Research Article

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Evaluation of texture in Serra da Estrela cheese manufactured in different dairies

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Abstract: Serra da Estrela cheese is a traditional product from artisanal manufacture using raw ewe's milk coagulated with dried, wild thistle flower. The present study aimed to investigate the variation of textural properties in Serra da Estrela cheeses manufactured in different dairies through time, namely from April to June, following the end of the cheese making season. Three types of tests were conducted: compression, puncture and spreadability. These were carried out on samples coming from six different dairies situated in the PDO (Protected Designation of Origin) region of this type of cheese.

The results obtained showed some non-negligible differences for some textural properties between the top and bottom sides of the cheeses evaluated, as well as between cheeses from different dairies. Nevertheless, the properties of springiness, resilience, cohesiveness and adhesiveness (all from the compression test), were not significantly different in the samples analysed. In what concerns the variations along the milking season, it was possible to conclude that three of the considered dairies produced cheeses with a more constant textural profile in the period comprised between April and June. Furthermore, statistical analysis revealed that the correlations between the textural properties were strong for some interactions between properties form the same test and/or from similar nature.

Keywords: Cheese quality; Compression test; Puncture test; Spreadability.

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1 Introduction

Cheese is a dairy product obtained from milk fermentation, and is one of the ancient foods still important in the Mediterranean diet. Cheese is usually well tolerated and easily digested and can also constitute a good alternative to milk for people who are intolerant to lactose. Cheese is a nutritive food that contains a high concentration of essential nutrients, such as proteins, bioactive peptides, fat, fatty acids (FA), vitamins and minerals (Ferrão and Guiné 2019). Among the constituents in cheese, it is highlighted the content in dietary calcium, with approximately 35 g of hard cheese providing 250 mg of Ca. Furthermore, in normal dietary conditions, the bioavailability of calcium is higher in milk and dairy products, such as cheese, when compared to other foods, such as vegetables or cereals (Caroli et al. 2011; Chen et al. 2016; Hinrichs 2004; Keller et al. 2002; Rozenberg et al. 2016; Weaver et al. 1999). Nevertheless, some cheeses have a high content of saturated fatty acids, and in that case the consumption, must be moderated owing to their contribution for increasing low-density lipoprotein (LDL) cholesterol, which has been associated with cardiovascular diseases (Guiné and Florença 2019; Mihaylova et al. 2012).

Serra da Estrela cheese is a traditional product from artisanal manufacture using raw ewe's milk coagulated by an aqueous extract obtained from dried thistle flower (*Cynara cardunculus*). The milk to manufacture Serra da Estrela Cheese is obtained from sheep of *Bordaleira da Serra da Estrela* or *Churra Mondegueira* breeds. It is a cured cheese, which can have semi-soft buttery paste and yellowish-white colour in case of the Serra da Estrela Cheese, or semi-hard to extra-hard paste of brown-orange colour in the case of Serra da Estrela Old Cheese. The manufacture processing depends on the availability of ovine milk, which is seasonal coinciding with the months when sheep give birth and feed their offspring. This is usually comprised between autumn and spring, more precisely from December to May, and therefore it is believed that many factors influence milk composition, such as: climatic conditions and soil composition that influence the pastures, the nutritional and physiological status of the flock, or lactation stage. In this way, it is expected some variation in the physicochemical and microbiological composition of milk than in turn will reflect on the final characteristics of the cheese (Guiné et al. 2019; Tavaria et al. 2003).

Traditional cheeses are characterised by strong links to their territory of origin and constitute a tribute to the history and the culture of the community that manufactures them. Due to the importance of this product for the Portuguese food market, some studies have been developed to better understand the effects of manufacturing operations and ripening conditions of the final quality of the cheese; however focus mainly the chemical, biological or biochemical changes, and less on the physical properties (Guiné and Florença 2019). For example, Tavaria et al. (2003) studied the changes occurring in the amino acids and soluble nitrogen throughout ripening and Reis and Malcata (2011) evaluated the microstructure of Serra da Estrela Cheeses along the ripening process. Also the study by Tavaria et al. (2006) focused on the microbiological and microstructural characteristics of Serra da Estrela cheese, but only for fully ripe cheese evaluating the influence of factors like dairy and milk refrigeration. Cunha et al. (2016) undertook a different kind of study, investigating markers to detect the adulteration of this traditional food, owing the PDO (Protected Designation of Origin), with a high commercial value.

Although some studies have been previously conducted to investigate the many aspects related to the quality of this traditional product, the textural properties have not yet been fully addressed. The aim of the present work was to investigate the variation of textural properties in Serra da Estrela cheeses manufactured in different dairies from April to June, following the end of the cheese making season. For this, different texture measurements were performed for a more complete evaluation of the textural characteristics.

2 Materials and methods

2.1 Samples

The samples used for the study were triplicates obtained from six dairies situated in PDO region for Serra da Estrela cheese: Sabores & Ambientes in Oliveira do Hospital (D1), Casa Agrícola dos Arais in Celorico da Beira (D2), Casa da Ínsua in Penalva do Castelo (D3), Queijaria de Germil again in Penalva do Castelo (D4), Quinta de São Cosme in Gouveia (D5) and Quinta da Lagoa in Nelas (D6).

The milk used for the Serra da Estrela cheese came from manual milking and was filtered through a white cloth. To the milk heated at about 30°C was added salt and vegetable rennet (dried wild thistle flower). After 45 to 60 min, the curd was manually cut and filtered to remove the remaining whey. Then, followed the steps of moulding, pressing and salting of the surface, and finally the cheese was ready for maturation, being turned and washed every day for the first 15 days and then more sporadically until the end of the ripening process, which lasted about 45 days.

