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ORIGINAL RESEARCH

Texture, physicochemical and sensory properties of artisanal Adobera cheese from Los Altos de Jalisco, a genuine Mexican cheese

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Physicochemical and sensory properties of Adobera, a genuine, understudied Mexican raw-milk cheese, were explored by analysing commercial samples from different manufacturers and seasons. Composition-wise, Adobera could be considered a fresh cheese with a high moisture content (42.5%), although its relatively low water activity (0.953) and pH (5.14) and high free amino acid content (0.46 mmol/g, dry basis) could indicate otherwise. Instrumental texture corresponded to that of a semifirm cheese, while its colour was whitish-to-ivory. Both texture and composition were significantly affected by sampling season and cheese composition, while some attributes of sensory acceptability significantly varied with brand.

Keywords Mexican cheese, Texture profile, Chemical composition, Raw milk.

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INTRODUCTION

Around 343 000 tons of cheese are produced annually in Mexico (SAGARPA 2016). Over 40 varieties have been categorised as artisanal, several of which are produced with raw, nonstandardised milk (Cervantes and Villegas de Gante 2012). Highly acceptable sensory-wise, these cheeses are frequently manufactured by micro- and small businesses located in rural communities through processes with low degree of technification (Pomeón and Cervantes 2010; Villegas de Gante and Cervantes 2011). As a result, cheese safety could be compromised, and quality features could be difficult to control, as cheese composition may vary from batch to batch and with the manufacturing season. Important efforts for characterising and preserving Mexican cheeses have been carried out by local authorities, organisations of artisanal cheesemakers and research groups (Cervantes *et al.* 2008; Grass *et al.* 2013; Solís *et al.* 2013; Aldrete *et al.* 2014; Grass and Cesín 2014; Ruvalcaba *et al.* 2014; Villegas de Gante *et al.* 2014). Some successful cases stand out, as the identity of some cheeses has been protected through collective marks (e.g., Cotija cheese) (Yescas 2013). However, the information available on most genuine artisan Mexican cheeses is either limited or nonexistent; thus, research on what makes each cheese unique is paramount to help establish desirable physicochemical features, standard making procedures, and, in the end, regulations (Gonzalez *et al.* 2016). So far, most of the available reports on artisanal Mexican cheeses are mainly focused on describing their microbiota or in testing their microbial quality, either for showing their microbiological safety (Palacios 2006; Romero *et al.* 2009; Cervantes *et al.* 2013) or oriented towards the development of protocols to improve cheese quality (Flores *et al.* 2011; Caro *et al.* 2013; Castro *et al.* 2013; Aldrete *et al.* 2014). Reports documenting the historical context, evolution, geographical distribution and peculiarities of specific Mexican cheese varieties abound (Villegas de Gante and Cervantes 2011; Cervantes and Villegas de Gante 2012; Grass *et al.* 2013; Grass and Cesín 2014; Yescas 2013). However, studies on Adobera cheese are scarce and mainly oriented to evaluate its microbiological safety (Torres *et al.* 2012; Ruvalcaba *et al.* 2016; Ruvalcaba *et al.* 2017). This cheese is mostly produced in the municipalities of Los Altos de Jalisco, a region with humid, subtropical climate and one of the biggest milk producer regions in Mexico (Cervantes *et al.* 2016). A fresh to lightly ripened type of *Pasta Filata* cheese, Adobera (Figure 1), is made from raw Holstein cow milk and acidified by its native lactic acid bacteria (LAB). Adobera cheese production protocol (Figure 2) comprises the following operations: raw milk reception, standardisation to 3% milk fat (not frequently made), rennet coagulation (1:10 000 rennet:milk ratio), cutting of coagulum (it used to be performed using wooden shovel but recently it has been replaced by stainless steel lyres), stirring (to brake the coagulum and promote syneresis) and removal of whey. A crucial step to produce Adobera cheese is cheddaring (18–24 h at room temperature or under refrigeration at 4–7 °C), which causes a drastic decrease in pH. Finally, acidified curd is salted (1–2% NaCl), milled, moulded (using moulds made of stainless steel, plastic or, to a lesser extent, wood) and pressed (usually with screw press) for 1–7 h. After the elaboration process, cheese is lightly ripened for up to 96 h and then packed in polyethylene plastic film, labelled and kept at 4 °C until distributed or sold (Cervantes *et al.* 2008; Villegas de Gante *et al.* 2014). The final product exhibits a whitish-to-yellowish colour, a grainy paste that becomes firmer when slightly aged, and, because of its low pH, melts upon heating (Cervantes *et al.* 2008; Cervantes and Villegas de Gante 2012). Recently, Murugesan *et al* (2018) identified melting and nonmelting Adobera cheese varieties providing information on both bacterial (*Streptococcus* sp., *Lactococcus* sp., *Lactobacillus* sp.) and fungal (*Saccharomyces* sp., *Scheffersomyces* sp., *Galactomyces* sp.) communities found on them; proteobacteria from the genus *Marinomonas* sp. were also abundant, especially in the nonmelting type. Cheese composition was also reported, ranging from 39.24 to 44.28%, 38.86 to 47.72% and 34.81 to 39.12% for moisture, fat in dry matter and protein in dry matter, respectively. However, no data on cheese pH and other important physicochemical parameters were given. As authenticity has become a major food trend, Adobera cheese consumption and marketing area have been increasing in recent times (Cervantes *et al.* 2016). Consequently, it is essential to identify key physicochemical features of raw-milk cheeses as a preliminary step towards developing safer pasteurised alternatives. Thus, this study was aimed to depict the gross composition, free amino acid (FAA) content as a ripening index, instrumental colour, texture profile, water activity, sensory acceptability and pH of commercial raw-milk Adobera cheeses from Los Altos de Jalisco region, analysing possible seasonal and brand differences.

