Chemical, Physical, and Sensorial Characteristics of “Terrincho” Ewe Cheese: Changes During Ripening and Intravarietal Comparison

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ABSTRACT

The objectives of this study were to monitor the changes in chemical [moisture, acidity, pH, and water activity (a_w)] and physical (color and texture) parameters of “Terrincho” ewe cheese during 60 d of ripening, and to determine the correlations between the changes in instrumental texture and color parameters and the ripening time of the product. Intravarietal comparison of Terrincho ewe cheese from 5 different dairy plants was performed by evaluation of mechanical parameters from texture profile analysis (TPA) and color parameters in terms of CIELAB color space (L^* , a^* , and b^*). In addition to mechanical and color tests, composition analyses and sensory tests were performed. The results were evaluated with statistical methods (single valued and multivariate analysis). During the first 20 d of ripening, an increase in hardness, fracturability, gumminess, chewiness, and yellowness occurred. Simultaneously, adhesiveness, resilience, L^* (inside cheese, “i” and external “e”), and cohesiveness decreased. After 20 d of ripening hardness, fracturability, gumminess, and chewiness decreased and cohesiveness increased. The ripening time of Terrincho cheeses can be estimated with 6 variables: L^* (external, e), L^* (i), b^* (inside cheese, i), hardness, a^* (i), chewiness, and a constant. The estimation error was 4.2 d. Evaluation of composition, pH, texture profile analyses, color, and related sensory characteristics of Terrincho cheeses from 5 different dairy plants (with 30 d of ripening) revealed correlations between these parameters.

(Key words: texture profile analysis, color, ewe cheese, ripening)

Abbreviation key: a_w = water activity, CATPCA = categorical principal component analysis, PC1 = first component, PC2 = second component, PCA = principal

components analysis, PDO = Protected Denomination of Origin, TPA = texture profile analysis.

INTRODUCTION

Texture and color are important criteria used to evaluate cheese quality; these 2 parameters are often a primary consideration of consumers when making purchasing decisions. This is especially true for “Protected Denomination of Origin” (PDO) cheeses, which often represent a large variety of textures and tastes. Ensuring consistently high-quality cheeses continues to be a challenge for people involved in the chain of production. Thus, there is an increasing need for characterization of PDO cheeses, including study of changes that occur during ripening and intravarietal comparison (Lebecque et al., 2001). For this reason, some research groups have carried out studies on chemical, physical, and sensory characteristics of different cheese varieties (Bertola et al., 2000; Bugaud et al., 2001; Lebecque et al., 2001; Romani et al., 2002; Gómez-Ruiz et al., 2002; Pilonel et al., 2002), helping to assess maturity and preventing such cheeses from adulterations and imitations.

Terrincho ewe cheese is a typical product of the north-eastern region of Portugal and is manufactured from raw “Churra da Terra Quente” ewe’s milk, according to the specifications of its Denomination of Origin Regulatory Board D.N. No. 293/93. Thus the area and conditions for “Terrincho” ewe cheese production are well established. This cheese undergoes a minimum of 30 d of ripening and its consumption has increased over the past few years. It is marketed in round blocks weighing approximately 1 kg. Its surface is smooth, flexible, dry, or slightly fatty to the touch, and its exterior and interior are uniformly light yellow in color. It is easy to cut, tender in the mouth, and its taste and smell is characteristically aromatic, succulent, and pleasantly salted.

Cheese texture may be defined as a composite sensory attribute resulting from a combination of physical properties and perceived by the senses of sight, touch, and

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hearing. Rheological mechanical properties are manifested by the reaction of food to a stress applied during consumption (e.g., squeezing between the fingers, manual cutting, and mastication). They comprise the following characteristics: hardness, cohesiveness, viscosity, springiness, chewiness, and gumminess. The mechanical properties are measured organoleptically by the pressure exerted on the cheese by a finger, knife or teeth, tongue, or the roof of the mouth during eating.

Cheese texture and cheese rheology are closely related in that many of the textural properties of cheese (such as the mechanical attributes texture) are determined by its rheological properties.

The rheological properties of a cheese depend on its structure. The 3 major constituents of cheese are casein, fat, and water. The structural differences between various types of cheese result from the effects of the differences in manufacturing procedures on the structure (Bara-Herczech et al., 2002). A good curd is a prerequisite to obtain a quality cheese; thus, milk coagulation is a major step of cheese manufacturing and largely determines the texture of the product (Lebecque et al., 2001).

