

Compositional, Functional and Sensory Characteristics of Selected Mexican Cheeses

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ABSTRACT

The aim of this study was to describe the compositional, functional and sensory properties of six traditional Mexican cheeses: Panela, Oaxaca, Manchego, Manchego Botanero, Tenate, and Morral. A total of 50 cheeses were analysed. Relevant compositional parameters including pH, a_w , proximate composition, NaCl, sugars, lactic and acetic acids, mineral contents, free-amino acid nitrogen, fat acid degree value and total fatty acids were determined. In addition, colour and texture profile analyses of unmelted cheeses and their meltability were investigated. Furthermore, other 30 cheeses were used for a descriptive sensory analysis. Properties of cheeses were described, compared between each cheese, and related to their respective making processes.

KEYWORDS

Cheese Properties; Oaxaca; Panela; Manchego; Botanero; Morral; Ethnic Food; Tenate; Traditional Cheese

1. Introduction

There are a considerable variety of local cheeses in Mexico, with most of them evolving from traditional farmhouse methods. Six of the typical cheeses from Central Mexico are Panela, Oaxaca, Mexican-Manchego, Manchego-Botanero, Tenate, and Morral. These are all made from cows' milk and are usually marketed and consumed unripened or shortly ripened. Hnosko *et al.* [1] have described the sensorial characteristics of some of those cheeses. In their study, the increasing popularity of Latin American cheeses in USA has been remarked.

Scientific international literature on the subject of Mexican cheeses has been focused on different aspects. Several studies have been conducted on food safety [2-4] or isolation and characterization of microflora [5-7]. Furthermore, an increasing number of studies dealing with the chemical and functional properties of Mexican cheeses,

i.e., Chihuahua, Fresco, Panela, Asadero and Oaxaca, have been recently published [8-15]. However, to our better knowledge, there is no information on the chemical, functional and/or sensory characteristics of most of the cheeses considered in the present study.

Therefore, the aim of this study was to investigate the chemical composition and functional and sensory characteristics of the six above-mentioned cheese varieties. This information would be useful not only for the cheese-making industry involving those cheeses production, but also for the protection and preservation of cheese-making traditions.

2. Materials and Methods

2.1. Sampling

For the chemical and functional analyses, 50 cheeses (9 Panela, 10 Oaxaca, 9 Botanero, 9 Mexican Manchego, 6 Tenate and 7 Morral) were sampled from 17 regional

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dairy plants in Central Mexico, just prior to being sent to retail markets. Once sampled, cheeses were transported to the laboratory and were stored in their original packages for 4 days at 5°C in an attempt to simulate the conditions at retail stores. After this period, pH, colour, texture, and meltability analyses were carried out. Then, 250 g of each sample were homogenized and kept frozen at -40°C until further chemical analysis. Moreover, 5 additional cheeses from each type were sampled for the sensory analysis. These cheeses were not stored after sampling, *i.e.*, they were analyzed on the next day of sampling.

Key points of the making process of the cheeses sampled, according to the cheese producers, are shown in Table 1, and Figure 1 shows photographs of each of the cheeses studied.

2.2. Chemical Analyses

The pH of cheeses was measured after homogenising the sample with distilled water (1:5, w/v). Water activity (a_w) was determined at 25°C using an Aqualab CX-2 hygrometer (Decagon Devices, Inc. Pullman, WA, USA). Moisture, fat, protein, and ash contents were determined in triplicate (Official Methods no. 926.08, 933.05, 920.123 and 935.42, respectively) [16]. Lactose, galactose, NaCl, lactic and acetic acids, and free amino acid nitrogen (α -NH₂-N) were first extracted from cheese samples with 4.5 mM H₂SO₄ [17]. Lactic and acetic acids were analyzed according to the method described by González de Llano *et al.* [18]. Extracts were filtered through 0.45-µm filters, and 30 µL of filtrate were injected into the chromatograph. The analysis was performed using a Waters 2690 separation module (Waters Corporation, Milford, MA, USA) equipped with an Aminex HPX-87H ion exchange column (Bio-Rad Laboratories, Inc., Hercules, CA, USA), protected by a cation H⁺ Microguard cartridge (Bio-Rad Laboratories, Inc.), and maintained at 65°C. Detection was carried out at 210 nm with a Waters 996 photodiode array detector (Waters Corporation). Elution was performed with 3 mM H₂SO₄ at an initial flow of 0.5 mL·min⁻¹ for 30 min, after which it was increased to 0.8 mL·min⁻¹ up to 40 min. Sugars and NaCl were analyzed using the same methodology to the one used for lactic and acetic acid, except for that the column temperature was 60°C, detection was carried out using a Waters 410 differential refractometer (Waters Corporation) and the eluent was 5 mM H₂SO₄ at a constant flow of 0.6 mL·min⁻¹. Finally, total free α -NH₂-N groups in that extract were analyzed in duplicate according to the method described by Rosen [19].