2.2 Analysis of texture

To analyse the textural characteristics, three types of tests were carried out using a Texture Analyser (model TA.XT. Plus, Stable Micro Systems): (a) compression test, (b) puncture test and (c) spreadability test.

2.2.1 Compression test

The texture profile analysis (TPA) for all samples was made using a texturometer (TA.XT. Plus from Stable Micro Systems). The test consisted in two consecutive compression cycles between parallel plates, with a 5 s interval, using a flat 75 mm diameter probe (P/75) and a 50 kg force load cell. The pre-test, test and post-test speed was 1.0 mm/s, in all cases, and the compression distance was 4 mm. The textural properties: hardness, adhesiveness, springiness, cohesiveness, resilience and chewiness were calculated using equations (1) to (6) (Figure 1):

$$\text{Hardness (N)} = F1 \quad (1)$$

$$\text{Adhesiveness (N.s)} = A3 \quad (2)$$

$$\text{Springiness (\%)} = T2/T1*100 \quad (3)$$

$$\text{Cohesiveness} = A2/A1 \quad (4)$$

$$\text{Resilience (\%)} = A5/A4*100 \quad (5)$$

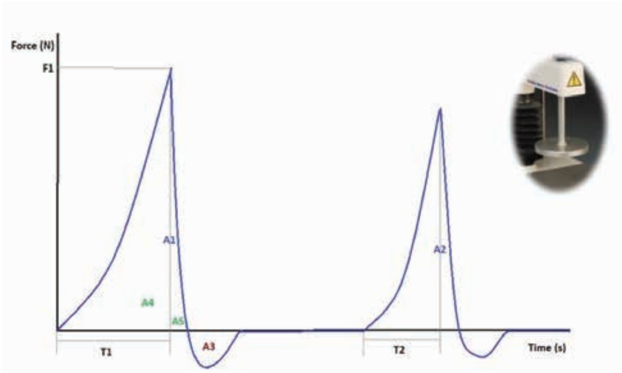

Figure 1: Example of a graph obtained with the compression test using the P/75 probe

Chewiness (N) = F1*T2/T1*A2/A1 (6)

For this test the evaluations were made in three different samples in both sides of the cheese (top and bottom), allowing to calculate the mean value and standard deviation.

2.2.2 Puncture test

In this case the test performed was measure force in compression and the probe used was P/2 (2mm diameter cylinder). The operational parameters were: pre-test speed = 2.00 mm/s, test speed = 1.00 mm/s and post-test speed = 1.00 mm/s, distance = 10.0 mm and load cell = 50 kg. The curve force (N) *versus* time (s) (Figure 2) allowed calculating the crust firmness, the inner firmness, adhesiveness and stickiness, according to equations (7) to (10):

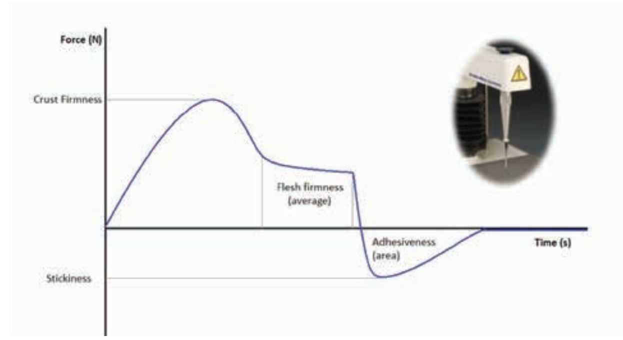

Figure 2: Example of a graph obtained with the puncture test using the P/2 probe

Crust firmness (N) = Fe *(maximum force)* (7)

Inner firmness (N) = Fi
(average force between lines 1 and 2) (8)

Adhesiveness (N.s) = A *(negative area – marked green)* (9)

Stickiness (N) = Fn *(minimum force – negative)* (10)

For this test the evaluations were made in 3 different samples in both sides of the cheese (top and bottom), with five perforations on each side.

Spreadability test

In this case the test also involved measure force in compression, but using a spherical probe P/1S (stainless ball). The operational parameters were: pre-test speed = 1.50 mm/s, test speed = 2.00 mm/s and post-test speed = 10.00 mm/s, distance = 10.0 mm and load cell = 50 kg. The curve force (N) *versus* time (s) (Figure 3) allowed calculating hardness and stickiness, according to equations (11) and (12):

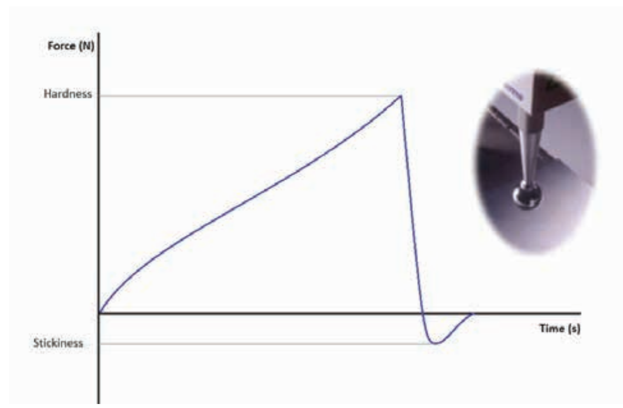

Figure 3: Example of a graph obtained with the spreadability test using the P/1S probe

Hardness (N) = Fe *(maximum force)* (11)

Stickiness (N) = Fn *(minimum force – negative)* (12)

For this test the evaluations were made in three different samples in both sides of the cheese (top and bottom).

2.3 Statistical analysis

To verify if the results obtained in terms of mean value were statistically different between samples, a statistical analysis was applied. The Post-Hoc Tukey HSD (Honestly Significant Difference) test was used, coupled to an analysis of variance (ANOVA) for comparison between the samples from different dairies. Tukey's test is a statistical tool to identify the differences between groups of data and consists of a single multi-step process for comparison, carried out in conjunction with ANOVA. The test identifies where the difference between two mean values is higher than the standard error which could be expected.

