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Prediction of Texture Sensory from Instrumental Measurements in Processed Cheeses with Different Fat Contents

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Abstract

This study evaluated the correlation between instrumental and sensory textural measurements of light processed cheeses. Nine formulations of cheeses with different contents of fat and moisture were processed. The sensory characterization of cheese texture was performed using Quantitative Descriptive Analysis. Nine trained judges evaluated the texture attributes "consistency", "viscosity", "adhesivity" and "spreadability" using an unstructured 9-centimeter scale. Rheological evaluations were measured at 10 and 25 ºC in a rotational rheometer, HAAKE MARS, using a serrated parallel plate sensor with a 1 mm gap. "Yield stress", "apparent viscosity (η_{10})" and the mechanical spectra of cheeses at a frequency range from 0.01 Hz to 10 Hz were measured. Instrumental parameters, including "firmness", "chewiness", "gumminess", "cohesiveness" and "springiness", were also measured in a mechanical universal testing machine (Instron). All instrumental measurements, except "cohesiveness", correlated with the sensory attributes of texture ($|r| > 0.50$ and $p < 0.10$).

Keywords: Rheology, Texture Profile Analysis, Descriptive Analysis

1. Introduction

Texture properties are increasingly recognized as important attributes of the quality, acceptability and consumption of food (Szczesniak, 2002). Sensory descriptive methods can determine the most desirable consumer characteristics of cheeses and differentiate different types of cheeses to segment consumers by preference (Murray & Delahunty, 2000; Bleibaum et al., 2002; Meilgaard et al., 2006). Texture characteristics are sensory properties by definition (IS0 1981), and diverse instrumental techniques for the evaluation of texture are encountered in the literature.

However, sensory evaluation in the food industry is difficult due to the cost and time required for training and leading a sensory panel. The use of instrumental methods that correlate with sensory measures is an interesting alternative because instrumental measurements are usually cheaper and easier to control (Lassoued et al., 2008).

Many instrumental methods to determine the properties of food texture have been developed (Bourne, 2002). Texture Profile Analysis has been effectively applied to a range of foods, including chocolate (Martínez-Cervera et al., 2011), yogurt (Sandoval-Castilla et al., 2004), dulce de leche (Ares et al., 2006), ice cream (Lim et al., 2008), apples (Perera et al., 2010), juice (Guillermin et al., 2006), bread (Wang et al., 2007), snacks (Bower & Whitten, 1999), sausage (Dong, 2009), rice (Prakash et al., 2005), wine (Meullenet et al., 1998) and cheeses (Lemay et al., 1994; Guinee et al., 2000; Messens et al., 2000; Gonzalez et al., 2001; Irigoyen et al., 2002; Van Hekken et al., 2007). Instrumental measurements of hardness are well correlated with sensory hardness and springiness, but instrumental techniques do not accurately profile the entire sensory textural experience. Tamime et al. (1999) evaluated the sensory and instrumental measurements of the texture of processed cheeses with fat substitutes and reported that spreadability was positively correlated ($p < 0.05$) with the instrumental parameter elasticity and negatively correlated with cohesiveness. A significant correlation ($|r| > 0.50$ and $p < 0.10$) between the sensory and instrumental measurements of firmness in Manchego cheese has also been observed (Gonzalez-Vinas et al., 2001).

Many complications are associated with the development of imitative tests. Mimicking the human sensory experience requires the simulation of the physical changes that occur in the mouth due to salivary interactions and changes in phase and temperature. Mastication is also a dynamic process, and traditional mechanical tests only measure a ‘single’ event, the forces and deformations that are associated with the ‘first’, and sometimes ‘second’, bite during consumption (Brown et al., 2003).

The accurate measurement of the fundamental rheological properties to determine their role in sensory texture is one alternative approach. Fundamental rheological properties are theoretically linked to the gel network structure and interactions. Therefore, these properties provide insight into the molecular basis of texture (Brown et al., 2003). Irigoyen et al. (2002) verified the correlations between the subjective (sensory) and fundamental (rheological) tests of the texture of low-fat cheeses using a stepwise procedure that fit the prediction models to the instrumental sensory measurements.