MATERIALS AND METHODS

Cheese samples were obtained from five cheese factories from Los Altos de Jalisco region. Only factories manufacturing raw-milk cheeses, containing no food additives and prepared according to the traditional procedure described above (Cervantes *et al.* 2008; Villegas de Gante *et al.* 2014) were selected. As cheese characteristics could be subjected to seasonal variations, sample collection was done in both dry (November to May) and rainy (June to October) seasons. Cheese samples from three different processing batches were randomly selected from each manufacturer and kept under refrigeration (4 °C) for no longer than 48 h until used.

Cheese composition

Gross composition was determined in duplicate on 3–4 days ripened Adobera cheeses. Moisture (oven drying at 102 ± 1 °C), fat (Gerber method) and protein (Kjeldahl method) contents were analysed according to standard methods (Wehr and Frank 2004).

Free amino acid content

Free amino acid content of Adobera cheese samples was determined as a proteolysis indicator measuring their colorimetric reaction with the Cd-ninhydrin reagent (Wick *et al.* 2004). Reaction mixtures were deposited in microtiter plates and measured in a Multiscan™ FC spectrophotometer (Thermo Scientific, Waltham, MA, USA) at 490 nm; FAA concentration was calculated from the absorbance values based on a calibration curve prepared with a standard leucine (Leu) solution. Samples were analysed with duplicates and results were expressed as mmol of Leu per g of moisture-free cheese.

pH

Cheese pH was measured with a Denver™ B-10 potentiometer (Denver instrument, NY) equipped with a previously calibrated flat-tip electrode. Ten grams of finely grated Adobera cheese was mixed with 20 mL of distilled water and pH measurements were made in duplicate from the supernatant.

Figure 1 Artisanal Adobera cheese from Los Altos de Jalisco, México. [Colour figure can be viewed at wileyonlinelibrary.com]

Water activity

Samples of each cheese (10 g) were finely grated and used to determine water activity (Aw) in duplicate using a previously calibrated Aqualab™ Series 3 dew-point hygrometer (Decagon, Pullman, WA) (AOAC 1996).

Cheese surface colour analysis

Tristimulus colour was determined in 4 × 5 cm rectangular cheese sections using a Colorflex EZ (HunterLab™, Reston, VA, USA) colorimeter in the Hunter *L*, *a*, *b* colour space (where *L* = brightness, *a* = red–green, *b* = blue–yellow), with a D65 illuminant and 10° observer angle. Four measurements of each cheese piece were collected, two corresponding to its rind and two from its internal section. Hue angle and chroma values were calculated as the inverse tangent of b^*/a^* ratio and as $(a^2 + b^2)^{1/2}$, respectively (Wadhwani and McMahon 2012).

Texture profile analysis

Texture profile analysis of cheese was carried out in a TA.XT Plus™ texturometer (Stable MicroSystem Ltd., Surrey, UK) using cylindrical samples (2.0 cm high and 1.6 cm diameter). Samples were compressed twice at 50% height with a 2.4 cm diameter cylindrical probe at 3 mm/s, with a 5 s delay between compressions. Hardness, cohesiveness, springiness and resilience values were calculated from the corresponding force vs distance curves, while chewiness was calculated as the product of hardness, cohesiveness and springiness with the software of the device (Texture Exponent 32) (Delgado *et al.* 2011).

Sensory evaluation

In order to obtain basic information about the sensory characteristics of Adobera cheese, a consumer acceptability test was conducted. Commercial Adobera cheese samples from rainy season were obtained from the same cheese factories and evaluated. All cheeses had been ripened for 3 days at the time of evaluation. Visual impression, tactile texture, aroma, taste, buccal texture and overall impression of Adobera cheese were evaluated using a nonstructured 9-cm hedonic scale (0 = dislike extremely, 9 = like extremely). (Pedrero and Pangborn 1997; Stone *et al.* 2012; Civille and Carr 2015). The evaluation was conducted in four rounds (1 randomised sample per round) with 28 untrained panellists including both students and staff members from our institution and cheesemakers (men and women, age range of 20–45 years). All panellists were preselected as regular (at least weakly) Adobera cheese consumers. Each round, the panellist received a wedge-shaped cheese portion for visual evaluation and four cubic-shaped portions (1.5 cm^3) for tactile texture, aroma, taste and buccal texture evaluation; cheese samples were tempered at 25 °C for 1-h prior to evaluation in individual booths using white fluorescent light. Unsalted crackers and water were provided for mouth rinsing between samples.

Statistical analysis

A general linear model (GLM) analysis followed by Tukey's pairwise mean comparisons ($P < 0.05$) was conducted on collected data in SAS™ 9.0 statistical package (SAS Institute Inc., NC, USA) to assess brand and seasonal differences between cheese samples. A correlation procedure was performed to identify associations between cheese attributes. Sensory data were analysed by one-way ANOVA test with Tukey's test for pairwise comparisons ($P < 0.05$) using the same statistical software. The graphs obtained from the texture profile analysis of the cheeses were analysed in Origin® ver. 8.0 software (OriginLab, Northampton, MA, USA).

