changes are presented in Table 8.

Table 6 Acidity through storage of eight prepared sauce systems

System	Fresh	First week	Second week	Third week	Four week
	Mean (%, in the sample) and standard deviation (% of acidity)				
T1	1.88 ± 3.4	1.69 ± 0	1.72 ± 1.7	1.60 ± 2.5	1.78 ± 4.2
T2	1.89 ± 3.3	1.69 ± 2.5	1.82 ± 1.8	1.72 ± 0.8	1.85 ± 4.0
T3	1.88 ± 3.2	1.64 ± 0	1.61 ± 4.2	1.72 ± 14.4	1.78 ± 5.9
T4	1.89 ± 3.4	1.69 ± 2.5	1.63 ± 4.2	1.88 ± 11.9	1.87 ± 5.0
T5	1.92 ± 3.2	1.93 ± 0	1.99 ± 1.7	2.66 ± 2.5	2.01 ± 4.2
T6	1.94 ± 3.3	1.90 ± 2.0	1.91 ± 1.8	2.54 ± 0.8	1.89 ± 4.0
T7	1.92 ± 3.0	1.93 ± 0	2.01 ± 4.0	2.73 ± 14.4	1.88 ± 5.9
T8	1.94 ± 3.2	1.90 ± 2.5	2.27 ± 4.2	2.44 ± 11.9	1.96 ± 5.0

Table 7 pH through storage of eight prepared sauce systems

System	Fresh	First week	Second week	Third week	Four week
	(Mean and standard deviation)				
T1	3.38 ± 0.04	3.32 ± 0.02	3.39 ± 0.01	3.13 ± 0.04	3.14 ± 0.01
T2	3.42 ± 0.03	3.39 ± 0.01	3.40 ± 0	3.19 ± 0.01	3.11 ± 0.01
T3	3.38 ± 0.04	3.38 ± 0.03	3.37 ± 0.02	3.15 ± 0	3.11 ± 0.01
T4	3.42 ± 0.03	3.37 ± 0.03	3.38 ± 0.04	3.20 ± 0	3.11 ± 0.01
T5	3.22 ± 0.03	3.42 ± 0.02	3.39 ± 0.01	3.31 ± 0.02	3.18 ± 0.04
T6	3.28 ± 0.03	3.48 ± 0.03	3.49 ± 0.01	3.38 ± 0.01	3.32 ± 0.01
T7	3.22 ± 0.03	3.46 ± 0.01	3.48 ± 0.04	3.30 ± 0.03	3.24 ± 0.05
T8	3.28 ± 0.03	3.52 ± 0.02	3.48 ± 0.04	3.36 ± 0.02	3.36 ± 0.08

Table 8 Color Parameters through storage of eight prepared sauce systems

System		Week of storage								
		0	1	ΔE	2	ΔE	3	ΔE	4	ΔE
T1	L*	27.95	26.88		24.46		25.37		26.65	
	a*	17	16.47	1.45	15.62	4.44	15.52	3.3	16.31	1.65
	b*	15.95	15.5		13.58		14.52		15.2	
T2	L*	27.25	25.95		24.85		24.83		25.44	
	a*	17.12	16.43	1.58	15.7	3.27	15.35	3.32	15.93	2.41
	b*	15.59	15		13.89		14.17		14.53	
T3	L*	27.95	25.59		23.04		25.46		23.75	
	a*	17	15.74	3	13.65	6.61	15.01	3.36	13.19	6.21
	b*	15.95	14.59		13.04		14.88		13.41	
T4	L*	27.25	25.04		23.51		22.73		23.15	
	a*	17.12	15.74	2.79	14.05	5.34	13.01	6.62	13.31	6.11
	b*	15.59	14.59		13.33		13.05		13.13	
T5	L*	26.93	24.45		24.46		25.37		23.49	
	a*	16.44	15.49	3.18	15.62	3.29	15.52	2.1	14.36	4.42
	b*	15.58	13.85		13.58		14.52		13.76	
T6	L*	30.52	25.25		24.85		24.83		23.74	
	a*	16.62	15.69	5.52	15.7	6.05	15.35	6.05	14.82	7.25
	b*	15.79	14.41		13.89		14.17		13.96	
T7	L*	26.93	23.49		23.04		25.46		20.98	
	a*	16.44	13.99	4.7	13.65	5.42	15.01	2.17	11.4	8.24
	b*	15.58	13.53		13.04		14.88		12.91	
T8	L*	30.52	24.59		23.51		22.73		22.09	
	a*	16.62	14.44	6.52	14.05	7.86	13.01	9.01	12.23	9.78
	b*	15.79	14.17		13.33		13.05		13.46	