For mineral content determination, duplicate aliquots of approximately 1 g (± 0.01) of each of the homogenized cheese samples were accurately weighed and digested with 10 mL of concentrated HNO₃ in tightly closed screw

Table 1. Key points in the cheese making processes.

Panela	Pasteurized milk; rennet coagulation. Curd grain at cutting: 1 - 2 cm ³ . Curd time in vat before draining: 30 min. Salting in vat by adding dry salt. Moulding.
Oaxaca	Raw or pasteurized milk; mixed coagulation. Curd grain at cutting: 1 cm ³ . Final pH of curd in the vat: 5.2 - 5.4. Kneading and stretching of curd (pasta filata) in hot water (c.a., 72°C). Forming of long thin strips of curd. Cooling of strips in chilled water. Salting of strips by adding dry salt. Cutting of strings into segments. Wounding of segments into balls.
Manchego	Pasteurized milk; mixed coagulation. Curd grain at cutting: 2 - 3 mm ³ . Final pH of curd in the vat: 6.2. Moulded and pressed for 6 - 12 hours. Salting by adding salt on surface. Drying for 1 - 3 days at 10°C.
Botanero	Similar to Manchego. Final pH of curd in the vat: 5.4. Herbs and <i>Capsicum</i> fruits, and common salt are added to the curd grains before moulding.
Tenate	Raw milk; mixed coagulation. Curd grain at cutting: 2 - 3 mm ³ . Final pH of curd in the vat: 6.0. Draining of curd into 5-kg capacity cloth bags for 24 hours at room temperature. Milling of curd (hand-broken) into small pieces and salting dry salt. Moulding in palm baskets, the curd is covered on the upper side with cloth. Slightly pressed. Ripening at 10°C for one week.
Morral	Pasteurized milk; mixed coagulation. Curd grain at cutting: 2 mm ³ . Salting in the vat with a part of the whey. Final pH of curd in the vat: 5.4 - 5.6. Moulding and draining of curd in a cloth basket called "morral". Pressed.

cap glass tubes for 18 h at room temperature and then for a further 4 h at 90°C. Afterwards, mineral content was determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) according to the methodology described by Osorio *et al.* [20].

Fat extraction was carried out by homogenizing 20 g of sample with 100 mL of chloroform and filtering. Twenty ml of water were then added to the filtrate and the mixture was shaken and decanted. The chloroform phase was then collected, 1 g of Na₂SO₄ was added, and the mixture was shaken and filtered. The determination of the acid degree value (ADV) of fat was done in duplicate by titrating 10 mL of lipid extract dissolved in 20 mL of ethanol/diethyl-ether (1:1, v/v) with an ethanolic

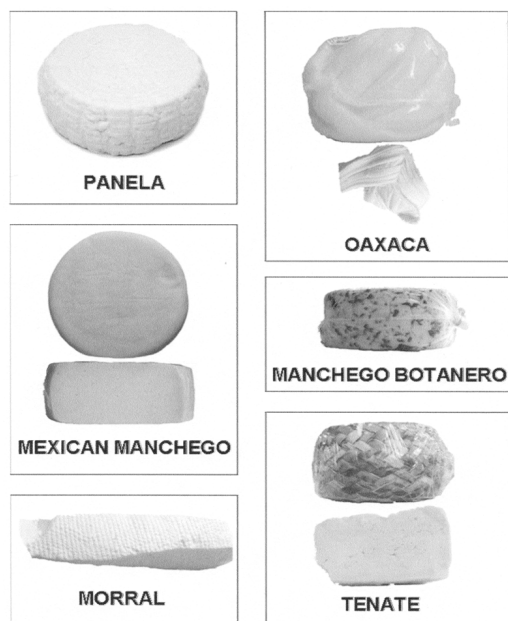


Figure 1. Photographs with the cheeses sampled.