RESULTS AND DISCUSSION

Adobera cheese is a staple of the central-western Mexican cuisine; Villegas de Gante *et al.* (2014) reported that cheesemakers in this region processed an average daily volume of 4700 L of milk, mostly used for Adobera cheese production, with yields ranging from 9 to 12 g/100 g of milk. Cheeses used in this study came from both small to medium

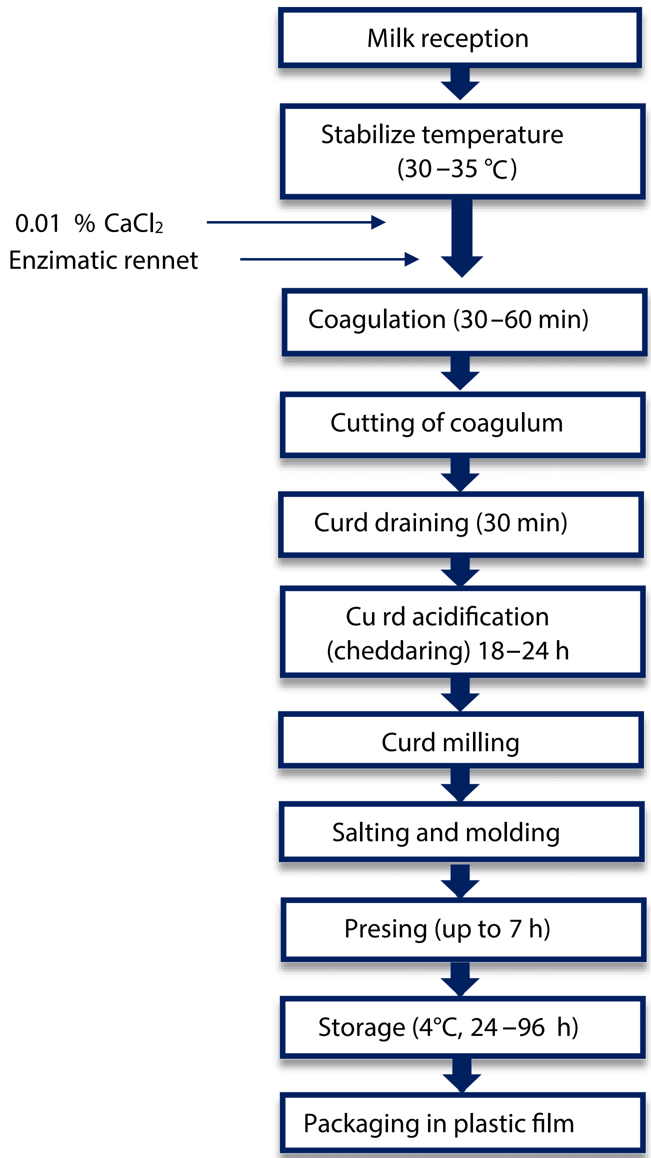

Figure 2 Generalized flow chart of artisanal Adobera cheese from Los Altos de Jalisco production. [Colour figure can be viewed at wileyonlinelibrary.com]

scale production sites using average milk volumes between 200 L and 35 000 L daily. The making procedure followed for preparing all sampled cheeses in the five chosen sites was very similar and complied with the standard protocol previously described (Cervantes *et al.* 2008; Villegas de Gante *et al.* 2014). The reported shelf life of the cheeses used ranged from 15 to 40 days. Although quality controls are not always implemented, most producers confirmed that they quantified fat, protein and moisture contents, freezing point and somatic cell count upon receipt on the milk used to produce cheese; besides, milk was checked for absence of antibiotics (data not shown).

Cheese composition

Composition data and physicochemical properties of sampled Adobera cheeses from both dry and rainy seasons are shown in Table 1. According to the results, Adobera cheese could be defined as a semihard, unripened/fresh cheese, based on its moisture content on a fat-free basis (MFFB, 66%) (CODEX STAN 283-1978). Fat and moisture were the most variable components in cheese samples, ranging from 36.43% to 49.21%, and 37.73% to 48.35%, respectively. Significant differences ($P < 0.05$) in fat content were observed between brands; however, there was no significant difference in the average content of this parameter between seasons. Meanwhile, average moisture content in cheese was significantly ($P < 0.05$) higher in dry season cheeses; cheeses from brand 5 stood out as the difference in moisture content between dry and rainy seasons on cheese was close to 8%. Besides, significant differences between the brands in cheese composition were observed ($P < 0.05$). Differences in cheese composition between brands might be attributed to slight modifications in the cheesemaking protocol (including curd cutting time and rate and extent of syneresis) or seasonal variations in cheese milk composition.