The final product composition, including variable concentrations of fat, moisture and casein in the cheese matrix, primarily affects the cheese texture (Jack & Paterson 1992; Irigoyen et al., 2002). These constituents greatly influence the sensory and instrumental textural properties of cheese and affect the sensory and rheological parameters (Pereira et al., 2005). Fat content is primarily related to cheese texture because of the structural distribution of protein and fat; proteins form an open matrix that traps fat globules within the cells (Bryant et al., 1995). The amount of fat distribution within the cells of the matrix protein determines the deforming ability of the cheese in response to stress; an increase in the fat-to-protein ratio weakens the protein structure and increases cheese flexibility.

A growing demand for low-fat dairy products exists in the marketplace because of the potential association between high saturated fatty acid and cholesterol levels with cardiovascular diseases such as arteriosclerosis (Pearce, 1996). Consumers reject low-fat cheeses with elevated casein concentrations, which strengthen the protein-protein interactions and increase the cheese firmness (Sheehan & Guinee, 2004; Floury et al., 2009). The dissolution of the matrix protein by increasing the moisture content of the product enables the recovery of creaminess and satisfies the consumer demand for low-fat cheese (Olson and Price, 1961; Zalazar et al., 2002).

The present study evaluated the texture properties of processed cheeses with different levels of fat and moisture using subjective, imitative, and fundamental methods and correlated measurements of sensory texture with the mechanical properties.

2. Material and Methods

2.1 Samples

Nine formulations of low-fat processed cheese were utilized. The Central Composite Rotatable Design (CCRD) was used with two factors (fat and moisture) at two levels (2^2), and four axial points (2x2) and the central point to define the formulations. The central point was repeated three times to estimate the pure error for a total of 11 trials (2^2 + 2x2 + 3) (Figure 1).

The processed cheese samples were produced through the direct hot acidification of milk at 70 °C in accordance with previous technology (Alves et al., 2007). Products were composed of a dairy mass (raw skim milk, lactic acid 85% PA), cream (Funarbe), water, whey protein concentrate (2.0% - WPC 34% - Gemacom), NaCl (0.80% - Cisne), emulsifying salts (0.70% - Joha S9) and potassium sorbate (0.020% - Gemacom) and nisin (0.017% - Danisco) as preservatives. Processing was performed in an open pan with mechanical agitation. The addition of ingredients to the different formulations was controlled by mass balance, which varied the total content of fat and water between products. The products were stored under refrigeration (10 ± 1 °C) prior to instrumental and sensory analyses.

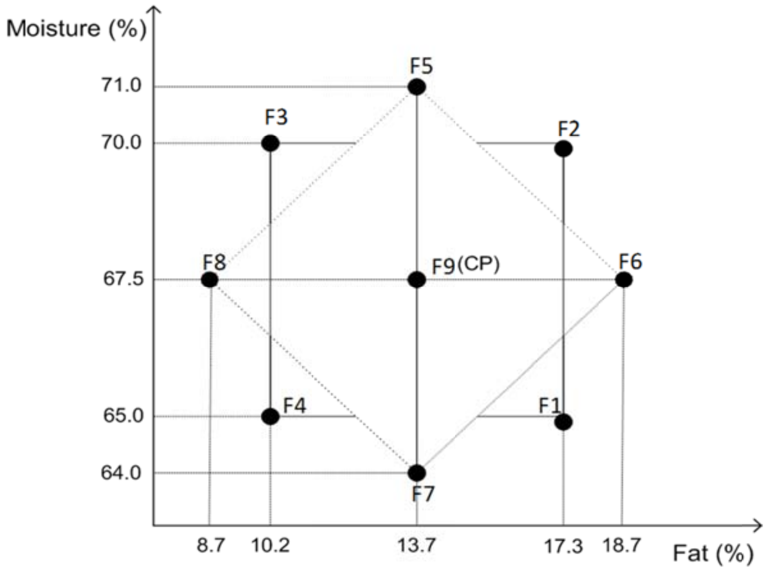


Figure 1. Disposition of the experimental points in the Central Composite Rotatable Design.

2.2 Chemical Analysis

Chemical analyses (moisture, fat and protein contents) of the experimental cheeses were performed in duplicate according to Pereira et al. (2001).

2.3 Instrumental Analysis

2.3.1 Texture Profile Analysis

The TPA was performed in a universal testing machine (Instron – Series 3367, United Stated 2005) at 10°C. A double compression cycle test was performed to a 20% compression of the original portion height (40 mm high and 50 mm diameter) using a 15-mm aluminum cylinder probe and a 5 s gap between compression cycles. Force–time deformation curves were obtained using a 1 KN load cell at a crosshead speed of 1.0 mm/s (Gallina et al., 2008). Firmness (N), chewiness (J), gumminess (N), cohesiveness (dimensionless) and springiness (mm) were quantified by automatic evaluation of the force (N) x time (s) curves in Blue Hill 2.0 software (Instron, United States, 2005) (Bourne 1978). All measurements were performed five times, and repetitions of the central point estimated the pure error.