0.02 M KOH solution, using phenolphthalein as indicator. To determine total fatty acid (FA) composition of cheeses, 0.250 g of lipids from each sample were lyophilized and the transesterification-in-situ technique described by [21] was followed. Analysis of FA was performed according to Osorio *et al.* [22].

2.3. Functional Properties

The L^* , a^* , and b^* colour values of cheese samples were measured in triplicate at room temperature on the cheese surface using a Minolta Colorimeter CR-300 (Konica Minolta, Osaka, Japan). The measurement conditions were: D65 illuminant, 10° observed angle, SCI mode, 11 mm aperture for illumination, and 8 mm aperture for measurement.

Samples for texture profile analysis (TPA) were obtained from the core of the whole cheese blocks, discarding 0.5 cm of the outer layer, except for Oaxaca cheese, where that layer was not removed. A total of four 20-mm-sided cheese cubes were placed in an airtight plastic bag, sealed to prevent dehydration, and held in an incubator at 8°C overnight before measurement. A two-bite penetration test was performed using the Texture Analyser (TAHDI; Texture Technologies Corporation, Scarsdale, NY, USA). The instrument operated with a 50-kg load cell and a 100-mm-diameter disk-shaped probe, moving at a crosshead speed of $1\text{ mm}\cdot\text{s}^{-1}$ for a penetration distance of 10 mm. Hardness, adhesiveness, springiness, and cohesiveness were evaluated [23]. In addition, melt time and flowability were determined in triplicate according to the method described by Guinee *et al.* [24]. Flowability was expressed as the percentage increase in

diameter of a cheese disc upon heating at 280°C for 4 min.

2.4. Sensory Analysis

A quantitative descriptive sensory analysis of cheeses was carried out by a group of 12 assessors. Assessors (4 men and 8 women, with a mean age of 25 years old) were staff and students of the Instituto de Ciencias Agropecuarias (ICAP), Universidad Autónoma del Estado de Hidalgo (Tulancingo, Mexico). Assessors were trained in ten twenty-minute sessions. During training, relevant flavour and texture characteristics of cheeses were explained and discussed [25,26]. Then, two Mexican cheeses of each type, which were purchased from the market, were tasted. Afterwards, assessors selected a reduced number of characteristics that were considered as most appropriate for the flavour and texture description of the Mexican cheeses. Selected characteristics were defined and discussed; moreover, reference standards for those characteristics were prepared and presented to the assessors. The proposed characteristics (into brackets the reference used) were: sweetness, acidness, saltiness, bitterness and pungent (1.5 g of fructose, 3 g of citric acid, 7 g of NaCl, 1 g of caffeine and 2 g of “chile jalapeño”-capsicum fruit per 100 g of non-salted ricotta, respectively); cooked milk (UHT milk); sour (acidified milk by an homofermentative culture); buttery (10 g of butter dispersed in 100 ml of milk); intensity and persistence (2 ml of Cheddar cheese flavour in 100 ml of milk); moistness (watermelon); crumbliness (cooked egg white as no crumbly and a muffling as high crumbly standard); and creaminess (spreadable processed cheese). Finally, the cheeses purchased for training were tasted and ranked according to the intensity of the characteristic proposed.

The sensory analysis was carried out in one session for each cheese type (six sessions in total, five samples by session), at the ICAP's tasting room, in individual partitioned-off booths under soft white lighting and at 20°C . Five 1.5-cm cubes of each sample were presented in white plastic dishes, coded with randomly chosen 3-digit numbers. A small cup of still mineral water and salt-free bread crackers were given to the assessors to cleanse their palate between samples.

Assessors were asked to evaluate the selected flavour and texture characteristics on a nine-point linear scale, where 1 represented the absence or very low intensity of a specific flavour or texture descriptor and 9 a very high intensity (referred to the reference standard). Assessors were allowed to swallow the samples if so desired.

2.5. Statistical Analysis

One-way ANOVA analysis was used in order to detect significant differences between cheese types. Means of

variables for each pair of cheeses were compared using the Tukey statistical test (Statistica, release 6.0; Statsoft inc., Tulsa, OK, USA).