The luminosity ranged from 22.09 to 30.52, in which both extreme values corresponded to system T8, being the highest for fresh sample, and the lowest for that, stored four weeks. The red color exhibited a variation from 11.40 for sauce system T7 at fourth week of storage, to 17.12 for fresh sauces T2 and T4. Whereas the b* parameter showed a range from 12.91 to 15.95, corresponding the lowest value to sauce T7 stored four weeks, and highest magnitudes for two fresh systems, T1 and T3. A not general trend of decreasing in the three-color parameters was observed.

The color changes are well represented by the net color change that exhibited low values, all samples were below 10, in a range of 1.45 to 9.78, being the lowest magnitude for the sauce T1 after a week, and the highest corresponded to sauce T8 after four weeks of storing. Five of the higher changes were computed at the fourth week of storage, for samples T4 (6.11), T5 (4.42), T6 (7.25), T7 (8.24) and T8 (9.78), that could be related with the storage. Four of these five system received the treatment, then the oxidative process on carotenoids could be involved, affecting the net change of color. The only significant factor in ANOVA test on the net change of color, was the temperature, that as expected, it influenced the quality of this liquid food item.

Density of these prepared sauces was basically constant through storage, ranging from 1018.84 to 1035.7 kg/m^3 and being a little lower than the commercial items. Similarly, low changes happened with moisture and water activity, being constants during the storage; moisture varied from 87.67 to 89.15% and corresponded to the range determined in commercial items; whereas water activity varied from 0.978 to 0.992, that was also inside the range of commercial sauces. Water activity had significant influence of xanthan gum.

With respect to stability of phases, the incorporation of xanthan gum at 0.40 % (w/w) favored the stability of all systems, in which a high percentage was determined, above 96%. All sauces had 100% as fresh items; whereas two systems (T1 and T5) exhibited 98%, and two systems (T2 and T6) were 99% at first week; T8 system was 98% and T2 system was 99% at second week; one system (T5) with 97%, another system (T3) with 98%, and three systems (T1, T2, T6) with 99% at third week; whereas at the last week of storage, the stability was 96% for T5, 98% for T7 and 99% for T1 and T3. The rest of the analyzed samples showed 100% of stability.

Microbiological counts of the stored systems

Even though the quantity of chemical preservative was augmented, the counts of mesophilic bacteria was high, mainly as fresh items, in contrast to the absence of molds and yeasts. The logarithmic counts of bacteria are presented in Table 9.

Table 9 Microbiological counts through storage (in logs) of eight prepared sauce systems

Sauce system	Week of storage (log of UFC/mL)				
	0	1	2	3	4
T1	6.3	6.9	6.5	6.5	6.2
T2	6.3	6.8	6.3	6.3	4.3
T3	6.3	6.5	5.9	4.1	3.9
T4	6.3	6.7	4.4	2.7	0
T5	4.9	5.4	2.3	2.1	2
T6	4.9	5.2	2.2	1.9	1.7
T7	4.9	4.4	0.7	0	0
T8	4.9	0	0	0	0

Similarly, to the microbial determinations of the first group of sauces, at this part of the work we found high counts for aerobic-mesophilic bacteria, with counts ranging from 0 to 6.9 (log of UFC/mL), being the most contaminated the system T2 at first week of storage and the less contaminated, the system T8 at the same time.