The main parameters that have an effect on the physical properties of the curd are milk composition and the amount of rennet. During cheese manufacturing, the curd is cut into small pieces so that serum can drain away. The granules formed are pressed and aggregated, making a more compact and homogeneous structure with its own rheological properties.

The role of pH in cheese texture is particularly important because changes in pH are related directly to chemical changes in the protein network of the cheese curd. The influence of the water activity and salt content on the rheological properties of cheese is indirect. Decreases in water activity greatly decrease the rate of proteolytic activity in cheese. A high concentration of salt increases the osmotic pressure, diverting a significant quantity of water from the structural bonds of the casein network (Prentice et al., 1991).

Easily determinable texture parameters can be useful in the testing of the product and in the evaluation of ripening conditions as described by Bara-Herczech et al. (2001) when analyzing ewe cheeses mechanical parameters determined with a texture profile analyzer (TPA). With regard to the visual aspect, quality control involving color evaluation is carried out in numerous ways. Color perception differs from person to person, and depends on lighting and numerous other factors; many industries rely on human vision coupled with an instrumental system of color measurement. These instruments attempt to simulate the manner in which the average human eye sees the color of an object, under specified illumination conditions. The aims of this work

were: 1) to monitor changes in chemical (moisture content, acidity, pH, and water activity [a_w]) and physical (color and texture) characteristics of Terrincho cheese during the winter season, during 60 d of ripening; 2) to determine correlations between texture and color parameters and the ripening time of Terrincho cheese in order to estimate Terrincho cheese ripening time on the basis of such parameters; 3) to perform an intravarietal comparison of Terrincho cheeses from 5 different dairy plants according to its chemical, physical and sensory characteristics.

MATERIALS AND METHODS

Cheese Samples

In agreement with professionals (veterinarians, farmers, cheese makers, and marketing agents), 5 dairy plants (labeled B, V, R, T, and M) were selected for the quality and regularity of Terrincho cheese production. A total of 39 Terrincho ewe cheeses were manufactured including: 1) a batch of 24 Terrincho ewe cheeses used to study chemical, textural, and color parameters during ripening. From this batch, groups of 3 cheeses were picked after 0, 6, 12, 20, 30, and 60 d of ripening. At each ripening time, a fourth cheese was used for training the panelists; 2) another 4 batches of Terrincho ewe cheeses, 1 from each of the remaining dairy plants (B, V, R, T, and M), all produced during the same cheese-making season (winter) and ripened for 30 d (the minimum recommended ripening time). Three cheeses from each batch were used to study the physicochemical analysis and textural and color parameters. A fourth cheese within each batch was used for sensory analysis. Only 3 cheeses were available from the R dairy plant. Cheese samples were coded with a letter representing the respective dairy plant where they were manufactured, and a number.

During ripening, the cheeses were stored in a ripening chamber at 10 to 12°C and 88 to 89% relative humidity. All of the samples were ripened by the respective manufacturers; for each time, cheeses were sent to the laboratory in refrigerated boxes and analyzed immediately to monitor changes.

The average weights and volume of the cheeses ranged from 1.05 kg at 0 d to 0.707 kg at 60 d and 944 ml at 0 d to 540 ml at 60 d, respectively.

Physicochemical Analysis

The moisture, total protein content, NaCl, ash, and acidity were determined according to methods (AOAC, 2000a, 2000b, 2000c, 2000d). Fat content was determined according to ISO method (1972). The a_w was determined by a special apparatus (AW Sprint TH-500,

Novasina, Swiss) and pH value was determined at room temperature using a penetrometric electrode (Mettler-Toledo). Dry matter was evaluated using Scaltec instruments (Scaltec Instruments GmbH, Heiligenstadt, Germany).

Texture Analysis

In recent years, multifunctional texture test instruments have been developed which are easy to use and suitable for both imitative and empirical tests. In this work, the textural analysis was performed in a texturometer TA-Xt2i (Stable Micro Systems, Surrey, UK), with a load cell of 5 kg, by carrying out TPA.

Prior to TPA, a 0.5-cm layer was removed from the upper surface of the cheese to obtain a regular surface for probe penetration.