3. Results and Discussion

3.1. Chemical Composition

The values of pH, a_w , and the other chemical parameters of cheeses are shown in **Table 2**. Amongst the cheeses studied, Panela appeared to be the most different cheese. This finding can be explained by three main reasons: 1) The frequent use in Panela cheese making of skim milk or casein-fortified milk, which would be responsible for a lower fat-in-dry matter; 2) The differentiated coagulation process in Panela-cheese making (rennet coagulation), which would account for the pH-related differences; 3)

The larger size of the curd grains and the shorter time in the vat after cutting in Panela cheese making, which would result in a higher moisture content.

The pH of recently produced Panela should be similar to the pH of fresh milk (6.7 - 6.8). However, bacterial growth in milk and the subsequent acidification of cheese during distribution and storage could account for the lower pH of cheeses (6.1). The composition of Panela cheese was comparable to that obtained for other soft fresh rennet-coagulated cheeses such as the Spanish Burgos cheese [27] or a Belgium soft cheese variety [28]. Composition of Panela was also similar to those of other Latin American fresh cheeses such as the Mexican Fresco [6,29] or the Brazilian Minas Frescal [30], although pH and moisture content were slightly higher in the Panela cheese.

Table 2. pH, a_w , concentrations and ratios of six Mexican cheeses; mean values (standard deviations).

	Panela (n = 9)	Oaxaca (n = 10)	Manchego (n = 9)	Botanero (n = 9)	Tenate (n = 6)	Morral (n = 7)
pH	6.12 (0.41) ^a	5.02 (0.21) ^b	5.30 (0.21) ^b	5.40 (0.43) ^b	5.34 (0.16) ^b	5.31 (0.11) ^b
a_w	0.988 (0.004) ^a	0.973 (0.006) ^b	0.968 (0.007) ^b	0.968 (0.009) ^b	0.963 (0.007) ^b	0.971 (0.009) ^b
Moisture (%)	54.2 (5.2) ^a	50.8 (2.2) ^{ab}	42.1 (3.4) ^{cd}	46.3 (3.5) ^{bc}	40.3 (2.9) ^d	44.3 (3.6) ^{cd}
Fat (%)	18.8 (3.36) ^d	22.4 (2.52) ^d	28.4 (3.51) ^{ab}	25.9 (3.04) ^{bc}	31.8 (3.57) ^a	29.0 (0.70) ^{ab}
Protein (%)	18.4 (2.16) ^c	21.4 (1.40) ^b	26.0 (1.59) ^a	22.2 (1.83) ^b	22.4 (1.01) ^b	22.1 (2.77) ^b
Lactose (%)	2.23 (0.75) ^a	0.15 (0.16) ^b	0.23 (0.22) ^b	0.13 (0.13) ^b	0.15 (0.15) ^b	0.20 (0.21) ^b
Galactose (%)	0.19 (0.35) ^a	0.19 (0.27) ^a	0.62 (0.42) ^a	0.23 (0.28) ^a	0.16 (0.25) ^a	0.27 (0.24) ^a
Ash (%)	2.57 (0.29) ^c	3.50 (0.40) ^{ab}	3.39 (0.44) ^{ab}	3.76 (0.67) ^a	3.95 (0.50) ^a	3.02 (0.26) ^{bc}
NaCl (%)	1.41 (0.38) ^b	1.61 (0.69) ^{ab}	1.69 (0.81) ^{ab}	1.79 (0.64) ^{ab}	2.46 (0.80) ^a	1.16 (0.48) ^b
Fat-in-DM (%)	40.0 (3.2) ^c	45.6 (4.9) ^{bc}	48.5 (4.3) ^{ab}	48.3 (4.1) ^{ab}	53.2 (5.4) ^a	52.3 (2.0) ^{ab}
Protein-in-DM (%)	39.5 (4.0) ^{ab}	43.5 (2.8) ^a	44.6 (4.8) ^a	41.5 (3.9) ^{ab}	37.6 (2.5) ^b	39.3 (3.1) ^{ab}
MNFS (%)	65.4 (3.9) ^a	65.6 (2.8) ^a	58.8 (2.9) ^b	62.5 (3.5) ^{ab}	59.1 (4.0) ^b	65.0 (3.0) ^a
NaCl/moisture ratio	0.024 (0.005) ^b	0.032 (0.010) ^b	0.041 (0.020) ^{ab}	0.039 (0.014) ^{ab}	0.062 (0.024) ^a	0.027 (0.013) ^b
Moisture/protein ratio	3.00 (0.54) ^a	2.39 (0.22) ^b	1.62 (0.15) ^d	2.10 (0.28) ^{bc}	1.80 (0.15) ^{cd}	2.02 (0.39) ^{bc}
Lactic acid (%)	0.53 (0.24) ^b	1.89 (0.48) ^a	2.12 (0.75) ^a	2.23 (0.92) ^a	1.73 (0.50) ^a	2.36 (0.53) ^a
Acetic acid (%)	0.06 (0.06) ^{ab}	0.07 (0.05) ^{ab}	0.03 (0.04) ^b	0.14 (0.09) ^a	0.16 (0.08) ^a	0.03 (0.03) ^b
α -NH ₂ -N	0.91 (0.21) ^a	1.86 (0.74) ^b	1.45 (0.54) ^{ab}	1.50 (0.46) ^{ab}	1.43 (0.20) ^{ab}	1.43 (0.50) ^{ab}
ADV	4.18 (0.78) ^{ab}	3.43 (0.67) ^b	5.50 (1.63) ^a	4.78 (1.42) ^{ab}	4.54 (0.60) ^{ab}	5.18 (1.80) ^{ab}
Ca (mg·100 g ⁻¹)	717 (65) ^a	581 (66) ^b	769 (97) ^a	708 (98) ^a	771 (35) ^a	770 (95) ^a
Na (mg·100 g ⁻¹)	431 (83) ^b	638 (192) ^{ab}	615 (245) ^{ab}	686 (224) ^{ab}	866 (274) ^a	419 (141) ^b
P (mg·100 g ⁻¹)	439 (31) ^{ab}	405 (29) ^b	459 (38) ^a	455 (39) ^a	481 (33) ^a	451 (35) ^{ab}
K (mg·100 g ⁻¹)	121 (34) ^a	78 (15) ^b	100 (10) ^{ab}	95 (17) ^{ab}	118 (26) ^a	102 (12) ^{ab}
Mg (mg·100 g ⁻¹)	30 (3) ^a	22 (3) ^b	30 (3) ^a	30 (3) ^a	30 (2) ^a	31 (4) ^a