Dry season samples exhibited significantly ($P < 0.05$) higher average pH values (5.18) than those of rainy season samples (5.09); the pH of the sampled cheeses ranged from 5.05 to 5.36 and from 4.93 to 5.21 in dry and rainy seasons, respectively; however, only cheeses from brand 1 showed significant pH differences between seasons. The pH in raw-milk cheese depends on several factors, including milk microbiota and cheese composition (which is greatly affected by variations in the making procedure). In Mexico, raw milk usually comes from small-scale, family-owned farms, (grass-fed cattle supplemented mainly with cutting-forages, corn silage and grain –based concentrates in the stable); the prevalence of inadequate hygiene practices during milk production has been proven to negatively affect milk quality microbial wise (Cervantes *et al.* 2001; Ruvalcaba *et al.* 2011). During the rainy season, an increase in humidity and average temperature favours microbial proliferation; thus, lower pH values are usually expected. In most cheese types, remaining lactose in curd cheese is converted to lactic and other organic acids, and the lactic acid:milk buffering compounds ratio determine cheese pH. Acid production rate has an additional effect on cheese pH, as it could enhance syneresis during curd handling and pressing, resulting in greater losses of moisture and colloidal calcium phosphate (Walstra *et al.* 2006). Variations in artisanal cheese pH may also be related to a more heterogeneous bacterial population in raw milk compared to pasteurised cheese milk, and, consequently, with a greater exogenous proteolytic and lipolytic activity, mostly attributed to native LAB. Low pH values (especially below 5.0) in artisanal cheeses might be a useful factor for pathogen control (Torres *et al.* 2012; Ruvalcaba *et al.* 2018).

Table 1 Physicochemical composition of different artisan Adobera cheese brands from Los Altos de Jalisco*

Brand	*Season*	*Protein† (%, wt/wt)*	*Fat† (%, wt/wt)*	*Water content (%, wt/wt)*	*Water activity*	*pH*	*FAA† (mmol/g)*
1	Dry	$33.42^{a,A,B}$ (±4.17)	$42.74^{b,B}$ (±4.86)	$42.15^{a,B}$ (±1.99)	$0.968^{a,A}$ (±0.004)	$5.36^{a,A}$ (±0.09)	$0.36^{b,C}$ (±0.11)
	Rainy	$34.81^{a,A}$ (±3.72)	$44.09^{a,A}$ (±2.98)	$40.89^{a,B}$ (±3.21)	$0.941^{b,C}$ (±0.005)	$5.18^{b,A,B}$ (±0.05)	$0.45^{a,A,B}$ (±0.28)
2	Dry	$30.64^{b,A,B}$ (±0.04)	$36.43^{b,C}$ (±2.468)	$48.35^{a,A}$ (±1.16)	$0.954^{a,A,B}$ (±0.007)	$5.06^{a,B}$ (±0.04)	$0.53^{a,A}$ (±0.17)
	Rainy	$35.61^{a,A}$ (±3.06)	$40.43^{a,A}$ (±6.44)	$47.47^{b,A}$ (±2.37)	$0.953^{a,A}$ (±0.003)	$5.01^{a,B,C}$ (±0.11)	$0.57^{a,A}$ (±0.37)
3	Dry	$30.06^{a,B}$ (±6.33)	$42.81^{a,B}$ (±1.62)	$44.37^{a,B}$ (±1.31)	$0.969^{a,A}$ (±0.002)	$5.18^{a,B}$ (±0.04)	$0.37^{a,B,C}$ (±0.12)
	Rainy	$36.82^{a,B}$ (±2.34)	$41.51^{a,A}$ (±5.07)	$41.78^{a,B}$ (±3.79)	$0.947^{b,A,B}$ (±0.002)	$5.21^{a,A}$ (±0.09)	$0.38^{a,B}$ (±0.16)
4	Dry	$36.45^{A,B}$ (±5.91)	49.21^{A} (±2.47)	$45.50^{A,B}$ (±3.95)	0.947^{B} (±0.001)	5.05^{B} (±0.01)	0.32^{C} (±0.11)
	Rainy	NA	NA	NA	NA	NA	NA
5	Dry	$39.25^{a,A}$ (±3.12)	$43.84^{a,B}$ (±1.78)	$45.52^{a,A,B}$ (±0.88)	$0.955^{a,A,B}$ (±0.009)	$5.20^{a,A,B}$ (±0.04)	$0.46^{b,A,B}$ (±0.11)
	Rainy	$37.57^{b,A}$ (±1.92)	$41.36^{a,A}$ (±0.57)	$37.73^{b,B}$ (±0.01)	$0.945^{a,B,C}$ (±0.003)	$4.93^{b,C}$ (±0.08)	$0.63^{a,A,B}$ (±0.31)
Dry season		34.25^{a} (±5.77)	42.27^{a} (±4.71)	45.13^{a} (±2.86)	0.958^{a} (±0.009)	5.18^{a} (±0.13)	0.42^{b} (±0.15)
Rainy season		35.92^{a} (±2.87)	41.71^{a} (±4.82)	43.32^{b} (±4.44)	0.947^{b} (±0.005)	5.09^{b} (±0.14)	0.50^{a} (±0.29)
Average composition		34.96 (±3.40)	42.49 (±3.14)	43.75 (±2.07)	0.953 (±0.004)	5.14 (±0.06)	0.46 (±0.22)

^{a,b}Means between seasons of each brand with different superscripts are different ($P < 0.05$). ^{A,B,C}Brands in the same season with different superscripts are different ($P < 0.05$). NA: Data not available.*Values reported as a percentage on the dry basis.†Results are expressed as mean standard deviation.