Also, the Pearson correlation coefficients were used to analyse the possible associations and interdependence between properties. For absolute value of r = 0 there is no correlation, for r ∈]0.0, 0.2[the correlation is very weak, for r ∈ [0.2, 0.4[the correlation is weak, for r ∈ [0.4, 0.6[the correlation is moderate, for r ∈ [0.6, 0.8[the correlation is strong, for r ∈ [0.8, 1.0[the correlation is very strong, for r = 1 the correlation is perfect (Maroco 2012; Pestana and Gageiro 2014).

Complementary, a factor analysis (FA) was undertaken. The correlation matrix between the variables was analysed to identify some correlations. The Kaiser-Meyer-Olkin measure of adequacy of the sample (KMO) and the Bartlett's test were used to verify the intercorrelation between variables (Broen et al. 2015). After confirming that the data were suitable for application of factor analysis, this was applied considering extraction by principal component analysis (PCA) and Varimax rotation with Kaiser Normalization. The number of components was established by the Kaiser criterion (eigenvalues ≥ 1). In all cases, the communalities were calculated to show the percentage of variance explained by the factors extracted (Broen et al. 2015). Factor loadings with an absolute value exceeding 0.4 were used, because this lower limit accounts for about 16% of the variance in the variable (Rohm and Swaminathan 2004; Stevens 2009).

For all statistical analyses was used the software SPSS version 25 (IBM, Inc.) and the level of significance considered was 5% ($P < 0.05$).

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussion

3.1 Textural properties

Table 1 shows the textural properties on both sides of the cheeses (top and bottom) in the first moment of evaluation (month of April), obtained by the three different tests performed. For these cheeses the milk used would have been collected at around February, having in mind the 45 days of maturation. The compression tests allowed to measure six different textural properties: hardness, chewiness, springiness, resilience, adhesiveness and cohesion. Hardness corresponds to the force required to compress a food between the teeth or between the tongue and mouth, i.e., the force required to produce deformation. Adhesiveness comprises the force required to remove the material that adheres to a surface, for example the lips, palate or teeth. Springiness is linked to the ability to recover shape after deformation by compression, corresponding to the rate at which the product returns to the initial point after removal of the force. Resilience is the energy involved when a force is applied to a material without occurring rupture, with or without any residual strain, and is like an instant springiness. Cohesiveness, or cohesion, represents the internal forces on the food that impede the sample disintegration. Finally, chewiness measures the energy required to disintegrate the food to a state appropriate for swallowing.

The results in Table 1 (compression test) show that there are some differences between both faces of the cheeses, most especially for some dairies. Although during the ripening process it is supposed to turn the cheeses very frequently to provide the development of uniform characteristics, in reality that may not be so effective for some cases, maybe because the turns were not so frequent as expected or even due to other fortuitous causes. For example, hardness was very uniform for samples D1 and D5 but not for samples D4 or D6. Chewiness, which is directly linked with hardness (see Equation (6)), presents for that reason a very similar trend to that observed for hardness. Adhesiveness was found practically non-existent, which is an indicator of the dryness of the cheese crust, since these measurements by the compression test were made in the outer part of the cheese. Also in a study by Guiné et al. (2015) made with goat and sheep cheeses, the values of adhesiveness measured in the crust were very close to zero. The other properties, springiness, resilience and cohesiveness, were very similar on both sides of the cheeses analysed, and the values were also similar between different dairies.

The puncture tests allowed calculating four additional textural properties, the crust and inner firmness, adhesiveness and stickiness. However, unlike in the compression tests that were made to the outer part of the cheese, the crust, the puncture tests actually penetrated inside the inner paste and allowed measuring additional properties, important because they are more directly linked with the sensory perception of texture for this smooth cheese. The firmness of the outer layer and of the inner paste have a similar meaning to that of the hardness, previously described when discussing the results of the compression test. Adhesiveness has also been explained before, but stickiness is a new concept, that corresponds to the minimal force of the probe when receding from the sample.

Table 1: Textural properties on top and bottom faces of the cheeses in April (the first moment of evaluation), obtained by the different tests