α -NH₂-N: α -amino acid nitrogen expressed as percentage of α -NH₂-N in total N; ADV: acid degree value expressed as mmol KOH. 100 g⁻¹ fat; DM: dry matter; MNFS: moisture-in-non-fat substances; ^{a,b,c}: means of each row with no common letter presented significant differences by the post-hoc Tukey test ($p < 0.05$).

The other five cheeses studied showed a considerable number of characteristics in common. Their pH values were all between 5.0 and 5.4. Moreover, a_w ranges were within 0.96 and 0.97, and all of them can be classified as either semi-soft or semi-hard and fatty cheeses, according to their moisture and fat content, respectively. Furthermore, when considering their $\alpha\text{-NH}_2\text{-N}$ content, little difference was found between these five cheeses. These values were also not very different from those obtained for Panela (a cheese that is not ripened at all) probably due to absent or short ripening times.

Oaxaca cheese had the lowest pH value. Low curd pH values are already achieved in the vat [12], which would promote calcium solubilisation in the whey [31]. Both the low curd pH and the characteristic kneading and stretching would result in an important loss of soluble Ca^{2+} from the curd to the whey, which was reflected in the low Ca^{2+} contents (Table 2). A leaching of other soluble compounds such as phosphates, Mg^{2+} , K^+ , lactate, etc., would also be possible. The composition of Oaxaca cheese was similar to that of Asadero, another pasta-filata Mexican cheese [8,32], with the main difference between both being a 5% higher moisture content in Oaxaca cheese. There is also a similarity between the composition of Mozzarella, particularly low-moisture Mozzarella, and Oaxaca cheese [32,33].

Mexican Manchego is normally made by mixed coagulation of pasteurized milk [3]. When compared to the other Mexican cheeses in study, Mexican Manchego showed the highest protein and one of the highest fat contents. This could be the result of an intense expulsion of whey from curd by syneresis in the vat, due to the small size of curd cubes, and/or an evaporation of moisture from the cheese surface during the ripening period. Proximate composition and pH values of Mexican Manchego seemed to be similar to the ones reported for Chihuahua [9,32] and Monterrey cheeses [32]. Mexican Manchego composition was also similar to that of Spanish Tetilla and San Simón cheeses [27,34].