Testing conditions. Penetration tests were performed at $20 \pm 2^\circ\text{C}$ using a plastic cylindrical probe of 13 mm, a penetration depth of 20 mm, and 1 mm/s of crosshead speed. This test was done 5 times on each sample (1 on the middle and 4 on different parts of the cheese surface) and performed in triplicate.

Mechanical parameters. From the force vs. time texturograms 8 parameters were obtained: hardness (g), fracturability (g), adhesiveness (g.s), springiness (s), cohesiveness, gumminess (g), chewiness (g.s) and resilience. The interpretation of these texture parameters was made according to Armero and Collar (1997) and Bara-Herczegh et al. (2002).

Color Measurement

Color analyses were performed using a colorimeter CR 300 (Minolta, Osaka, Japan). The L^* , a^* , and b^* color measurements were determined according to the CIELAB color space, where L^* corresponds to light/dark chromaticity (changing from 0% dark to 100% light), a^* to green/red chromaticity (changing from -60% green to 60% red), and b^* to blue/yellow chromaticity (changing from -60% blue to 60% yellow). The instrument was calibrated with a white tile ($L^* = 97.10$, $a^* = -4.88$, $b^* = 7.04$) before the measurements.

Color determinations were made 5 times, 1 on the middle and 4 on different parts of cheese surface, before and after removing a 0.5-cm layer of upper surface.

Sensory Analysis

A panel composed of 7 members performed sensory analysis. Subjects were selected (2 sessions) for their sensory ability and trained (11 sessions) for descriptive analysis according to the guidelines in the ISO 11036:1994 standard texture profiles (ISO, 1994). Thus,

Figure 1. Changes in moisture and water activity (a_w).

before tasting the samples, screening and training were carried out in order to verify and discuss the use of texture attributes (Bárcena et al., 2000). Only those attributes whose variations were significantly perceived by the panelists were considered for the purpose of this study.

The following sensory attributes were assessed using a 7-point scale: intensity and homogeneity of color, elasticity when pressing with a finger, adhesiveness and fracturability when cutting with a knife, and hardness and adhesiveness when chewing.

Statistical Analysis

The averages and standard deviations were calculated for each parameter. Descriptive statistics, ANOVA, pairwise comparisons of mean values with Tukey's test, principal component analysis (PCA), and multiple regression were performed with SPSS for Windows version 11.5 (SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Changes in Physicochemical and Texture Characteristics During "Terrincho" Cheese Ripening

Physicochemical characteristics. Terrincho cheese samples from the M dairy plant used for studies during ripening had an average protein, fat content, NaCl, ash, of 40 g/100 g of DM, 50 g/100 g of DM, 5.5 g/100 g of DM, and 1.5 g/100 g of cheese, respectively.

Moisture and water activity showed significant differences during 60 d of ripening (Figure 1). These parameters greatly influence proteolytic activity in cheese.

Acidity increased during ripening, and pH decreased up to 30 d and increased slightly between 30 and 60 d, thus confirming the important metabolic activity of

Figure 2. Changes in acidity and pH during 60 d of ripening.

lactic acid bacteria (Figure 2). The decrease of pH values is related to texture parameters because no fusion of curd particles occurs until approximately pH 5.8 (Lawrence et al., 1986).

Texture Attributes of TPA

The mean values obtained for texture attributes of TPA during ripening together with ANOVA results are presented in Table 1.

Texture profile analysis revealed significant changes for fracturability, adhesiveness, cohesiveness, and resilience during 60 d of ripening as shown by F and P values of ANOVA. Hardness, fracturability, gumminess, and chewiness increased up to 20 d of ripening and afterwards decreased. A significant increase was observed between 12 and 20 d of ripening. Important changes in texture occurred after 20 d of ripening. At this time, pH decreased to 5.5. As the pH of cheese curd decreased, there was a concomitant loss of colloidal calcium phosphate from the casein submicelles and, below about pH 5.5, a progressive dissociation of the submicelles into smaller casein aggregates (Lebecque et al., 2001).

Cohesiveness decreased at the beginning of ripening, was maintained for up to 30 d of ripening, and increased significantly between 30 and 60 d. Maximal cohesiveness occurred between pH 5.2 and 5.8 (Lawrence et al., 1987).