2.3.2 Rheological Analysis

The rheological measurements were performed using a Modular Advanced Rheometer System (HAAKE MARS, Thermo Electron Corp., Germany) equipped with a water bath (Phoenix 2C30P, Thermo Electron Corp., Germany) and a serrated parallel plate system, PP 20S DIN (20 mm diameter), with a 1 mm gap size for all formulations. All of the measurements were performed at 10 and 25 ± 0.15ºC, and the samples were maintained at rest for 5 minutes for temperature stabilization and structural rearrangement. A new sample was used in each test.

Rotational Tests - The apparent viscosity (η_{ap}) and yield stress (τ_o) of all formulations were determined. Samples were subjected to a constant shear rate of 10 s^{-1} for 5 min to eliminate thixotropic effects and obtain the apparent viscosity. The yield stress values were obtained using the tangent crossover method. Steady stress sweep measurements were obtained across a range of steady stress rates (5 -1800 Pa) at 120 s.

Oscillatory Tests – The viscoelastic properties of processed cheeses were determined. The linear viscoelastic region was determined using oscillatory stress sweeps between 0.1 to 500.0 Pa at 1.0 Hz. The results indicated that shear stresses of 0.3 Pa, 10.0 Pa and 115.0 Pa were in the linear viscoelasticity range for formulation groups F2, F5 and F6, F1, F3 and F9, and F4, F7 and F8, respectively. Frequency sweeps were performed from 0.01 to 10 Hz to determine the mechanical spectra of the processed cheeses and obtain the elastic (G') and viscous (G") moduli values. The tan δ (G'"/G') was calculated for each point. Temperature sweeps were also performed from 5°C to 35ºC at frequency of 1 Hz to verify the viscoelastic behavior of the processed cheeses as a function of temperature. The measurement data were analyzed using the Haake RheoWin Data Manager.

2.4 Sensory Evaluation

A trained panel performed sensorial characterizations of the formulations using Quantitative Descriptive Analysis (QDA) (Stone et al., 1974; Stone & Sidel, 2004). The sensory panel was composed of nine trained judges (six females and three males between 20 and 32 years old) who were selected based on their discrimination ability between samples ($p.F_{SAMPLE} < 0.50$), the repeatability of results ($p.F_{REPETITION} > 0.05$) and consensus with a panel of judges, as recommended previously (Damásio & Costell, 1991). Testing was performed in a sensory laboratory that was equipped with individual booths (ISO 1988). The intensities of the sensory attributes ''consistency'', ''spreadability'', "viscosity" and "adhesivity" were scored on 9-centimeter nonstructured line scales from ''low'' (0) to ''high'' (9). The sensory attributes evaluated were: consistency (Force necessary to spread the cheese with a spoon), spreadability (Ability to spread the cheese on a cracker with a spoon), viscosity (Force necessary to pull the cheese from the spoon to the mouth) and adhesivity (Force necessary to remove the cheese which adheres to the palate).

"Consistency" and "spreadability" were evaluated using a plastic spoon (visual evaluation). A saltine cracker was used to evaluate spreadability of the samples. "Viscosity" and "adhesivity" were evaluated orally (i.e., oral evaluation). Samples at 10°C were presented to the judges at room temperature (25°C). A balanced complete block experimental design evaluated the samples with repetitions of the central point to estimate the pure error. The samples were served randomly on a separate plastic tray, and each sample was identified with a three-digit random code. The judges evaluated only one sample per session, and judges rinsed their mouths with mineral water between sample evaluations.

2.5 Statistical Analysis

One-way (samples) analysis of variance (ANOVA) was performed on the instrumental measurements to evaluate differences between the processed cheese samples. The G’, G” and tan δ values at 4.64 Hz were used to statistically analyze the results. Two factors, samples and assessors, were considered in the ANOVA for sensory parameters (i.e., complete block experimental design). The principal component analysis (PCA) with varimax rotation and the average values of sensory parameters were applied to the correlation matrix.