Manchego Botanero is a variety of Mexican Manchego cheese. As a main difference, in its making process, when the curd reaches a pH of 5.4 - 5.6, common salt and small pieces of “chiles jalapeños” (*Capsicum annuum*) and “epazote” (*Chenopodium ambrosioides*) are added to the vat and mixed with the curd. Then, the mix is moulded and pressed. The composition of Manchego Botanero cheese was quite similar to that of Mexican Manchego, but Botanero had more moisture, which in part could be due to a shorter drying time for this cheese. Significant differences ($p < 0.05$) between these cheeses were also observed for acetic acid, with Botanero having higher values.

Tenate is a semi-hard cheese, the driest, fattiest and the highest in salt content among the cheeses studied. The

draining of curd (c.a., 24 h) and the one-week ripening period would be two distinctive steps in which moisture could be lost. Finally, the composition of Morral, which is a semi-soft cheese, was intermediate for most of the parameters analyzed. However, the salt content was the lowest.

Table 3 shows the mean values of the fatty acid (FA) composition for all the Mexican cheeses studied. FA contents of individual cheeses are not shown because no significant differences were found between the cheeses studied. Moreover, only FA with levels higher than 0.5% of total FA acids were shown in the table for brevity.

Oleic acid (C18:1 n-9) was the most abundant FA, followed by palmitic (C16:0), stearic (C18:0), myristic (C14:0) and linoleic acids (C18:2 n-6). The FA composition of cheese-milk fat is relevant because it may affect significantly functional parameters of cheese such as firmness and flavour [35]. FA composition of cheese fat is roughly proportional to that of the milk used in its production. Moreover, the feeding system seems to be the main factor responsible for variations in milk FA composition [36].

3.2. Functional and Sensory Properties

The values found for the functional properties of the studied cheeses are shown in Table 4. Cheese colour depends on milk fat colour and the content of fat itself [37]. Furthermore, changes in the amount or structure of the skim phase of cheese may also result in changes in the absorption of light [38]. Colour parameters of Panela cheese most resembled those of milk [39]. Panela cheese had the highest lightness, while Tenate showed the lowest. Taking into account the results from all cheeses, L^* values appeared to be positively correlated to moisture content. Regarding a^* and b^* coordinates, Manchego and Manchego Botanero cheeses had the highest values for b^* , while Manchego showed the highest for a^* . The use of colorants and vegetables as ingredients in the manufacture of these two cheeses would account for the differences with respect to the other cheeses, where no colorants neither vegetables are usually added. The addition of natural colorants to milk is a common practice for cheese and milk product manufacture, resulting in increased values of a^* and b^* [40]. Achiote seeds (*Bixa orellana*) and β -carotene colorants are some of the most frequently colorants used.

Colour values for short-ripened, semi-soft cheeses (in the unmelted state) from all over the world have shown a great variability. As an example, L^* , a^* , and b^* data for three cheeses found in literature were: 86, -9 and 24 for reduced fat Mozzarella [41]; 84, -8 and 27 for Havarti [42]; and 81, -8 and 29 for Samso [43]. In this context, the a^* values found in the six Mexican cheeses, which fell between 1.1 and 3.6, presented noticeable differences

Table 3. Fatty acid content expressed as % in weight of total fatty acids[&]; mean values (standard deviation) from all the cheeses studied, n = 50.

Saturated fatty acids		Monounsaturated fatty acids		Polyunsaturated fatty acids	
C8:0	0.83 (0.12)	C14:1 9c	0.85 (0.16)	C18:2 n6	2.67 (0.57)
C10:0	1.89 (0.25)	C15:1 9c	0.07 (0.03)	ΣC18:2 undiff (4) [#]	0.83 (0.22)
C12:0	2.43 (0.29)	C16:1 9c	1.65 (0.20)	C18:3 n3	0.71 (0.16)
C14:0	7.94 (0.96)	ΣC16:1 undiff (5) [#]	0.53 (0.14)	ΣCLA (3) [#]	0.93 (0.26)
ΣC15:0 br (2) [#]	1.09 (0.19)	C18:1 9c	26.46 (1.89)	Total	5.92 (0.67)
C15:0	1.45 (0.21)	ΣC18:1 undiff (8) [#]	5.90 (1.03)		
C16:0	23.38 (1.85)	Total	36.83 (2.25)		
ΣC17:0 br (2) [#]	1.12 (0.15)				
C17:0	0.93 (0.11)				
C18:0	14.85 (1.72)				
Total	57.42 (2.55)				

[&]Only fatty acids exceeding the concentration of 0.50% are shown for brevity in the Table. Br: branched; Undiff: undifferentiated isomers; CLA: Conjugated linoleic acid; [#]: Sum of several isomers (the number between brackets corresponds to the number of isomers quantified).