In general, our results concerning texture changes during ripening were in good agreement with those described by Lawrence et al. (1987). Two distinct phases in texture development took place during cheese ripening. Initially, the rubbery texture of young cheese curd was converted into a smoother, more homogeneous product. After 20 d, a gradual change in texture was observed, as caseins suffer higher hydrolysis.

Table 1. Texture profile analysis, and color measurement, with ANOVA results during 60 d of ripening time.

Texture and color attributes ¹	Ripening time, d					ANOVA results	
	0	6	12	20	30	60	P
Hardness, g	915.4 ± 65.1 ^a	1417.0 ± 58.9 ^a	1578.1 ± 145.6 ^a	2871.4 ± 677.7 ^{bc}	1926.3 ± 392.5 ^{bc}	1810.8 ± 291.7 ^a	9.933
Fracturability, g	846.9 ± 77.8 ^a	1107.3 ± 258.1 ^{ab}	1491.0 ± 103.1 ^{ab}	2394.4 ± 458.4 ^c	1730.3 ± 303.5 ^{bc}	1549.2 ± 164.4 ^{ab}	11.65
Adhesiveness, g.s	-1393.8 ± 285.9 ^a	-887.7 ± 103.1 ^a	-1230.4 ± 65.3 ^a	-2778.4 ± 496.3 ^{bc}	-2448.1 ± 493.2 ^b	-3495.4 ± 53.2 ^c	24.96
Springiness	0.98 ± 0.00 ^a	0.97 ± 0.0 ^a	0.81 ± 0.14 ^a	0.97 ± 0.01 ^a	0.98 ± 0.01 ^a	0.84 ± 0.14 ^a	2.709
Cohesiveness	0.49 ± 0.00 ^{ac}	0.44 ± 0.01 ^b	0.45 ± 0.01 ^b	0.43 ± 0.0 ^b	0.45 ± 0.01 ^{ab}	0.52 ± 0.01 ^c	10 ⁻⁴
Gumminess	444.5 ± 38.3 ^a	617.8 ± 35.1 ^a	707.4 ± 86.3 ^a	1254.2 ± 322.9 ^b	871.5 ± 154.4 ^{ab}	941.2 ± 165.5 ^{ab}	8.003
Chewiness	435.7 ± 38.6 ^a	598.9 ± 34.4 ^a	671.3 ± 30.0 ^a	1221.4 ± 320.7 ^b	857.1 ± 157.4 ^{ab}	991.7 ± 145.4 ^{ab}	8.209
Resilience	0.09 ± 0.01 ^a	0.10 ± 0.00 ^a	0.09 ± 0.01 ^a	0.08 ± 0.00 ^{ab}	0.05 ± 0.00 ^{bc}	0.05 ± 0.00 ^c	20.043
L*(i)	87.19 ± 0.21 ^a	86.61 ± 0.1 ^a	86.60 ± 0.96 ^a	83.42 ± 0.40 ^a	82.61 ± 1.04 ^b	79.63 ± 1.67 ^c	33.594
a*(i)	-6.96 ± 0.08 ^a	-7.24 ± 0.09 ^{ab}	-7.28 ± 0.14 ^{ab}	-7.33 ± 0.09 ^{ab}	-7.83 ± 0.23 ^b	-7.03 ± 0.59 ^a	9.098
b*(i)	16.38 ± 0.05 ^a	16.66 ± 0.04 ^a	17.79 ± 0.19 ^{ab}	18.12 ± 0.54 ^{ab}	20.66 ± 1.09 ^c	19.76 ± 2.23 ^{bc}	13.778
L*(e)	84.63 ± 0.58 ^a	84.50 ± 0.32 ^a	84.23 ± 1.47 ^a	83.36 ± 0.50 ^a	76.87 ± 2.51 ^b	59.46 ± 1.94 ^c	108.29
a*(e)	-6.24 ± 0.02 ^{ab}	-7.40 ± 0.08 ^c	-6.63 ± 0.44 ^{ac}	-6.50 ± 0.19 ^{ac}	-5.50 ± 0.55 ^b	-4.31 ± 0.09 ^d	27.979
b*(e)	17.97 ± 0.34 ^a	19.88 ± 0.30 ^a	21.31 ± 1.18 ^a	22.26 ± 0.85 ^a	28.43 ± 3.92 ^b	20.86 ± 0.70 ^a	11.691

^{a,b,c,d}Means in lines without common superscripts are significantly different ($P < 0.05$; $n = 18$).