Property1	**Side**	**D1**	**D2**	**D33**	**D4**	**D5**	**D6**
Compression test							
Hardness (N)	Top	21.06±4.07^{a}	17.79±4.16^{a}	64.52±n.a.	35.10±14.32^{ab}	12.39±7.13^{a}	71.63±27.81^{b}
	Bottom	20.34±3.92^{a}	24.46±3.83^{a}	80.61±n.a.	58.96±30.03^{a}	12.47±4.92^{ab}	101.46±16.80^{c}
Chewiness (N)	Top	14.10±1.25^{a}	12.15±3.36^{a}	44.15±n.a.	25.07±12.33^{ab}	8.29±4.43^{a}	56.68±22.61^{b}
	Bottom	13.99±2.80^{a}	15.51±2.34^{a}	58.09±n.a.	40.11±24.20^{ab}	8.08±3.36^{a}	80.66±14.00^{b}
Adhesiveness (N.s)	Top	-0.07±0.08^{a}	-0.02±0.00^{a}	-0.02±n.a.	0.00±0.00^{a}	0.00±0.00^{a}	0.00±0.01^{a}
	Bottom	-0.85±1.12^{a}	-1.01±0.52^{a}	-0.60±n.a.	-0.01±0.01^{a}	-0.45±0.03^{a}	-0.03±0.01^{a}
Springiness (%)	Top	84.38±3.71^{a}	83.88±1.77^{a}	85.88±n.a.	84.13±3.81^{a}	84.00±2.21^{a}	89.69±1.33^{a}
	Bottom	85.38±0.71^{a}	84.06±0.62^{a}	87.50±n.a.	82.58±4.82^{a}	83.46±1.28^{a}	89.88±0.35^{a}
Resilience (%)	Top	38.35±5.55^{a}	39.95±1.92^{a}	43.71±n.a.	41.12±5.36^{a}	41.13±2.38^{a}	55.70±0.79^{b}
	Bottom	39.19±4.27^{a}	36.73±1.00^{a}	45.24±n.a.	43.57±2.80^{a}	45.14±6.24^{a}	59.10±0.61^{b}
Cohesiveness	Top	0.80±0.05^{a}	0.81±0.02^{a}	0.80±n.a.	0.83±0.04^{a}	0.80±0.03^{a}	0.88±0.00^{a}
	Bottom	0.81±0.00^{a}	0.76±0.00^{a}	0.82±n.a.	0.80±0.04^{a}	0.77±0.02^{a}	0.88±0.00^{b}
Puncture test							
Crust Firmness (N)	Top	2.38±1.23^{a}	2.90±0.54^{a}	6.15±0.73^{b}	6.54±2.34^{b}	3.78±0.71^{a}	10.67±2.87^{c}
	Bottom	1.23±0.37^{a}	1.30±0.42^{a}	3.28±0.55^{b}	3.81±0.85^{b}	2.76±0.85^{b}	7.15±1.34^{c}
Paste Firmness (N)	Top	0.87±0.34^{a}	1.11±0.09^{a}	1.88±0.24^{b}	2.37±0.82^{b}	0.96±0.20^{a}	3.21±0.60^{c}
	Bottom	0.74±0.25^{a}	0.85±0.16^{ab}	1.22±0.06^{bc}	1.37±0.23^{c}	1.03±0.39^{abc}	2.36±0.51^{d}
Stickiness (N)	Top	-0.67±0.31^{d}	-0.76±0.16^{d}	-2.20±0.23^{b}	-1.78±0.57^{bc}	-0.94±0.16^{cd}	-3.44±1.25^{a}
	Bottom	-0.47±0.13^{d}	-0.51±0.08^{d}	-0.97±0.09^{bc}	-1.10±0.33^{b}	-0.67±0.18^{cd}	-2.11±0.59^{a}
Adhesiveness (N.s)	Top	-4.30±2.15^{c}	-4.82±1.05^{c}	-14.49±2.43^{b}	-12.43±4.38^{b}	-6.13±1.11^{c}	-25.85±11.08^{a}
	Bottom	-2.89±0.80^{c}	-2.74±0.57^{c}	-5.43±0.81^{bc}	-7.35±2.67^{b}	-4.22±1.31^{bc}	-16.05±4.76^{a}
Spreadability test							
Hardness (N)	Top	10.54±6.11^{a}	11.09±3.39^{a}	22.69±n.a.	17.71±2.66^{a}	11.06±1.73^{a}	36.76±2.68^{b}
	Bottom	6.76±2.09^{a}	9.45±3.17^{a}	27.89±n.a.	16.29±4.88^{a}	10.36±0.97^{a}	33.82±8.49^{b}
Stickiness N)	Top	-0.13±0.07^{a}	-0.11±0.01^{a}	-0.49±n.a.	-0.09±0.06^{a}	-0.04±0.01^{a}	-0.14±0.15^{a}
	Bottom	-0.15±0.07^{a}	-0.20±0.00^{a}	-1.03±n.a.	-0.15±0.10^{a}	-0.09±0.09^{a}	-0.17±0.07^{a}

[1]Values given as mean ± standard deviation. Values in the same line with the same superscript are not significantly different (ANOVA with Tukey Post Hoc, $P < 0.05$).
[2]For this evaluation only one cheese was successfully analysed, and therefore for some measurements it was not possible to compute standard deviation (n.a.) and Tukey's test was also not possible to perform for those cases.

The results in Table 1 (puncture test) reveal that the firmness of the crust was considerably harder when compared with that of the inner paste, and in this case the variability between sides was more evident for all samples, when it comes to the hardness of the crust. Regarding the inner paste, the differences between sides were considerably lower, which means that inside there is a higher uniformity of texture. The adhesiveness was higher when compared with that measured with the compression test, because the puncture test penetrates inside the cheese contacting with the paste that is smoother and creamier. Because this product is expected to have a soft texture with a creamy feeling in the mouth, higher intensity of adhesiveness (i.e. lower negative values) are preferable, like in the case of samples D6 and D3. The stickiness is much linked also with adhesiveness and therefore also higher stickiness is appreciated, like in the cases of samples D6 and D3.

In the work by Correia et al. (2014), texture was measured for Serra da Estrela Cheese also through puncture test, but varying the thistle flower ecotypes. In their work they also found intensive adhesiveness (values around -5 to -7 N.s) and stickiness (approximately -1 N) and a crust firmness higher when compared to the inner firmness (approximately 3 and 1 N, respectively). Also Correia et al. (2016) reported similar trends for Serra da Estrela Cheese along maturation time, with values of the textural properties being at 90 days of maturation 2.4 – 5.6 and 0.8 – 1.8 N for crust and inner firmness, respectively, while being -1.6 – -0.5 N for stickiness and -11.3 – -3.0 N.s for adhesiveness.

The spreadability tests allowed calculating also hardness and stickiness, although in a different way than previous tests, being these differences associated with the usage of a spherical probe. The results presented in Table 1 for the spreadability show once more that the hardness of the crust can be quite different when evaluated in different sides of the cheeses, like for example sample D1. Stickiness as measured in the outer crust was low, presenting a similar trend to that observed for the adhesiveness also measured on the outer part of the cheeses.