Table 4. Functional parameters of the Mexican cheeses; mean values (standard deviations).

	Panela (n = 9)	Oaxaca (n = 10)	Manchego (n = 7)	Botanero (n = 9)	Tenate (n = 6)	Morral (n = 6)
<i>L</i> [*]	88.3 (1.4) ^a	86.0 (2.9) ^{ab}	79.6 (3.1) ^c	82.0 (4.2) ^{bc}	76.6 (2.3) ^c	81.7 (4.6) ^{bc}
<i>a</i> [*]	1.1 (0.7) ^b	1.0 (1.00) ^b	3.6 (1.7) ^a	1.9 (0.7) ^b	2.1 (0.8) ^{ab}	2.3 (1.2) ^{ab}
<i>b</i> [*]	15.1 (1.4) ^c	19.7 (2.7) ^b	23.0 (1.2) ^a	23.1 (1.6) ^a	20.5 (3.3) ^{ab}	20.2 (2.6) ^{ab}
Hardness (N)	24.9 (5.7) ^{bc}	14.9 (6.4) ^c	41.7 (23.1) ^{ab}	40.0 (17.0) ^{ab}	51.1 (19.5) ^a	36.1 (15.6) ^{abc}
Springiness	0.83 (0.08) ^a	0.73 (0.07) ^b	0.85 (0.05) ^a	0.86 (0.04) ^a	0.76 (0.05) ^{ab}	0.83 (0.04) ^a
Cohesiveness	0.52 (0.08) ^{ab}	0.62 (0.09) ^a	0.56 (0.07) ^{ab}	0.49 (0.07) ^b	0.31 (0.10) ^c	0.55 (0.13) ^{ab}
Adhesiveness (N mm)	0.17 (0.14) ^c	0.17 (0.24) ^c	1.14 (0.43) ^b	0.65 (0.46) ^{bc}	0.71 (0.38) ^{bc}	1.99 (0.46) ^a
Flowability (%)	ND	22.8 (4.0) ^a	13.9 (3.8) ^b	16.1 (8.2) ^{ab}	12.7 (3.9) ^b	20.0 (5.2) ^{ab}
Melt time (s)	ND	1.5 (0.4) ^a	2.0 (0.5) ^a	1.7 (0.8) ^a	1.8 (0.7) ^a	1.6 (0.7) ^a

ND: not determined. ^{a,b,c}: means of each row with no common letter presented significant differences by the post-hoc Tukey test ($p < 0.05$).

with respect to those reported for the above-mentioned cheeses.

Regarding TPA parameters of unmelted cheeses (**Table 4**), most cheeses presented significant differences between each other in at least one parameter ($p < 0.05$), and Tenate and Oaxaca cheeses showed the highest differences. The former had the highest hardness and lowest cohesiveness, and the latter had the lowest hardness and springiness and highest cohesiveness. TPA has been studied in different fresh or very shortly ripened cheeses such as Colby, Havarti, Mozzarella, and Fresco cheeses [29,44,45]. Roughly, the values observed for the Mexican cheeses in this study fell within the range of values obtained for those cheeses.

Among the studied cheeses, Oaxaca showed the highest meltability (highest flowability and shortest melt time) (**Table 4**), followed by Morral and Botanero, while Manchego and Tenate showed lower meltability. The flowability values of commercial low-moisture Mozzarella, determined using the same methodology as in the present study [46], was twice as high as the values obtained for Oaxaca cheese. Differences can be related to differences in the degree of proteolysis during ripening, since Mexican cheeses are unripened or shortly ripened (up to one week) and commercial Mozzarella is normally ripened for more than one week, which is considered necessary to obtain the desired melting characteristics [33].

Finally, **Table 5** shows the sensory scores of the

Table 5. Sensory scores of the Mexican cheeses; mean values (standard deviations), n = 5.