¹L*(e), a*(e), and b*(e) correspond to parameters measured on cheese surface (external) and L*(i), a*(i), and b*(i) corresponded to parameters measured on cheese surface after removing a 0.5-mm layer (inside cheese).

Table 2. Principal component loadings for texture profile analysis and color parameters.

Item ¹	Component			Communalities
	1	2	3	
Adhesiveness	-0.932	0.169	-0.191	0.934
L*(i)	-0.883	0.304	-0.026	0.873
Resilience	-0.860	0.319	0.230	0.895
b*(i)	0.835	0.006	-0.480	0.928
Gumminess	0.782	0.455	0.387	0.969
Chewiness	0.775	0.481	0.373	0.971
L*(e)	-0.732	0.643	0.024	0.950
a*(e)	0.730	-0.628	-0.020	0.927
Fracturability	0.696	0.0573	0.233	0.867
Hardness	0.693	0.608	0.365	0.983
Cohesiveness	0.317	-0.869	0.091	0.865
Springiness	-0.210	0.0356	-0.282	0.250
a*(i)	-0.407	-0.514	0.680	0.892
b*(e)	0.0594	0.367	-0.656	0.917

¹See Table 1 for an explanation of L*(i), L*(e), b*(i), b*(e), a*(i), a*(e).

Color Measurement

The mean values obtained for L*, a*, and b* parameters are also shown in Table 1 and presented considerable changes during ripening. The L* (e), a* (e), and b* (e) correspond to parameters measured on the cheese surface (external), and L* (i), a* (i), and b* (i) correspond to parameters measured on the cheese surface after removing a 0.5-mm layer (inside cheese). The L* value decreased significantly during ripening; this was more prominent on the exterior surface ($F = 108.3$) than on the interior surface ($F = 33.6$).

An increase in yellowness b* (i) and b* (e) was observed up to 30 d of ripening; however, at 60 d, cheeses were less yellow.

These results were in agreement with other authors who described a decrease in lightness and a slight increase in both redness (a) and yellowness (b) during cheese ripening (Pillonel et al., 2002).

Evaluation of Texture and Color Parameters by PCA

The PCA was carried out on 14 variables for 18 cheeses with different ripening time. The correlations of the original variables demonstrated that they could be reduced to 3 principal component variables. As shown in Table 2, communalities among the variables were high, ranging between 0.865 and 0.983, except for springiness, which was 0.250. The first 3 principal components cover more than 87.3% of the variance of the original variables. The first component (PC1) by itself condensed 50% and the second component (PC2) represented almost 25% of the total information.

Loading coefficients obtained from the application of PCA to the data are shown in Table 2. Component PC1 was high in adhesiveness, resilience, L* (i), and L* (e)

(negative values), and in b* (i), gumminess, chewiness, hardness, and fracturability (positive values). Component PC2 was high in cohesiveness and a* (e) (negative values), and in hardness and L* (e) (positive values). Terrincho cheese samples (from 0 to 60 d of ripening) as a function of the first 2 principal components are plotted in Figure 3.

In this figure, the most important texture and color parameters for the definition of these components are shown on the axes' edges, indicating the direction in which the values of TPA and color parameters increased, as is conventionally done in any PCA.

Changes in texture and color during ripening of Terrincho cheese can be summarized in 2 phases: the first

Figure 3. Scores of texture and color attributes of Terrincho ewe cheese during 60 d of ripening on 2 principal components.

Figure 4. Estimation of cheese ripening time. Y = ripening time, x = texture and color parameters, SE = standard error. $Y = 257.782 - 1.160 \times L^*(e) - 1.655 \times L^*(i) + 3.376 \times b^*(i) + 0.01067 \times \text{hardness} + 9.750 \times a^*(i) - 0.01919 \times \text{chewiness}$. $SE = 4.2$, $R = 0.972$, $n = 89$, $P < 0.001$.

phase, up to d 20 of ripening, was characterized by an increase in hardness, fracturability, gumminess, chewiness, and yellowness. During this phase, adhesiveness, resilience, L^* (i and e), and cohesiveness decreased. The second phase took place after d 20, and was characterized by a decrease in hardness, fracturability, gumminess, and chewiness, and an increase in cohesiveness (this phase was mostly explained by PC2).