As it happened with pH, dry season samples displayed significantly ($P < 0.05$) higher average Aw values (0.958) than those of rainy season samples (0.947), with only brands 1 and 3 exhibiting seasonal variations. As raw-milk cheese consumption could represent a health hazard, factors such as pH and Aw, along with LAB competition, are of key importance for controlling pathogen survival in lightly ripened cheeses such as Adobera. Differences in Aw and, to a lesser degree, pH between rainy and dry seasons cheeses could be related to their salt and FAA content. While salt content in directly salted cheeses such as Adobera is mostly affected by pressing, changes in FAA concentration arises from variations in native and exogenous enzymatic activity usually affected by cheese ripening conditions and microbiota which, in turn, can be influenced by environmental seasonality.

Free amino acid content in cheese is used as an indicator of proteolysis induced by native milk enzymes (including plasmin and cathepsin D), coagulant agent (like chymosin and other microbial proteinases commonly used) and cheese microbiota (Kelly *et al.* 2006; Law and Tamine 2010). As shown in Table 1, rainy season cheeses for all brands exhibited a higher FAA content than their dry-season counterparts, although the difference between means was only significant ($P < 0.05$) for brands 1 and 5. The average FAA content for dry season cheeses was 0.42 mmol/g vs 0.54 mmol/g cheese (dry basis) for rainy season cheeses. Because of its artisanal process and the milk used, a high incidence of both starter and nonstarter LAB and several contaminant microorganisms could directly contribute to FAA content in Adobera cheese by increasing microbial contribution to peptidolysis and proteolysis. As previously stated, seasonality may affect cheese proteolysis rate because of a higher average environmental temperature and humidity. Modifications in this hydrolytic reaction could modify quality characteristics of the final product, as proteolysis is considered the most complex and important primary biochemical change affecting texture and flavour formation in cheese (O'Brien *et al.* 2017). Free amino acid concentrations resemble those recently reported by Sulejmani and Hayaloglu (2017) for an artisanal, white-brined, raw-milk cheese when lightly ripened (0.4 mg Leu/g cheese). Although Adobera cheese is only slightly aged, some peculiarities of its making procedure, including the prolonged curd acidification, and its high humidity content are factors that favour the FAA accumulation, reaching relatively high levels of proteolysis, which could be associated with its characteristic intense flavour.

Texture Profile Analysis (TPA)

Texture profiles of Adobera cheese samples are shown in Table 2. Significant differences ($P < 0.05$) in cheese texture attributes were found between sampling seasons for all attributes evaluated; in general, dry season cheeses were harder and more elastic, resilient and cohesive than their rainy-season counterparts; in consequence, chewiness, the overall work required for the double compression, was also higher in dry season cheeses. Besides, all texture parameters

Table 2 Texture profile analysis of different artisan Adobera cheese brands from Los Altos de Jalisco, Mexico*

Brand	*Season*	*Hardness (kg)*	*Cohesiveness (−)*	*Springiness (−)*	*Chewiness(kg)*	*Resilience (−)*
1	Dry	$1.76^{a,A}$ (±0.42)	$0.58^{a,A}$ (±0.03)	$0.76^{a,A}$ (±0.06)	$0.77^{a,A}$ (±0.23)	$0.22^{a,A,B}$ (±0.02)
	Rainy	$1.62^{a,A}$ (±0.21)	$0.32^{b,B}$ (±0.10)	$0.56^{b,A}$ (±0.08)	$0.31^{b,A}$ (±0.17)	$0.13^{b,A}$ (±0.04)
2	Dry	$1.60^{a,A,B}$ (±0.40)	$0.41^{a,B}$ (±0.07)	$0.69^{a,B}$ (±0.10)	$0.47^{a,B}$ (±0.20)	$0.27^{a,A}$ (±0.16)
	Rainy	$1.15^{b,B,C}$ (±0.36)	$0.40^{a,A}$ (±0.07)	$0.58^{b,A}$ (±0.06)	$0.28^{b,A}$ (±0.12)	$0.15^{a,A}$ (±0.03)
3	Dry	$0.86^{a,C}$ (±0.39)	$0.57^{a,A}$ (±0.14)	$0.70^{a,B}$ (±0.12)	$0.32^{a,B,C}$ (±0.16)	$0.23^{a,A,B}$ (±0.07)
	Rainy	$0.85^{a,C}$ (±0.22)	$0.39^{b,A,B}$ (±0.06)	$0.61^{b,A}$ (±0.04)	$0.20^{b,A,B}$ (±0.04)	$0.15^{b,A}$ (±0.03)
4	Dry	1.93^{A} (±0.40)	0.57^{A} (±0.03)	0.77^{A} (±0.15)	0.91^{A} (±0.37)	$0.24^{A,B}$ (±0.02)
	Rainy	NA	NA	NA	NA	NA
5	Dry	$1.14^{a,B,C}$ (±0.27)	$0.38^{a,B}$ (±0.05)	$0.52^{a,B}$ (±0.08)	$0.23^{a,C}$ (±0.10)	$0.23^{a,B}$ (±0.03)
	Rainy	$1.40^{a,A,B}$ (±0.22)	$0.15^{b,C}$ (±0.02)	$0.38^{b,B}$ (±0.06)	$0.08^{b,B}$ (±0.02)	$0.08^{b,B}$ (±0.01)
Dry season		1.43^{a} (±0.54)	0.50^{a} (±0.12)	0.68^{a} (±0.22)	0.51^{a} (±0.40)	0.22^{a} (±0.09)
Rainy season		1.20^{b} (±0.38)	0.33^{b} (±0.17)	0.55^{b} (±0.11)	0.22^{b} (±0.13)	0.13^{b} (±0.05)
Average texture		1.37 (±0.32)	0.43 (±0.08)	0.62 (±0.07)	0.39 (±0.14)	0.18 (±0.06)