The correlations between the instrumental and sensory texture measurements were determined using the PCA and *Pearson* correlation coefficient (r). Regression analysis was used to model the relationship between the instrumental and sensory data. The instrumental parameters of texture (TPA) and rheological parameters at 10ºC were correlated with the sensory attributes that were visually examined at 10ºC ("consistency" and "spreadability"). "Viscosity" and "adhesivity" were correlated with the rheological measurements at 25°C. According to Engelen et al. (2003), 25ºC is the mean oral temperature during the consumption of semisolid foods at 10ºC. All analyses were performed using the SAS statistical program version 9.1 (SAS Institute, Inc., Cary, NC, USA).

3. Results and Discussion

3.1 Chemical Analysis

The fat, moisture and protein contents of light processed cheeses are presented in Table 1. Different combinations of fat and moisture produced cheese samples with different matrix protein contents. A reduction in fat and moisture content increased cheese protein (casein) levels. These results are similar to Soares et al. (2002) and Cunha et al. (2006) for the centesimal composition of low-fat cheeses.

Table 1. Centesimal composition of the light processed cheese samples

Processed cheeses	Moisture (%)	Fat (%)	Protein (%)
F1	64.90 ± 0.10	16.50 ± 0.20	14.02 ± 0.25
F2	69.75 ± 0.10	16.40 ± 0.10	10.01 ± 0.20
F3	69.75 ± 0.10	10.50 ± 0.13	14.35 ± 0.25
F4	65.47 ± 0.10	11.50 ± 0.32	18.14 ± 0.04
F5	71.02 ± 0.10	13.00 ± 0.18	12.07 ± 0.30
F6	67.20 ± 0.00	18.50 ± 0.53	10.54 ± 0.09
F7	63.50 ± 0.10	13.10 ± 0.08	18.46 ± 0.25
F8	66.67 ± 0.05	8.45 ± 0.13	19.40 ± 0.17
F9	67.23 ± 0.24	13.20 ± 0.18	15.49 ± 0.24

Fat and moisture inversely influenced the percentage of protein in the processed cheese samples; products with different combinations of fat and moisture (F1, F3 and F9) presented similar matrix protein levels (approximately 14.6%) due to moisture compensation in the protein content, which was generated by the fat reduction. Elevated protein content (approximately 18.7%) was observed when fat reduction did not accompany the increase in moisture content (F4, F7 and F8). However, the processed cheese samples with greater percentages of fat also presented elevated moisture content (F2, F5 and F6) and low protein levels (approximately 10.9%).

3.2 Instrumental Analysis

3.2.1 Texture Profile Analysis (TPA)

ANOVA indicated that different combinations of fat and moisture affected firmness, gumminess, chewiness, elasticity and cohesiveness ($p < 0.10$). The averages of each sample and the relationships to the instrumental measurements are presented in Table 2.

Table 2. Means of the texture properties of the light processed cheeses

	Texture Properties				
	Firmness (N)	Gumminess (N)	Chewiness (J)	Choesiviness (dimensionless)	Elasticity (mm)
F1	0.29	0.25	1.18	0.87	4.46
F2	0.02	0.02	0.00	1.20	0.00
F3	0.23	0.08	0.00	0.96	0.00
F4	1.64	1.26	8.78	0.77	6.95
F5	0.04	-0.04	0.00	-1.24	0.00
F6	0.02	0.03	0.00	1.45	0.00
F7	1.93	1.42	10.09	0.74	7.10
F8	2.34	1.58	10.51	0.67	6.66
F9	0.23	0.23	0.92	0.96	4.16
MSE	0.0002	0.0006	0.0112	0.0003	0.0156

MSE: mean square error; N: Newton; J: Joule; mm: millimeter.

The F4, F7 and F8 formulations (high casein matrix) exhibited greater intensities of firmness, gumminess, chewiness and elasticity, but the F2, F5 and F6 formulations (low casein matrix) presented lower intensities in these parameters. Processed cheeses F1, F3 and F9 (intermediate casein content) demonstrated intermediate intensities on instrumental measurements. These results demonstrate the relationship between these constituents with the protein matrix. A lower fat and moisture content yields a greater casein content, which favors protein-protein interactions and causes a hardening of the curd. The increase in texture strength properties following a reduction in the fat content of the curd is consistent with previous studies (Rudan et al., 1999; Sheehan & Guinee, 2004; Cunha et al., 2006; Floury et al., 2009; Silva et al., 2012). The combination of different fat and moisture levels yielded products with different texture profiles.