Estimation of Terrincho Cheese Ripening Time

Terrincho cheese ripening time was estimated with stepwise variable selection involving the 14 variables by multiple linear regression analysis. The general formula of the estimation equation is as follows:

$$y = a_1 x_1 + a_2 x_2 + \dots + a_n x_n$$

where y is cheese ripening time and $x_1, x_2, \dots, x_n$ are texture and color parameters. The correlation between the measured and estimated values is shown in Figure 4.

The product ripening time can be estimated with 6 variables: L^* (e), L^* (i), b^* (i), hardness, a^* (i), and chewiness, as well as a constant. The estimation error is 4.2 d. The estimation of cheese age on the basis of

texture parameters during similar a period of time was made by other authors (Bara-Herczegh et al., 2002) with an accuracy of approximately 15 to 16 d. The use of 2 texture and 4 color parameters greatly improved the accuracy of estimation.

Intravarietal Comparison

The chemical composition, the texture attributes of TPA, and the color parameters of 14 samples of Terrincho cheeses with 30 d of ripening from 5 different dairy plants are listed in Table 3.

In general, cheeses from the 5 dairy plants presented similar compositions, except for ash content as result of different NaCl content. For DM and fat content in DM especially, small variability was observed, as shown by the low F values of ANOVA analysis: $F = 6.12$ and 6.26 , respectively. Larger variability was observed for protein content in DM ($F = 52.4$).

Regarding texture attributes of TPA, cheeses from B, V, T, and R dairy plants presented similarity with respect to hardness, springiness, and chewiness; only cheeses from M dairy plant were significantly different for those attributes. The attribute that presented greater variability between cheeses from different dairy plants was cohesiveness ($F = 75.57$).

With respect to color attributes, no significant differences were observed on L^* , a^* , b^* measured on the exterior surface and L^* measured on the interior of cheeses from (B, V, T, R, and M) dairy plants. However, significant differences were observed between a^* and b^* measured on the interior of the same cheeses. Cheeses from M plant were the most yellow and V cheeses were the least yellow. These results are in agreement with those obtained by Alvarenga (2000), where $b^*(i)$ was the most important parameter to distinguish Serpa cheeses from 2 different producers.

A categorical principal component analysis (CAT-PCA) was performed to simplify data from chemical composition, texture, and color attributes (of Terrincho cheeses from 5 different dairy plants in a total of 14 samples). This procedure simultaneously quantified categorical variables while reducing the dimensionality of the data. The optimal-scaling approach allowed to be scaled at different levels.

The results have been depicted on a two-dimensional plot (Figure 5) that explained 79% of the total variance. The dimension 1 ($k = 14.1$) explained 64% of the variance in data. The negative segment of the plot for dimension 1 was related to hardness, gumminess, chewiness, ash, springiness, fracturability, L^* (e), b^* (i), and b^* (e), whereas the positive segment of the plot for that dimension was mainly related with protein, adhesiveness, cohesiveness, fat, a_w , $a^*(i)$, and a^* (e). Dimension

Table 3. Chemical composition and attributes of texture and color of Terrincho ewe cheeses from 5 dairy plants.