All prepared sauces were higher in bacteria count that the indicated by the Mexican norm (3.7 log, or 5000 CFU/mL) for the fresh and one week of storage, with exception of the sample T8. The systems without treatment recorded higher mesophilic counts for almost all the storage time; only the system T4 exhibited logs of 2.7 and 0 for third and fourth weeks. In contrary, those systems with the applied sanitizing treatment, had accepted bacterial counts since the second week of storage (< 2.3 logs), indicating the utility of the treatment, not immediately, but from the second week.

Thus, the statistical conclusion was that treatment, temperature and storage time had significant effect on microbial response of the eight sauces.

Rheological properties

The flow nature of these eight prepared sauces was non-Newtonian, of pseudoplastic nature without yield stress and better fitted by the Power Law model. Therefore, the evolution of the flow parameters for the sauce systems, is showed in Table 10.

Table 10 Rheological parameters through storage of eight prepared sauce systems

System		Week of storage				
		0	1	2	3	4
T1	n	0.257	0.206	0.199	0.214	0.2406
	K	9.6	9.38	8.46	8.33	8.79
T2	n	0.247	0.225	0.229	0.251	0.221
	K	9.83	9.57	9.04	8.97	8.79
T3	n	0.257	0.213	0.219	0.236	0.216
	K	9.6	9.04	8.97	8.7	8.61
T4	n	0.247	0.259	0.231	0.228	0.23
	K	9.83	9.79	8.97	8.76	8.74
T5	n	0.25	0.218	0.201	0.202	0.23
	K	10.55	9.2	8.97	8.79	9
T6	n	0.235	0.238	0.226	0.223	0.216
	K	8.98	8.16	8.29	8.08	8.74
T7	n	0.25	0.248	0.225	0.219	0.214
	K	10.55	9.29	9.36	8.65	8.59
T8	n	0.235	0.281	0.227	0.239	0.23
	K	8.98	9.01	8.74	8.57	8.75

n (flow behavior index) dimensionless; K (consistency coefficient) Pa s^n

All sauces, fresh and stored, had a clear shear thinning behavior, with a flow index very low (0.199 – 0.281), clearly far of the Newtonian nature, and with high consistency, with a range of 8.08 to 10.55 Pa s^n; and exhibiting a light trend to decrease the viscosity or consistency, through the storage. These systems were more viscous than the previous group.

ANOVA analysis indicated, that the flow behavior index; only was affected by storage time, whereas the consistency coefficient was influenced significantly by two factors, the storage time and sodium benzoate. Obviously, the structure of the systems changed with storing and the salt involved in the gum chains also, that varied with storing time; something similar was reported by Mandala et al.[20] for the effect of sodium chloride on gum chains.

Sensorial assessment

For this last part of the work, three sauces were utilized to carry out the sensory analysis; they corresponded to two studied systems and one commercial. The selected sauces, based mainly on formulation and microbial results, were the systems T7 and T8, and a similar commercial hot sauce (CS), was selected, that manufactured with "chile de arbol", "Don Carlos" brand.

The assessment was completed with 20 non-trained persons, in which the T7 sauce was qualified with a mean value of 7.75 ($\pm$ 0.91), and the T8 sauce was evaluated with a mean value of 7.70 ($\pm$ 0.99), whereas the CS item, received a mean evaluation of 6.30 ($\pm$ 2.0). Indicating the good acceptability of our prepared sauces: the words "I like very much" were expressed for both sauces, T7 and T8, whereas the commercial sauce was qualified between "I like moderately" and **"**I like little".