^{a,b}Means between seasons of each brand with different superscripts are different ($P < 0.05$). ^{A,B,C}Brands in the same season with different superscripts are different ($P < 0.05$). NA: Data not available. *Values reported as a percentage on the dry basis. Results are expressed as mean standard deviation.

exhibit significant ($P < 0.05$) differences between brands, cheese hardness values ranged from 0.86 to 1.93 kg and 0.85 to 1.62 kg; cohesiveness ranged from 0.38 to 0.58 and 0.15 to 0.40, and springiness ranged from 0.52 to 0.77 and 0.38 to 0.58 for dry season and rainy season cheeses, respectively. Such differences could be related to variations in cheese composition, as it has been proven elsewhere. Álvarez *et al.* (2007) reported both positive and negative correlations between goat cheese chemical composition and selected instrumental texture parameters; hardness was reported to be positively correlated to fat and negatively to water content and on the contrary, both cohesiveness and springiness were positively correlated to water content and negatively correlated with both fat and protein contents. The authors considered that as water content augmented, the force exerted by the internal cheese bonds was stronger thus increasing cheese cohesiveness. Seasonal differences between Adobera cheese samples could be strongly associated with differences in cheese milk composition and milking and handling practices, which in turn affect Adobera cheese composition. Similarly, Lawlor *et al.* (2001) reported significant correlations between cheese texture and composition attributes; for example, protein content in cheese positively correlated with firmness and chewiness but negatively with gumminess, while water content in cheese was positively correlated to chewiness, but negatively with gumminess. Fat content was reported to negatively affect gumminess and chewiness values. Some other components in the cheese such as calcium and ash can favour attributes such as firmness, gumminess and chewiness, while pH also exhibited a negative correlation with firmness and chewiness scores. In this study, through correlation analysis, we observed that some texture attributes, including chewiness, springiness and resilience, could be defined by FAA content ($P < 0.05$), while FAA was correlated with water content in the cheese ($P < 0.05$). Water content also exhibited correlations with colour profile of the cheese, negatively impacting on the L, a and b scores, and consequently on chroma values, but positively on the hue values of colour ($P < 0.05$). Positive correlations were also observed between pH and cohesiveness, springiness and resilience of cheese samples. In that context, we previously observed, for Adobera cheese, that LAB content had a positive effect in pH reduction, correlated to a higher FAA concentration while playing an important role on the sensory profile of cheese; thus, LAB content showed a negative correlation with gumminess, resilience and FAA content; meanwhile, FAA was negatively correlated with pH, resilience, gumminess, chewiness and hardness in Adobera cheese (Ruvalcaba *et al.* 2016); which strengthens the hypothesis of pH as determinant for Adobera cheese control quality. Cheese pH also controls the dissolution rate of colloidal calcium phosphate (CCP) from the casein micelles.

Cheese colour

Colour scores for Adobera cheese samples are shown in Table 3. Rainy season Adobera cheeses were brighter and yellower than cheeses from the dry season; average hue scores were 81° to 83° for dry and rainy season cheeses, respectively; meanwhile, chroma for rainy season cheeses was higher than those of dry season. Hue values close to 90° in cheese indicates that it possesses an ivory to a yellowish colour. Correlation values shown that fat content in cheese was negatively correlated with luminosity (L*) scores

Table 3 Colour values of different artisan Adobera cheese brands from Los Altos de Jalisco, Mexico*

Brand	*Season*	L	a	b	*Colour (°hue)*	*Chroma*
1	Dry	$84.51^{a,B}$ (±1.37)	$2.59^{b,A}$ (±0.49)	$19.29^{b,B}$ (±1.52)	$82.36^{a,B}$ (±1.37)	$19.47^{a,B}$ (±1.53)
	Rainy	$84.93^{a,C}$ (±0.49)	$4.90^{a,A}$ (±2.03)	$25.66^{a,A}$ (±1.50)	$79.21^{b,B}$ (±4.45)	$26.19^{b,A}$ (±1.48)
2	Dry	$89.46^{a,A}$ (±0.70)	$1.44^{b,B}$ (±0.13)	$16.74^{b,C}$ (±1.78)	$85.03^{a,A}$ (±0.87)	$16.80^{a,C}$ (±1.77)
	Rainy	$89.19^{a,A,B}$ (±0.65)	$2.50^{a,B}$ (±0.18)	$19.66^{a,B}$ (±1.55)	$82.73^{b,A}$ (±0.44)	$19.82^{b,B}$ (±1.55)
3	Dry	$89.02^{b,A}$ (±0.95)	$2.53^{b,A}$ (±0.37)	$15.86^{b,C}$ (±1.47)	$80.90^{a,C}$ (±1.44)	$16.06^{a,C}$ (±1.48)
	Rainy	$90.05^{a,A}$ (±0.70)	$3.30^{a,B}$ (±0.24)	$20.18^{a,B}$ (±0.71)	$80.72^{a,B}$ (±0.55)	$20.45^{b,B}$ (±0.72)
4	Dry	84.47^{B} (±1.23)	2.55^{A} (±0.37)	21.77^{A} (0.77)	83.31^{B} (±1.06)	21.92^{A} (±0.75)
	Rainy	NA	NA	NA	NA	NA
5	Dry	$90.08^{a,A}$ (±0.69)	$1.73^{b,B}$ (±0.17)	$15.05^{b,C}$ (±1.06)	$83.44^{a,B}$ (±0.69)	$15.15^{a,C}$ (±1.06)
	Rainy	$88.77^{b,B}$ (±2.09)	$2.89^{a,B}$ (±0.09)	$17.74^{a,C}$ (±0.86)	$80.73^{b,A,B}$ (±0.50)	$17.97^{b,C}$ (±0.85)
Dry season		87.78^{a} (±2.62)	2.13^{b} (±0.59)	17.42^{b} (±2.69)	83.00^{a} (±1.79)	17.56^{a} (±2.70)
Rainy season		88.51^{b} (±2.14)	3.30^{a} (±1.23)	20.63^{a} (±2.93)	81.02^{b} (±2.32)	20.91^{b} (±3.05)
Average		88.09 (±2.38)	2.62 (±0.91	18.77 (±2.81)	82.17 (±2.05)	19.24 (±2.88)