3.2.2 Rheological Measurements

All of the rheological parameters of light processed cheeses, such as yield stress, apparent viscosity, elastic and viscous moduli, and tan δ, were significantly different ($p < 0.10$, F test).

Rotational Tests - The measurements of the rheological properties at two temperatures (10°C and 25ºC) are presented in Table 3. The yield stress (τ_o) and apparent viscosity (η_{ap}) decreased with increasing temperature. This result is generally observed in cheese (Rosenberg et al., 1995) because the temperature increase promotes a weakening of protein-protein interactions and partially liquefies fat (Hennelly et al., 2006).

Table 3. Measurements of the rheological properties at 10ºC and 25ºC

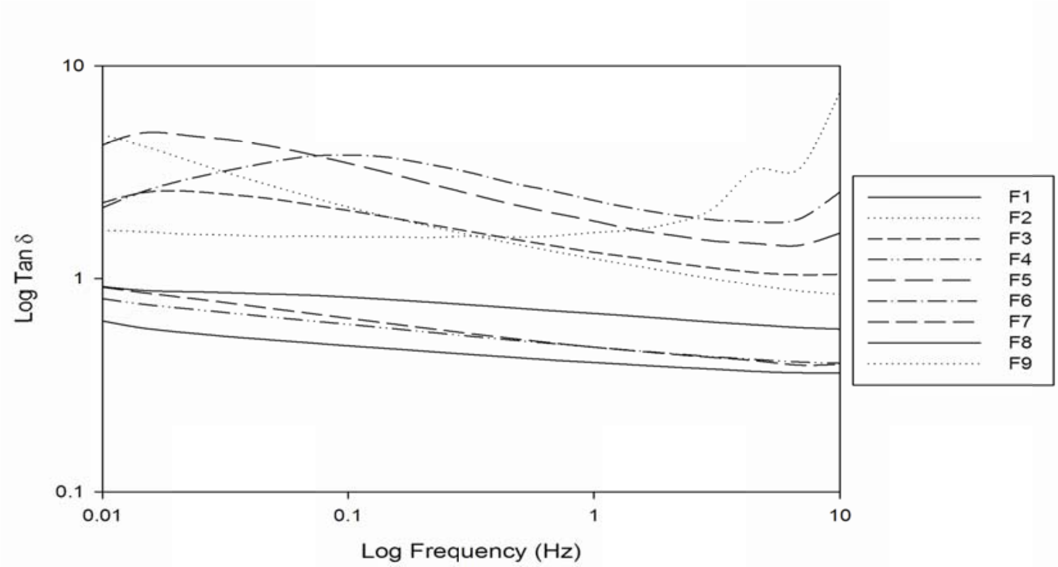
Processed chesses	Temperature 10ºC		Temperature 25ºC	
	τ_o (Pa)	η_{ap} (Pa.s)	τ_o (Pa)	η_{ap} (Pa.s)
F1	318.50	96.83	158.10	33.89
F2	10.22	5.41	6.20	4.47
F3	171.01	60.68	115.40	23.15
F4	1112.00	137.76	740.60	46.58
F5	14.07	19.85	11.50	9.07
F6	14.61	8.83	7.80	6.83
F7	935.30	137.05	614.90	32.87
F8	1669.00	154.47	878.70	46.58
F9	188.93	105.07	135.67	34.09
MSE	1.1630	82.6987	223.8530	5.5714

MSE: mean square error; τ_o: yield stress; η_{ap}: apparent viscosity.