In Table 2 shows the results obtained for the same properties of Table 1, but evaluated in the last month (June) of the evaluation interval considered. In general, the trends are similar, either when comparing both sides of the samples or when comparing the different dairies. Also, in this case springiness, resilience and cohesiveness were very similar in all measurements, while hardness and chewiness varied a little between sides (for example D2 and D5) and between dairies (from D1 to D2, for example). Regarding the properties of the puncture test, crust firmness was more variable between sides for samples D3 and D6, while inner firmness was very similar in both evaluations made for sample D3, thus evidencing that while being uniform in the inner paste, the crust presented important changes in texture for both sides. Adhesiveness, on the other hand, was highly variable for sample D3, with the value in the bottom (-14.25 N.s) almost doubling that of the top (-7.22 N.s). Regarding the results for stickiness, a higher constancy was observed for different samples and different sides.

Figures 4 to 6 show the evolution of the textural properties of the cheeses produced in the 6 dairies along the

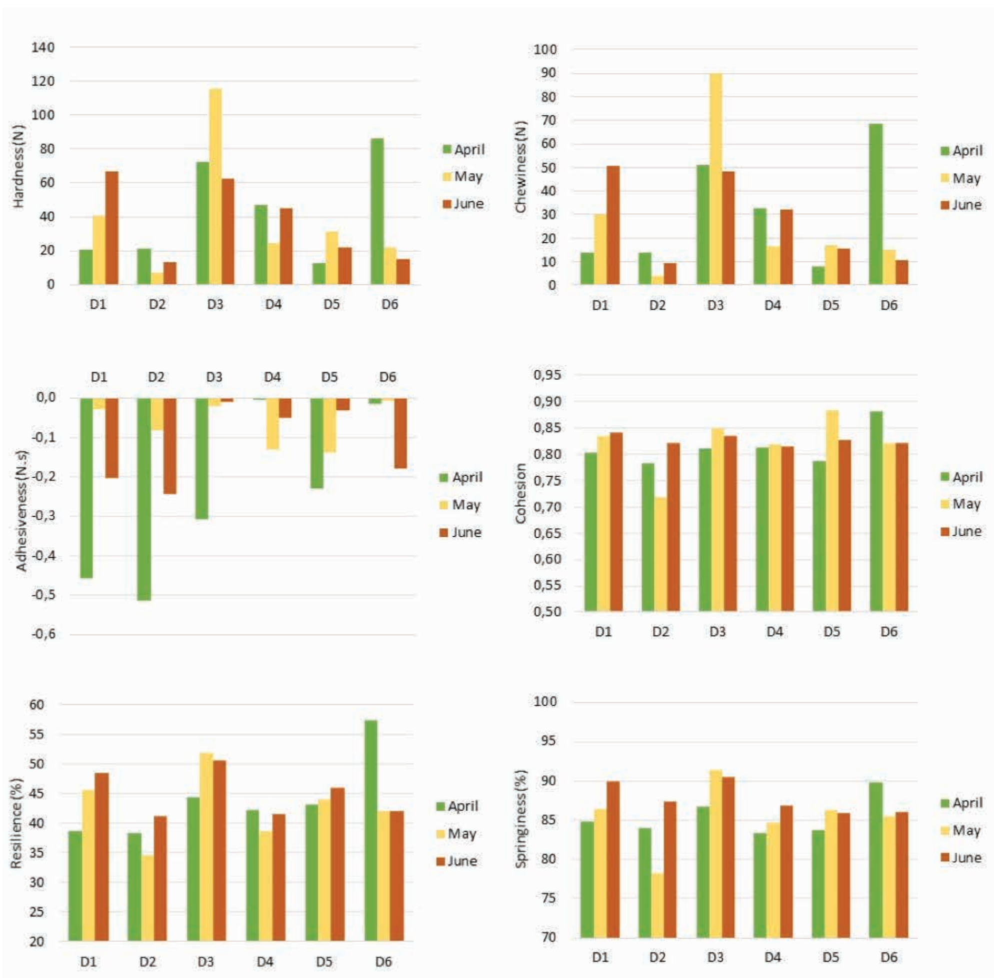

Figure 4: Variation of textural properties in the cheeses as a whole from April to June, obtained by the compression test

Table 2: Textural properties on top and bottom faces of the cheeses in June (the last moment of evaluation), obtained by the different tests