[a,b]Means between seasons of each brand with different superscripts are different (P < 0.05). [A,B,C]Brands in the same season with different superscripts are different (P < 0.05). NA: Data not available.*Values reported as a percentage on the dry basis. Results are expressed as mean standard deviation.

and water content could negatively affect red and green (a^*), and yellow and blue (b^*) proportions and therefore, hue and chroma scores ($P < 0.05$). Slight differences found between brands and seasons could also be associated with higher carotene contents in diets of dairy cows (Hernández *et al.* 2010). Moreover, cheese colour could also be influenced by the integrity of casein particles in cheese and the extent of proteolysis; these parameters, that have also been proven to affect other cheese quality features such as body, texture and melt/stretch, are influenced by both physicochemical features (ionic strength) and making procedure/ripening characteristics, such as pH development and temperature (Singh *et al.* 2003; Gómez *et al.* 2015). In overall, cheese colour is a key parameter that helps define cheese traits, thus aiding to differentiate Adobera from other cheese varieties.

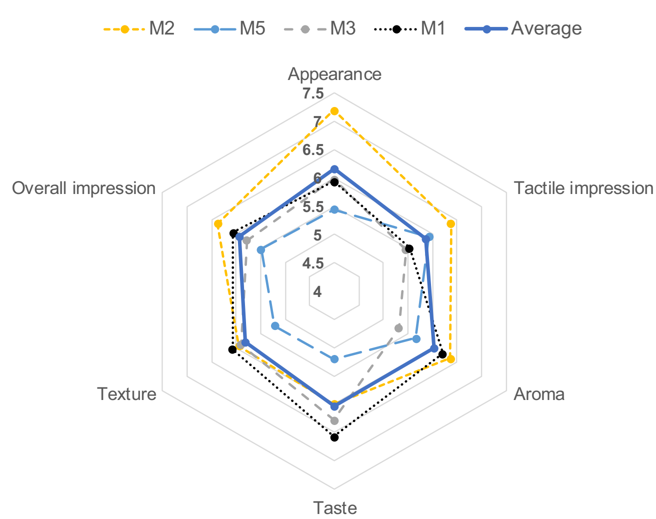

Figure 3 Mean scores of sensory acceptability test of different artisanal Adobera cheese brands from Los Altos de Jalisco, Mexico. [Colour figure can be viewed at wileyonlinelibrary.com]

Sensory analysis

Acceptability test results (Figure 3, Table 4) showed significant differences between cheese brands for appearance and taste ($P < 0.05$), but not for tactile impression, aroma, texture and overall impression. The observed average scores for all the attributes ranged from 5.2 to 7.2. Cheese 2 obtained a significantly higher score for appearance and the highest mean scores for tactile impression, aroma, texture and overall impression meanwhile cheese brand number 1 obtained the best mean score for taste. Correlation analysis (Figure 4) showed that appearance was mainly positive correlated ($r \geq 0.75$) to colour, cohesiveness, chewiness, resilience, water content, water activity and overall impression; tactil impression was positively correlated to colour, fat, water activity, FAA and appearance; but negatively with pH. Cheese aroma was also positively correlated to chewiness and overall impression but negatively with protein content. Meanwhile, cheese taste positively correlated with chroma scores, cohesiveness, springiness, chewiness, resilience, fat, pH and texture; but negatively with protein and FAA content. Perceived texture was positively correlated to instrumental cohesiveness, springiness, chewiness and resilience values, as well as to water content and pH, but negatively with protein and FAA content. Finally, correlation analysis showed that overall impression of cheese is mainly influenced by

Table 4 Sensory acceptability for different artisan Adobera cheese Brand from Los Altos de Jalisco