Item ¹	Dairy					F	P
	B	V	R	T	M		
Dry matter	45.52 ± 0.28 ^a	46.16 ± 0.78 ^{ab}	45.28 ± 1.59 ^a	47.72 ± 0.91 ^b	45.85 ± 0.68 ^a	6.12	0.01
Protein/DM, g/100 g	45.46 ± 0.78 ^a	46.95 ± 0.46 ^a	46.15 ± 1.84 ^a	50.73 ± 1.07 ^b	40.23 ± 1.23 ^a	52.4	10 ⁴
Fat/DM, g/100 g	55.2 ± 0.00 ^a	53.63 ± 2.47 ^{ab}	53.68 ± 2.50 ^{ab}	53.80 ± 0.78 ^a	50.88 ± 1.01 ^b	6.26	0.003
Ash content, g/100 g	3.08 ± 0.06 ^a	3.18 ± 0.11 ^a	3.62 ± 0.11 ^b	3.39 ± 0.03 ^c	5.52 ± 0.10 ^d	598	10 ⁴
NaCl/dry matter, g/100 g	2.54 ± 0.20 ^a	2.03 ± 0.16 ^c	3.29 ± 0.36 ^b	2.49 ± 0.31 ^c	6.26 ± 0.32 ^d	12.3	0.001
Acidity content, g/100 g	0.792 ± 0.03 ^a	0.708 ± 0.12 ^{ab}	0.642 ± 0.06 ^b	1.296 ± 0.12 ^c	0.648 ± 0.03 ^{ab}	1.29	10 ⁴
a _v	0.974 ± 0.001 ^a	0.972 ± 0.002 ^a	0.968 ± 0.001 ^b	0.973 ± 0.001 ^a	0.957 ± 0.001 ^c	184	10 ⁴
pH	5.26 ± 0.12 ^a	4.96 ± 0.04 ^b	5.08 ± 0.04 ^{bd}	4.86 ± 1.07 ^c	5.13 ± 0.04 ^d	77.5	10 ⁴
Hardness, g	313.9 ± 13.0 ^a	683.3 ± 48.2 ^a	497.6 ± 6.1 ^a	542.0 ± 72.3 ^a	1926.3 ± 392.5 ^b	34.5	10 ⁴
Fracturability, g	0 ± 0 ^a	467.1 ± 123.8 ^b	0 ± 0 ^a	239.6 ± 88.2 ^{ab}	1730.3 ± 303.5 ^c	58.5	10 ⁴
Adhesiveness, g.s	-1577.5 ± 23.6 ^{ab}	-2158.5 ± 152.5 ^{ac}	-1880.8 ± 149.3 ^{abc}	-1355.8 ± 122.2 ^{ab}	-2448.1 ± 493.2 ^c	8.83	0.004
Springiness	0.96 ± 0.01 ^a	0.97 ± 0.01 ^a	0.97 ± 0.00 ^a	0.96 ± 0.01 ^a	0.98 ± 0.01 ^a	1.92	0.191
Cohesiveness	0.56 ± 0.01 ^a	0.5 ± 0.01 ^b	0.57 ± 0.01 ^a	0.5 ± 0.01 ^b	0.45 ± 0.01 ^c	75.5	10 ⁴
Gumminess	174.4 ± 5.7 ^a	344.1 ± 20.7 ^b	271.2 ± 0.4 ^a	269.5 ± 31.5 ^a	871.5 ± 154.4 ^c	40.6	10 ⁴
Chewiness	168.3 ± 4.3 ^a	335.3 ± 24.4 ^a	264.3 ± 127.0 ^a	259.9 ± 30.2 ^a	857.1 ± 158.0 ^b	37.9	10 ⁴
Resilience	0.05 ± 0.00 ^a	0.03 ± 0.00 ^b	0.05 ± 0.00 ^a	0.04 ± 0.00 ^b	0.05 ± 0.00 ^a	30.6	10 ⁴
L*(i)	80.14 ± 0.90 ^a	81.79 ± 0.90 ^{ab}	81.48 ± 0.68 ^{ab}	81.92 ± 0.05 ^{ab}	82.61 ± 1.04 ^b	4.47	0.029
a*(i)	-7.38 ± 0.12 ^a	-6.52 ± 0.20 ^b	-6.63 ± 0.05 ^b	-6.47 ± 0.33 ^b	-7.83 ± 0.23 ^a	22.1	10 ⁴
b*(i)	17.34 ± 1.25 ^a	15.41 ± 0.38 ^a	15.87 ± 0.08 ^a	15.75 ± 0.81 ^a	20.66 ± 1.10 ^b	17.5	10 ⁴
L*(e)	69.81 ± 0.84 ^a	67.92 ± 2.15 ^a	67.63 ± 3.16 ^a	71.86 ± 8.68 ^a	76.87 ± 2.51 ^a	1.97	0.183
a*(e)	-4.64 ± 0.37 ^a	-4.80 ± 0.61 ^a	-5.22 ± 0.57 ^a	-4.55 ± 0.40 ^a	-5.50 ± 0.55 ^a	1.86	0.202
b*(e)	23.43 ± 1.21 ^{ab}	20.57 ± 0.63 ^a	21.63 ± 2.34 ^a	18.27 ± 1.38 ^a	28.43 ± 3.92 ^b	8.99	0.03

^{a,b,c,d}Means in lines without common superscripts are significantly different ($P < 0.05$; $n = 15$).