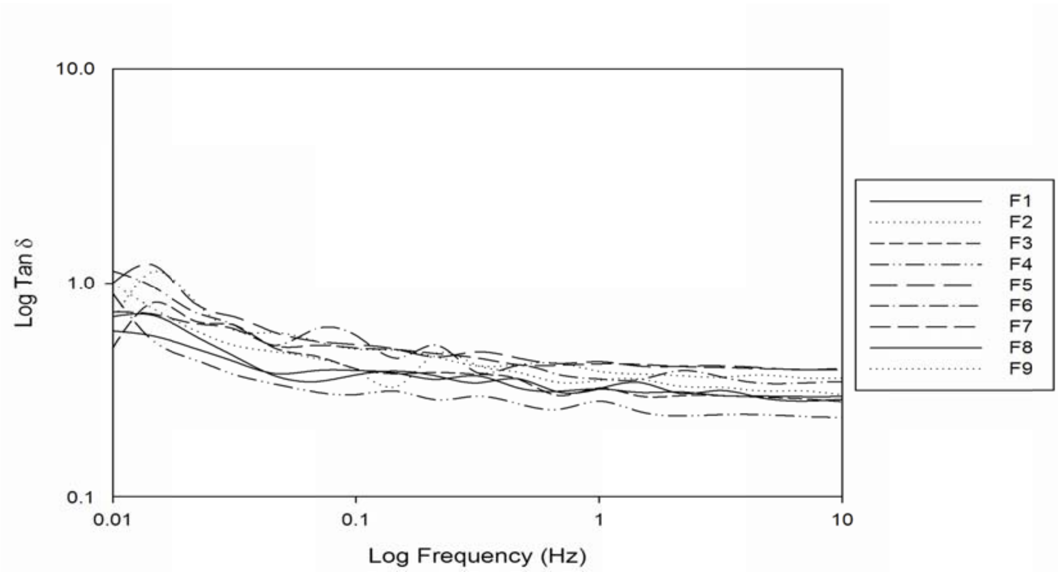
Oscillatory Tests - Figure 2 illustrates the predominant viscoelastic behavior of the formulations in the studied frequency ranges at 10°C (a) and 25°C (b). The formulations with higher moisture content and the same fat content yielded greater tan δ values at high frequencies at 10°C. Fat content also increased the intensity of this rheological parameter.

The tan δ value increased as a function of fat content at the same moisture level; formulations F8, F9 and F6 exhibited 8.7% and 18.7% fat, respectively. The same behavior was observed in cheeses F2 and F3 (70% moisture) and formulations F4 and F1 (65% moisture). Therefore, the higher fat content formulations and higher moisture levels produced higher tan δ values (i.e., these cheeses exhibited fluidity characteristics). All formulations demonstrated the viscoelastic behavior of a concentrated solution at 25°C because of the crossing of components (G' and G"') at a very low frequency, which demonstrated the predominance of the elasticity component. Viscoelasticity measurements (G' and G") increased with temperature, and the tan δ value was less than 1 for all formulations, which suggested a strengthening of the protein matrix.

A temperature scan (5°C to 35ºC) was performed at 1 Hz to verify the viscoelastic behavior of processed cheese. Figure 3 illustrates the curves of the temperature sweeps. The curves of the temperature sweeps revealed that the G' (Figure 3a) and G" (Figure 3b) moduli demonstrated the viscoelastic behavior that is commonly observed in cheeses at 22°C. However, exceeding this temperature elicited a sudden change in the behavior of the processed cheeses, and the G' and G" values increased with increasing temperature. Hennelly et al. (2006) reported a similar viscoelastic evaluation of imitation cheese supplemented with inulin; the cheeses with lower inulin content and the control behaved like typical cheese (i.e., G' and G" decreased with increasing temperature). However, the viscoelasticity moduli demonstrated an abrupt increase at high temperatures in formulations with higher inulin concentrations, which was caused by the gelling matrix of the cheese. The weak link between inulin and water leads to development of a gelled structure.



(a)