The application of a triangular test with 95% of significance, indicated that there was a significant difference between sensory assessment of the prepared sauces and the commercia one, favoring the studied sauces, that was a situation very satisfactory for the involved students and professors involved in the whole study.[21]

Conclusion

A hot sauce was formulated and prepared in order to determine its characteristics and properties, to know the influence of several factors, as well as the storage time (a month) on the studied systems, and also, evaluating sensorially three sauces, two from our studied systems and one commercial.

Four commercial items were analyzed to have a framework of accepted characteristics by the consumer. Experimentally, two groups of hot sauce systems were formulated and elaborated to measure their properties and how they are affected by some factors and by storage.

The four commercial sauces exhibited an acidity of 2.44-4.62%, a pH of 2.66-3.33, color parameters of 19.01 to 27.46 for L*, 14.40 to 20.48 for a*, and 11.39 to 17.10 for b*. With a density of 1038 to 1107.09 kg/m^3, a high stability of 97-100%, a moisture content of 83.33-92.92% and a water activity of 0.952-0.974. Their microbial counts were under that correspondent to a Mexican norm. They behaved as non-Newtonian fluids, two of them fitted to the Law Power model, and the other two, better fitted by the Herschel-Bulkley equation. All these properties were taken as a framework of those hot sauces studied in our labs, considering that are very well accepted by human consumers.

The first group of sauces, were prepared following a traditional recipe and testing the sodium benzoate and xanthan gum as the main formulation variants. The twelve sauces compared with commercial items, had a high pH (3.3 and 3.4), a higher moisture (> 83.3%) with only one exception, higher water activities (> 0.97), whereas density was inside the range, with lower values (1044-1064 kg/m^3). Color parameters were similar, with higher luminosity (22-30), lower redness (> 16.2), and yellowness (< 15.6), with very low net changes of color in two weeks (< 6.3). Phase stability was very good (> 91.0%), with exception of three sauce systems. And high bacteria count in this group of hot sauces, were related with low levels of sodium benzoate. The rheological response of these twelve sauces was non-Newtonian, similar to the commercial ones, and most of the systems (9/12) were better fitted by the Law Power relationship. Showing a range of flow properties, with a flow index of 0.11-0.42, and a consistency coefficient of 0.22-7.18 Pa s^n, influenced by the formulation. Some of them were comparable to the commercial sauces. Therefore, these prepared sauces were characterized, showing similarity to the commercial items, influenced by their formulation and the studied factors. We took the generated information for the next research stage.

The stability study, through four weeks of eight prepared hot sauces, in which additional factors (treatment and temperature) were incorporated, showed that the analyzed systems exhibited comparable properties to commercial and to the first group of sauces, under Mexican norm specifications. Acidity was lower than commercial and varied from 1.60 to 2.66; pH was slightly higher and varied from 3.11 to 3.52; color parameter was similar, with lower red component and with a desirable low net change of color (< 10). Density (1029-1036 kg/m^3) was lower than the first group, but similar to the low value of commercial ones; whereas moisture and water activity corresponded to the range of all hot sauces (commercial and first group). Phase stability was very good (> 96%), such the other analyzed sauces. Although this second group had a high bacterial count that varied as a function of the formulation, treatment, and storage time; it was notable the decreasing in bacterial counts for those sauce systems with sanitization treatment, after the second week of storage. For the flow response of this second group of prepared sauces, it was homogenous, due to the better fitting of the Power Law model, in which flow index varied as a function of storage in a non-general trend, whereas the consistency coefficient showed a light decreasing pattern through storage. Similarly, to the first group, the sauces prepared at this stage, presented good characteristics that were followed during four weeks of storage, with a very good performance.

Finally, the completed sensory assessment of two selected sauces and one commercial, allowed to notice that the prepared sauces satisfied the consumer expectations, being better evaluated than a commercial sauce. Thus, the manufacturers and interested people may elaborate a hot sauce in according to their desirable characteristics, knowing that they have typical characteristics and are well accepted.

Acknowledgments

None.

Conflicts of interest

All authors declare that they have no conflict of interests.