¹L*(e), a*(e), and b*(e) correspond to parameters measured on the cheese surface (exterior) and L*(i), a*(i), and b*(i) corresponded to parameters measured on the cheese surface after removing a 0.05-mm layer (interior).

Figure 5. Categorical principal component biplot showing the relationship between Terrincho ewe cheese from B, V, R, T, M, dairy plants and chemical composition, texture, and color.

2 was basically related to DM and $L^*(i)$ (negative coefficient) and resilience, acidity, and pH (positive coefficient).

Differences were observed between cheeses from B and M dairy plants and the cheeses from others dairy plants. As shown in Figure 5, cheeses from the R, T, and V dairy plants had similar chemical compositions, texture, and color because they clustered together. Cheeses from the B dairy plant were separated from the others mainly because of their lower DM and $L^*(i)$, and higher pH, resilience, acidity, fat content, and water activity. In addition, cheeses from the M dairy plant were separated from the others, mainly because of their higher hardness, gumminess, chewiness, fractureability, and springiness. These cheeses also presented higher $L^*(e)$, $b^*(i)$, $b^*(e)$, NaCl, and ash content. Textural analysis of cheese performed by Chen et al. (1979) also resulted in a positive correlation between the cheeses' NaCl content and hardness.

Following the same procedure, CATPCA was run on mean values from parameters and mean sensory scores for 4 texture attributes and color intensity of cheeses from the 5 dairy plants and yielded 2 components that explained 90 and 10% of the variance, respectively (Figure 6). The eigenvalue of dimension 1 is $k = 15.3$.

Cheese grouping according to TPA analysis, color, and sensory attributes was similar to the grouping according to instrumental analysis of these cheeses (Figure 5). As expected, panelists noted differences between cheeses from B and M dairy plants and cheeses from

Figure 6. Categorical principal component biplot showing the relationship between mean values from texture profile analysis and color parameters and mean sensory scores from 4 texture attributes and color intensity of cheeses from B, V, R, T, and M dairy plants.

the other dairy plants (R, T, and V). This last group of 3 cheeses presented similar chemical and sensory characteristics.

Color intensity, hardness on the mouth, fractureability when cutting with a knife, and elasticity when pressing with the fingers were positively correlated with $b^*(e)$, $b^*(i)$, TPA hardness, TPA fractureability, and TPA springiness. Only sensory adhesiveness was not correlated with TPA adhesiveness.

In spite of the differences observed between cheeses from the 5 dairy plants, estimation of ripening time using TPA and color parameters and the regression equation described above (Estimation of Terrincho Cheese Ripening Time) gave values around 30 d, 30.9, 32.9, 32.16, 29.7, and 29.4, respectively, for cheeses from B, V, R, T, and M dairy plants.

CONCLUSIONS

Changes in moisture, a_w , pH, acidity, texture, and color were monitored during Terrincho cheese ripening. Two phases were distinguished: the first, up to 20 d, was characterized by a slow decrease in moisture and a_w . During this period, pH decreased from 6.6 to 5.4, resulting in an increase in hardness, fractureability, gumminess, chewiness, and yellow color. After 20 d, the decrease in moisture and a_w was more prominent and the pH increased slightly. This second phase was characterized by an increase in cohesiveness and decrease in hardness and fractureability because caseins undergo increased hydrolysis into small peptides.

Estimation of ripening time using 2 texture and 4 color parameters and a constant was possible with a standard error of 4.2 d. This regression equation was applied with success to confirm the ripening time of Terrincho cheese from 5 different dairy plants. The estimation of ripening time is important in this type of cheese because it is made from raw ewe's milk and for food safety reasons, it must not be sold before 30 d of ripening.

Evaluation of composition, pH, TPA, color, and related sensory characteristics of Terrincho cheeses from 5 different dairy plants (with 30 d of ripening) revealed correlations between these parameters. Cheeses with slightly higher fat contents, moisture, and a_w , and lower sodium chloride contents presented lower hardness, fracturability, gumminess, and chewiness.

Color intensity, elasticity when pressing the fingers, fracturability when cutting with a knife, and hardness on the mouth, evaluated from sensory analysis, positively correlated with the same instrumental measurements. No correlation was found for adhesiveness.

Intravarietal comparison of Terrincho cheeses from 5 different dairy plants showed differences in cheeses from 2 dairy plants and similarities between cheeses from the other 3. However, real and estimated ripening time was in good agreement for all cheeses.

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