Property[1]	Side	D1	D2	D3	D4	D5	D6
Compression test							
Hardness (N)	Top	66.95±12.87^{b}	9.97±3.85^{a}	65.43±30.79^{b}	43.78±12.88^{ab}	16.14±7.09^{a}	12.19±1.69^{a}
	Bottom	66.92±12.05^{b}	15.80±5.80^{a}	59.28±28.62^{ab}	46.71±24.81^{ab}	27.72±0.83^{ab}	18.02±9.01^{a}
Chewiness (N)	Top	49.74±9.55^{b}	7.32±3.10^{a}	52.19±26.74^{b}	31.78±9.78^{ab}	11.64±5.21^{a}	8.70±0.84^{a}
	Bottom	51.81±10.64^{b}	11.28±4.26^{a}	44.27±22.49^{ab}	32.53±18.9^{ab}	19.52±1.67^{ab}	12.70±6.53^{a}
Adhesiveness (N.s)	Top	-0.16±0.22^{a}	-0.01±0.01^{a}	-0.01±0.01^{a}	-0.05±0.06^{a}	-0.01±0.00^{a}	-0.03±0.03^{a}
	Bottom	-0.24±0.35^{a}	-0.47±0.40^{a}	-0.01±0.00^{a}	-0.05±0.04^{a}	-0.06±0.05^{a}	-0.33±0.31^{a}
Springiness (%)	Top	89.50±0.82^{a}	87.46±2.91^{a}	92.03±3.47^{a}	88.04±1.83^{a}	86.13±3.43^{a}	86.54±2.10^{a}
	Bottom	90.46±1.68^{a}	87.21±1.05^{a}	88.94±2.24^{a}	85.06±1.68^{a}	85.58±3.76^{a}	85.58±3.59^{a}
Resilience (%)	Top	47.72±2.63^{a}	41.93±1.34^{a}	51.30±5.25^{a}	43.24±7.19^{a}	45.10±5.24^{a}	42.43±1.95^{a}
	Bottom	49.27±4.63^{a}	40.39±1.64^{a}	49.86±4.73^{a}	38.94±4.53^{a}	46.99±3.83^{a}	41.91±5.49^{a}
Cohesiveness	Top	0.83±0.01^{a}	0.83±0.03^{a}	0.85±0.04^{a}	0.82±0.04^{a}	0.83±0.04^{a}	0.83±0.03^{a}
	Bottom	0.85±0.01^{a}	0.82±0.02^{a}	0.83±0.03^{a}	0.81±0.03^{a}	0.82±0.04^{a}	0.81±0.02^{a}
Puncture test							
Crust Firmness (N)	Top	2.83±0.61^{a}	3.68±0.44^{a}	4.55±0.70^{abc}	4.94±2.52^{b}	3.60±0.38^{a}	5.77±3.04^{a}
	Bottom	2.63±0.54^{a}	1.27±0.64^{a}	6.14±1.95^{c}	4.24±1.82^{b}	2.46±1.34^{a}	2.64±0.30^{a}
Paste Firmness (N)	Top	1.31±0.25^{ab}	1.10±0.17^{ab}	1.39±0.22^{ab}	1.47±0.64^{b}	1.00±0.20^{a}	1.31±0.71^{ab}
	Bottom	1.28±0.33^{c}	0.67±0.25^{a}	1.20±0.44^{bc}	1.25±0.72^{bc}	0.67±0.35^{a}	0.82±0.29^{ab}
Adhesiveness (N.s)	Top	-5.24±1.18^{b}	-6.36±1.46^{ab}	-7.22±2.71^{ab}	-10.20±6.69^{a}	-7.08±2.15^{ab}	-9.69±5.59^{a}
	Bottom	-5.36±1.54^{bc}	-2.73±1.10^{c}	-14.25±7.77^{a}	-7.42±4.77^{b}	-4.15±3.52^{bc}	-4.08±1.10^{bc}
Stickiness N)	Top	-0.88±0.16^{b}	-0.91±0.18^{b}	-1.19±0.27^{ab}	-1.53±0.92^{a}	-1.01±0.25^{ab}	-1.56±0.91^{a}
	Bottom	-0.88±0.21^{bc}	-0.45±0.16^{c}	-1.87±0.95^{a}	-1.03±0.62^{b}	-0.62±0.47^{bc}	-0.66±0.11^{bc}
Spreadability test							
Hardness (N)	Top	26.67±4.81^{c}	6.39±1.96^{a}	17.58±2.47^{bc}	14.50±7.07^{ab}	10.91±1.83^{ab}	7.15±2.51^{a}
	Bottom	27.43±6.25^{b}	4.56±2.14^{a}	17.06±4.95^{ab}	17.44±9.03^{ab}	11.55±4.2^{a}	6.55±2.00^{a}
Stickiness N)	Top	-0.17±0.05^{a}	-0.23±0.14^{a}	-0.05±0.03^{a}	-0.12±0.08^{a}	-0.17±0.13^{a}	-0.11±0.05^{a}
	Bottom	-0.20±0.08^{a}	-0.19±0.06^{a}	-0.04±0.04^{b}	-0.05±0.02^{b}	-0.14±0.02^{ab}	-0.16±0.05^{ab}

[1]Values given as mean ± standard deviation. Values in the same line with the same superscript are not significantly different (ANOVA with Tukey Post Hoc, $P < 0.05$).

period considered in the milking season, but calculated as means values from the measurements made on both sides of the cheeses. The results of the compression test (Figure 4) indicate that, while for some dairies the properties kept more constant along the evaluation period considered, for others a high variability was observed. Regarding commercialization, it is important that dairies are able to provide products that minimize the variability in the organoleptic characteristics and in overall quality, to please and satisfy the consumers' expectations. While for dairies D2, D4 and D5 the soft characteristics (evaluated trough hardness and chewiness) remained just slightly unchanged over time, for dairies D1, D3 and D6 these properties were highly variable. The cheeses from dairy D1 showed a tendency to get harder along time, while for dairy D6 an opposite trend was observed, and for D3 the values obtained in May were completely out of the trend observed for April and June, when the values were very similar. Regarding adhesiveness, the values were all very small, with a maximum of about 0.5 N.s (absolute value), and therefore any variations seen in the graph do not have any true expression in the definition of the cheeses textural characteristics. For the textural properties resilience, springiness and cohesion, the most visible changes along time occur for dairies D2 and D6.

The results in Figure 5 (puncture test) indicate that the dairies who produced cheeses with a more uniform firmness were those who also had uniform hardness in