Funding

None.

References

1. Schubert H, Ax K, Behrend O. Product engineering of dispersed systems. *Trends in Food Science and Technology.* 2003;14: 9–16.
2. Dong-Jin K, Sung L, Yoo-Jin K, et al. Technical development of hot sauce with red pepper. *Korean Journal of Food Science and Technology*. 1998;30(2):391–396.
3. Gamonpilas, C, Pongiaruvat, W, Fuongfuichat, et al. Physicochemical and rheological characteristics of commercial chili sauces as thickened by modified starch or modified starch/xanthan mixture. *Journal of Food Engineering*. 2011;105(2):233–240.
4. Ulyarti S, Nazarudin L, Astrini Y. Physical properties of chili sauce as affected by different concentration of water yam's starch. *Indonesian Food Science and Technology Journal*. 2019;2(2):54–56.
5. NMX-F-102-NORMEX-2010. Official Mexican Norm for Non-alcoholic Beverages. *General Direction of Mexican Norms*. Mexico. 2000.

6. Díaz-Jiménez B, Sosa-Morales ME, Vélez-Ruiz JF. Effect of addition of fiber and fat reduction on physicochemical properties of yogurt. *Revista Mexicana de Ingeniería Química*. 2004;3:287–305.

7. AOAC. Official methods of analysis. 17th edn. *The Association of Official Analytical Methods*. USA: Gaithersburg, MD; 2000.

8. Weber FE, Taillie SA, Stauffer KR. Functional characteristics of mustard mucilage. *Journal of Food Science*. 1974;39(3):461–466.

9. Brookfield engineering laboratories. Brookfield Instruction Manual, DVIII. USA: Massachussets; 1985.

10. Ramírez-Sucre MO, Vélez-Ruiz JF. The physicochemical and rheological properties of a milk drink flavored with *cajeta*, a Mexican caramel jam. *International Journal of Dairy Technology*. 2011;64(2):294–304.

11. Vélez-Ruiz JF. Notes for food engineering course. Puebla, México: Universidad de las Américas; 2017.

12. Zuritz CA, Muñoz Puntes E, Mathey HH, et al. Density, viscosity and coefficient of thermal expansion of clear grape juice at different soluble solid concentrations and temperatures. *Journal of Food Engineering*. 2005;71(2):143.

13. NMX-F-092-SSA1-1994. Official Mexican Norm for aerobic bacteria count. Secretary of Economy. Mexico. 1994.

14. Lardmond B. Laboratory methods for sensory evaluation of food. Publication 1637. *Agriculture Department of Canada*. Ottawa, Canada. 1977.

15. Mckee LH, Christopher J, Bock MA. Quality evaluation of commercial chile-based salsas. *Plant Foods for Human Nutrition*. 2003;58:1–12.

16. Martinez LP, Rivera C. Flow behavior of Mexican sauces using a vane-in-a-large cup rheometer. *Journal of Food Engineering*. 2006;72(2):189–198.

17. Taherian AR, Fustier P, Ramaswamy HS. Effects of added weighting agent and xanthan gum on stability and rheological properties of beverage cloud emulsion formulated using modified starch. *Journal of Food Process Engineering*. 2007;30(2):204–224.

18. Sikora M, Badrie N, Deisingh AK, et al. Sauces and dressings: a review of properties and applications. *Critical Reviews in Food Science and Nutrition*. 2008;48(1):48–77.

19. NMX-F-377-1986. Official Mexican Norm for regional foods (packaged hot sauce). *General Direction of Mexican Norms*. MEXICO. 1986.

20. Mandala L, Michon C, Launay B. Phase and rheological behaviors of xanthan/amylose and xanthan/starch mixed systems. *Carbohydrate Polymers*. 2004;58(3):285–292.

21. NMX-F-111-SSA1-1994. Official Mexican Norm for molds and yeasts count. Secretary of Economy. Mexico. 2000.