	Panela	Oaxaca	Manchego	Botanero	Tenate	Morral
Taste and pungency						
Sweetness	4.0 (0.8) ^a	2.9 (0.5) ^b	2.4 (0.4) ^b	2.7 (0.3) ^b	2.6 (0.7) ^b	3.4 (0.4) ^{ab}
Acidness	3.2 (1.0) ^b	4.9 (0.6) ^a	4.2 (1.0) ^{ab}	4.4 (0.9) ^{ab}	4.2 (1.0) ^{ab}	4.4 (1.1) ^{ab}
Saltiness	3.5 (1.0)	3.8 (0.6)	3.5 (0.7)	3.7 (0.5)	4.9 (1.6)	3.9 (0.4)
Bitterness	2.1 (0.8)	2.9 (0.5)	3.2 (0.7)	3.0 (0.6)	3.4 (1.0)	3.7 (1.4)
Pungent	1.2 (0.2) ^b	1.3 (0.3) ^b	1.2 (0.2) ^b	4.3 (2.1) ^a	1.5 (0.3) ^b	1.2 (0.1) ^b
Flavour						
Cooked milk	3.7 (0.5) ^a	2.6 (0.4) ^b	2.3 (0.3) ^b	2.3 (0.4) ^b	2.7 (0.8) ^b	2.7 (0.4) ^b
Sour	2.8 (0.9) ^b	3.4 (0.8) ^{ab}	3.0 (0.5) ^b	3.2 (0.8) ^{ab}	4.1 (0.4) ^a	3.7 (0.3) ^{ab}
Buttery	1.8 (0.2) ^b	3.0 (0.6) ^a	3.2 (0.6) ^a	3.1 (0.2) ^a	3.2 (0.7) ^a	3.5 (0.6) ^a
Intensity	2.5 (0.6) ^b	3.4 (0.8) ^a	3.9 (0.7) ^a	3.9 (0.2) ^a	4.2 (0.3) ^a	4.2 (0.3) ^a
Persistence	2.0 (0.2) ^b	2.0 (0.2) ^b	2.5 (0.2) ^a	2.8 (0.3) ^a	1.4 (0.2) ^c	3.0 (0.5) ^a
Texture						
Moistness	4.1 (0.8)	3.4 (0.6)	3.1 (0.6)	3.1 (0.6)	3.8 (0.9)	3.3 (0.1)
Crumbliness	4.4 (0.8) ^b	4.4 (0.8) ^b	4.0 (0.2) ^b	5.0 (0.8) ^{ab}	6.0 (1.0) ^a	5.2 (0.8) ^{ab}
Creaminess	3.0 (1.0) ^b	5.4 (1.3) ^a	4.9 (1.1) ^a	5.4 (1.2) ^a	4.0 (1.2) ^{ab}	5.7 (1.4) ^a

^{a,b,c}: means of each raw with no common letter presented significant differences by the post-hoc Tukey test ($p < 0.05$).

cheeses. Scores for flavor were in most of the cases lower than 4 (in a 9-point scale), which indicates a no-strong flavour. Acidity was the flavour characteristic showing higher scores; nevertheless, saltiness was higher than acidness in Tenate cheese. As said before for the chemical composition, Panela was the most different cheese among the cheeses studied. Furthermore, Botanero had a high score in pungency due to the presence of hot *Cap-sicum* fruits. With regard to texture, it should be noticed the high creaminess showed by four of the cheeses studied (all except for Panela and Tenate) and the highest crumbliness of Tenate. The last could be attributed to its distinctly making process: in Tenate cheese making, after an intense draining in a cloth bag, the curd is reduced into small pieces, which are placed into basket molds, where pieces are slightly pressed.

4. Conclusions

The present study provides data on the chemical composition, functional and sensory properties of six Mexican cheeses. A high variation in most of the studied parameters, *i.e.*, proximate composition, common salt content, pH and lactic acid content, textural parameters, and meltability, within each type of cheese was found. Therefore, it should be advisable to improve the standardization of milk and cheese-making processes in order to produce

more uniform cheeses.

Most of the Mexican cheeses considered in the present study are unripened or shortly ripened and are melted before serving. Longer ripening periods could be suggested in order to increase their meltability. Further research on the effect of ripening on meltability and textural parameters of Mexican cheeses should be carried out. Moreover, the changes in the cheese properties due to storage time also need further study.

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