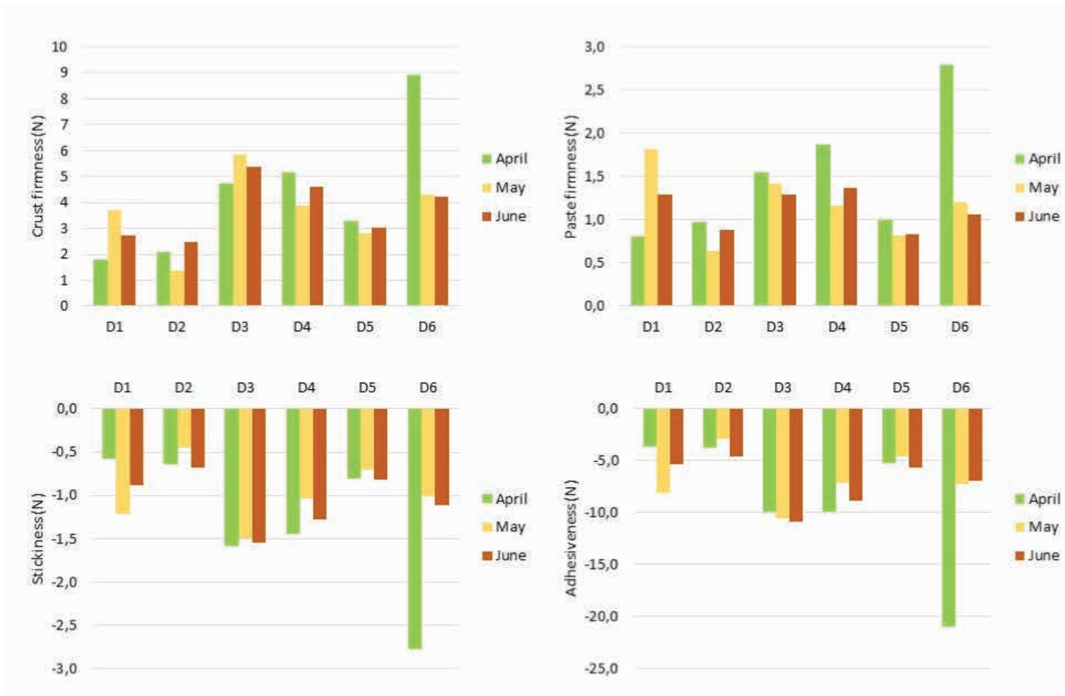

Figure 5: Variation of textural properties in the cheeses as a whole from April to June, obtained by the puncture test

Figure 6: Variation of textural properties in the cheeses as a whole from April to June, obtained by the spreadability test

the compression test, D2, D4 and D5, but in this case the samples D3 showed a uniformity of the textural properties evaluated by the puncture test, contrarily to the variability observed in the textural properties of the compression test. This indicates that samples D3 might present higher differences along time when it comes to the outer crust but inside the characteristics remain quite unchangeable along time, being these the most relevant for consumers, who primarily consume the inner paste. Nevertheless, the outer crust is also edible, and some people consume both the inner and outer parts of the Serra da Estrela Cheese, although valuing more the soft paste inside. Regarding stickiness and adhesiveness, samples from dairies D2, D3, D4 and D5 showed a residual variability along time, with D1 and D6 presenting the highest variations, most particularly in April for the cheese from dairy D6.

The results of the spreadability test (Figure 6) showed important differences along time for dairies D1, D3 and D6 when it comes to hardness but only for dairy D6 in terms of stickiness. These results obtained for hardness are is accordance with those of the compression test previously discussed.

4 Correlations

Pearson correlations between all the variables studied are presented in Table 3, corresponding to the textural properties obtained with the different tests. Generally, the properties from the puncture test did not correlate much with those from the compression or spreadability tests, which is expected given the highly different natures of each test: some corresponding to measurements on the surface (compression and spreadability) and the other comprising penetration inside the sample. Conversely, for the compression test alone, there are important correlations, as for example between chewiness and hardness (r = 0.997) which is a very strong correlation or between hardness and resilience (r = 0.733), hardness and springiness (r = 0.605), resilience and springiness (r = 0.721), chewiness and resilience (r = 0.759), springiness and cohesiveness (r = 0.716) and finally chewiness and springiness (r = 0.631), being all these considered strong correlations (values between 0.6 and 0.8). In the first case the very strong correlation found was expected, given that chewiness is directly related to hardness as demonstrated by Equation (6).

Analysing the correlations for the puncture test (Table 3), three correlations were found very strong: stickiness *versus* crust firmness (r = -0.916), adhesiveness *versus* crust firmness (r = -0.903) and adhesiveness *versus* stickiness (r = 0.987), being some of them with negative sign indicating that crust firmness is higher for lower values of stickiness and adhesiveness. This is expected, since softer cheeses tend to have a smoother paste. Besides these, all the other correlations for the puncture textural properties between themselves were strong: inner firmness *versus* crust firmness (r = 0.790), inner firmness *versus* stickiness (r = -0.790) and inner firmness *versus* adhesiveness (-0.744). Again, in some of these cases the correlations were negative, which means that the variables are inversely correlated, i.e., by increasing one variable the other decreases accordingly.

Finally, the values of r found for the properties of the spreadability test (Table 3), revealed only two very strong correlations and these were between hardness of the spread and compression tests (r = 0.814) and between hardness of the spread test and chewiness (r = 0.817). Again, these results were not surprising, having in consideration that these two tests measure hardness by compression on the surface and that chewiness is so much related to hardness as previously stated. Another two correlations were strong: hardness (spread) *versus* resilience (r = 0.692) and *versus* internal firmness (r = 0.621).