	Cheese sample			
Attributes	*M1*	*M2*	*M3*	*M5*
Appearance	5.9 ± 2.0^{b}	7.2 ± 1.3^{a}	6.0 ± 1.9^{b}	5.4 ± 2.1^{b}
Tactile impression	5.5 ± 2.0^{a}	6.4 ± 2.2^{a}	5.5 ± 2.3^{a}	5.9 ± 2.0^{a}
Aroma	6.2 ± 1.9^{a}	6.4 ± 1.8^{a}	5.3 ± 2.1^{a}	5.7 ± 2.0^{a}
Taste	6.6 ± 1.9^{a}	$6.0\pm1.8^{a,b}$	$6.3\pm1.8^{a,b}$	5.2 ± 2.2^{b}
Texture	6.1 ± 2.1^{a}	5.9 ± 1.5^{a}	5.9 ± 2.2^{a}	5.2 ± 2.2^{a}
Overall impression	6.1 ± 1.4^{a}	6.4 ± 1.2^{a}	5.8 ± 1.6^{a}	5.5 ± 1.7^{a}

[a,b]Different superscript letters in the same line indicate significant differences between means ($P < 0.05$).

cohesiveness, springiness, chewiness, resilience, water content, appearance, aroma and texture; but can be negatively affected by protein content.

CONCLUSIONS

Quality attributes of Adobera cheese, an artisanal Mexican cheese, could be affected by small variations in the make procedure and seasonality. Adobera can be described as a yellowish to ivory semihard, unripened/fresh cheese. Both texture and composition of Adobera cheese were influenced by season. Rainy season cheeses exhibited lower pH values in comparison to those produced during the dry season, resulting in a decrease in proteolysis extent and the scores of most instrumental texture attributes (hardness, cohesiveness, springiness, chewiness and resilience). Acceptability test showed important similarities in sensory impressions of different Adobera cheese brands, with only appearance and taste exhibiting significant differences. The characterisation of Adobera cheese attributes will help to better define their most sought-after features and the standardised manufacturing procedure needed to develop them.

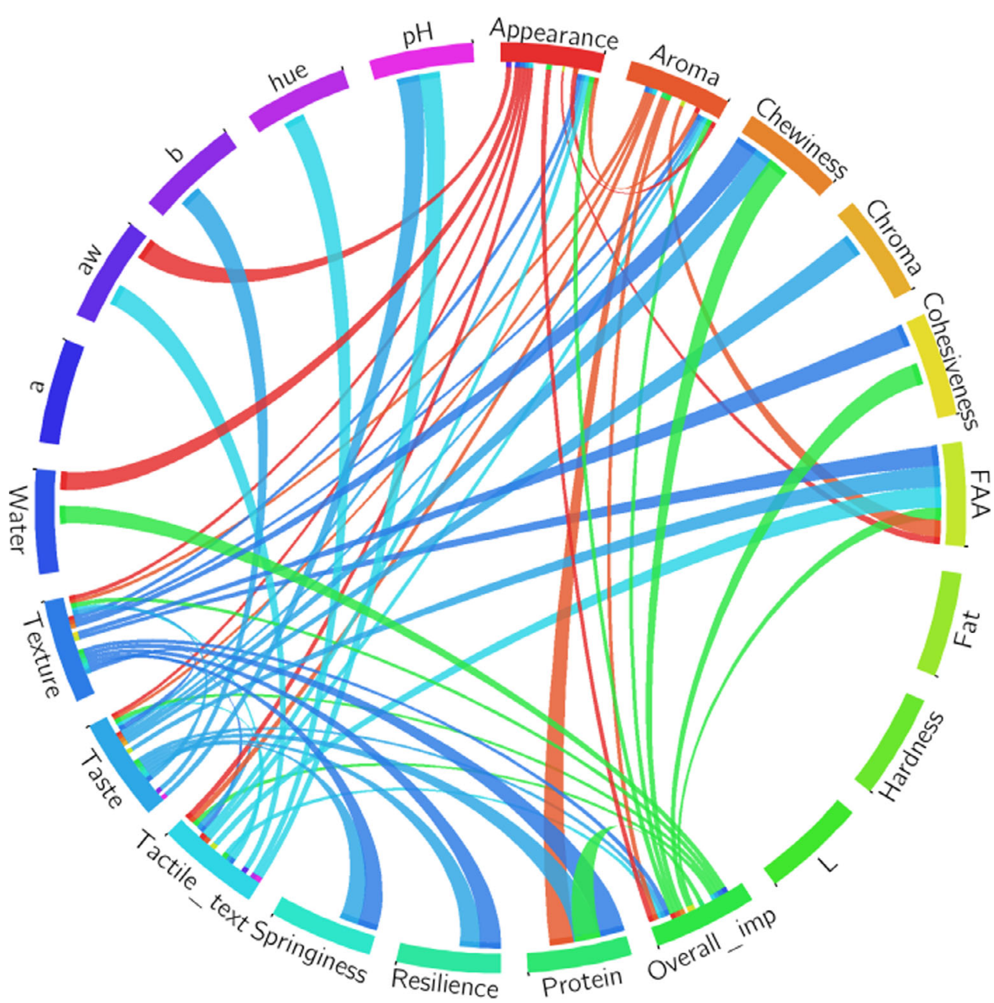

Figure 4 Schematic representation of Pearson correlations between sensory attributes of artisanal Adobera cheese with its texture and composition. Correlations ($r \geq 0.75$) are represented by bonds. Stronger correlations are represented by thicker bonds (Created with: Circos Table Viewer v0.63-9). [Colour figure can be viewed at wileyonlinelibrary.com]

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