5 Factor analysis

The analysis of the correlation matrix revealed some correlations between the variables, with 26 values higher than 0.4, being the highest value very close to 1 (0.997), which reflects some important correlations between the variables, thus allowing the application of FA. The value

Table 3: Pearson correlations between the textural properties

	Property[1]	Compression						Puncture				Spread	
		HAR	**ADH**	**RES**	**COH**	**SPR**	**CHE**	**CRFIR**	**INFIR**	**STI**	**ADHP**	**HARS**	**STIS**
Compression	**HAR**	1											
	ADH	0.085	1										
	RES	**0.733****	0.204	1									
	COH	0.497**	0.144	0.586**	1								
	SPR	**0.605****	0.001	**0.721****	**0.716****	1							
	CHE	**0.997****	0.083	**0.759****	0.425**	**0.631****	1						
Puncture	CRFIR	0.329**	0.335**	0.383**	0.362**	0.303**	0.346**	1					
	INFIR	0.392**	0.252*	0.376**	0.319**	0.288**	0.406**	0.790**	1				
	STI	-0.380**	-0.290**	-0.424**	-0.366**	-0.337**	-0.399**	**-0.916****	**-0.790****	1			
	ADHP	-0.343**	-0.286**	-0.399**	-0.369**	-0.299**	-0.363**	**-0.903****	**-0.744****	**0.987****	1		
Spread	**HARS**	**0.814****	0.151	**0.692****	0.355**	0.502**	**0.817****	0.545**	**0.621****	-0.573**	-0.543**	1	
	STIS	-0.103	0.328**	0.047	0.026	-0.012	-0.095	0.153	-0.005	-0.058	-0.062	-0.121	1

[1]HAR = Hardness, ADH = Adhesiveness, RES = Resilience, COH = Cohesiveness, SPR = Springiness, CHE = Chewiness, CRFIR = Crust firmness, INFIR = Inner Firmness, STI = Stickiness, ADHP = Adhesiveness (puncture), HARS = Hardness (spreadability), STIS = adhesiveness (Spreadability).
*Correlation is significant at the $P < 0.05$ level. **Correlation is significant at the $P < 0.01$ level.

of KMO was good (0.80) according to the classification of Kaiser and Rice (Kaiser and Rice 1974), and furthermore the results of the Bartlett's test indicated adequacy for applying FA (*P*-value was significant; $P < 0.0005$), thus leading to the rejection of the null hypothesis that the correlation matrix was equal to the identity matrix. By analysing the anti-image matrix, it was found that practically all values of MSA (Measure of Sampling Adequacy) were over 0.5, denoting that, in general, the variables were proper for inclusion in the analysis (Values of MSA for the variables: HAR = 0.734, ADH = 0.705, RES = 0.906, SPR = 0.7536, CHE = 0.743, COH = 0.732, CRFIR = 0.920, INFIR = 0.812, ADHP = 0.724, STI = 0.717, HARS = 0.911), just with exception of stickiness from the spreadability test, whose value was lower than 0.5 (STIS = 0.323). For this reason, the mentioned variable was not included in the following analysis which consisted in the rotation of FA with PCA, thus giving two components, based on the Keiser criterion to consider eigenvalues greater than 1. This solution explained 97.2% of total variance, distributed by the two factors like this: F1 – 92.4%, F2 – 4.8%.

The communalities for the extracted variables were: HAR = 0.999, ADH = 0.101, RES = 0.627, SPR = 0.413, CHE = 0.998, COH = 0.355, CRFIR = 0.658, INFIR = 0.583, ADHES = 0.720, STI = 0.722, HARS = 0.886). The analysis of the communalities revealed that the variables hardness and chewiness (compression test) had the largest fraction of variance explained by the solution, corresponding to 99.9% and 99.8%, respectively, followed by hardness from the spreadability test (88.6%). Nevertheless, there were some variables with communalities lower than 0.4, adhesiveness and cohesiveness, both from the compression test.

The rotation converged in three iterations and extracted two factors, as previously mentioned, which grouped the variables as shown in Table 4. The second factor was clearly linked to textural properties that were determined by the puncture test, differentiating from the properties determined by the other two tests, and that were grouped into factor 1. This is in accordance with the nature of the tests, since puncture involved the penetration inside the sample, while the other two tests are performed on the external surface.

The loading of the variables in factor 2 were very high (absolute values), being the lowest equal to 0.702, which reveals that all variables contributed importantly for the definition of this factor. On the other hand, for the properties of the compression test different degrees of importance were found, with variables hardness, chewiness and resilience contributing more strongly for the factor when compared with springiness or cohesiveness. Finally, hardness from the spreadability test also loaded into factor 1,

Table 4: Component matrix obtained by factor analysis with Varimax rotation

		Factor 1 (external pressure textural properties)	Factor 2 (perforation textural properties)
Compression	HAR	0.990	(*)
	ADH	(*)	(*)
	RES	0.717	(*)
	COH	0.450	(*)
	SPR	0.597	(*)
	CHE	0.988	(*)
Puncture	CRFIR	(*)	0.781
	INFIR	(*)	0.702
	STI	(*)	-0.797
	ADHP	(*)	-0.810
Spread	HARS	0.764	(*)

[1]HAR = Hardness, ADH = hesiveness, RES = Resilience, COH = Cohesiveness, SPR = Springiness, CHE = Chewiness, CRFIR = Crust firmness, INFIR = Inner Firmness, STI = Stickiness, ADHP = Adhesiveness (puncture), HARS = Hardness (spreadability)
(*) Loading under 0.4 were excluded.

with a high value (0.764), following what happened with hardness from compression test. The variable adhesiveness-compression did not show a representative loading in any of the factors considered (load under 0.4).

6 Conclusion

This investigation confirmed the interest in performing more than one type of test for texture analysis, because the results obtained allow a complementing evaluation of different aspects related to the texture of cheese. Regarding the textural properties of the Serra da Estrela cheeses evaluated, some differences were observed between the top and bottom sides of the cheeses, as well as between cheeses from different dairies, except for the properties springiness, resilience, cohesiveness and adhesiveness (all from compression test), for which no significant differences were found. In what concerns the variations along the milking season, it was possible to conclude that dairies D2, D5 and D4 were those that produced cheeses with a more constant textural profile along the time considered, which for this study was between April and June.

The correlations between the textural properties were strong for some interactions between properties from the same test and/or from similar nature, like the evaluations made by compression or spreadability of the external surface. Finally, factor analysis clearly identified two factors, one strongly associated with the external pressure textural properties and the other with the perforation textural properties.

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