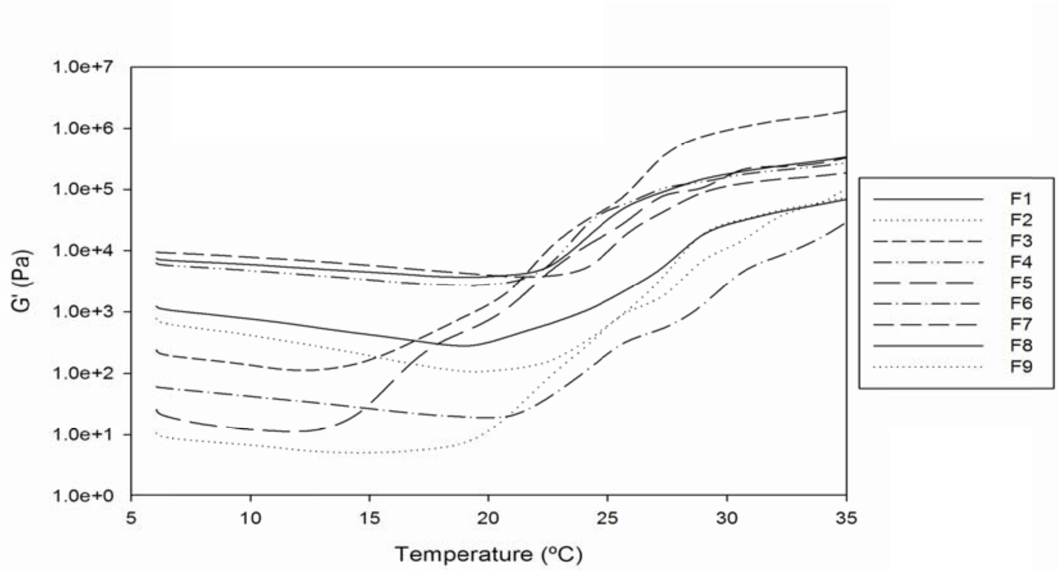


(b)

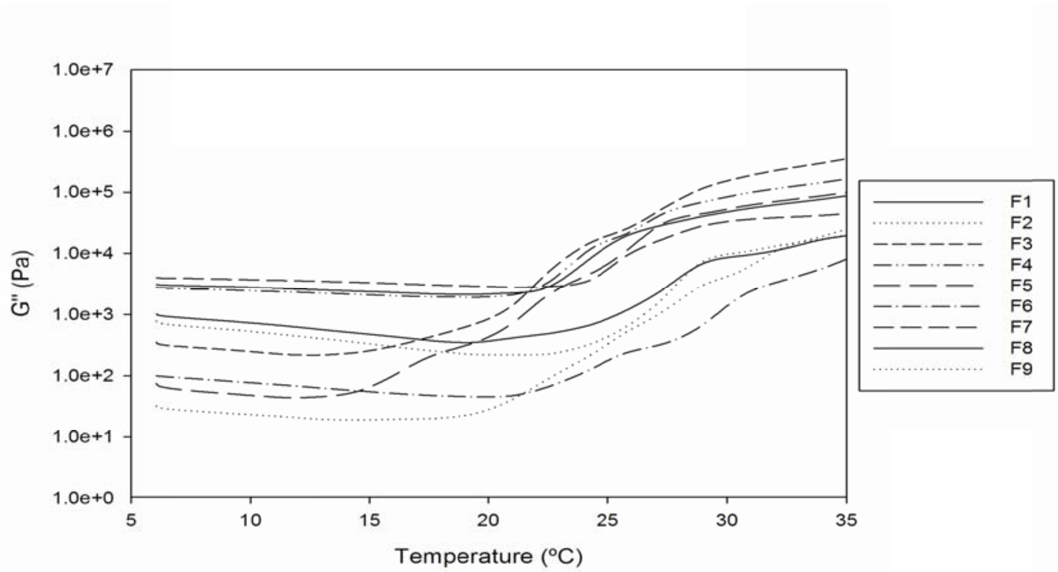
Figure 2. Predominant viscoelastic behavior of light processed cheeses. (a) Tan δ at 10ºC. (b) Tan δ at 25ºC.

Ingredients such as starch, guar gum, microcrystalline cellulose (MCC) and whey protein concentrate (WPC) form gels during temperature increases, which immobilizes large amounts of water and decreases the mobility of molecules (Cunha, 2007). WPC also forms aggregates with casein at approximately 25ºC, which strengthens the protein matrix via protein-protein bonding (Cunha, 2007). Therefore, the results in this study may be due to the interaction of

WPC with the water content, which strengthened protein-water interactions in the casein matrix with increasing gelation temperatures.



(a)



(b)

Figure 3. Viscoelastic behavior of processed cheeses from 5 to 35ºC at 1 Hz. (a) Elastic moduli. (b) Viscous moduli.

3.3 Sensory Analysis: Quantitative Descriptive Analysis

The sensorial panel included nine judges who demonstrated satisfactory discrimination and repeatability of results (Damásio & Costell, 1991). The sample x judge interaction was significant for all attributes. Therefore, the principal effect (samples) was recalculated using the interaction mean square as the denominator. The processed cheese samples differed among themselves ($p < 0.001$, F test) for all texture attributes.

The PCA revealed that the first principal component explained 91.96% of the data variation (Figure 4), and this component sufficiently discriminated the sensorial attributes of the formulations. However, only one dimension was considered. The spatial separation of the nine formulations suggested the formation of three distinct groups: (i) samples F4, F7 and F8; (ii) formulations F1, F3 and F9; and (iii) formulations F2, F5 and F6. Sensorial attributes are represented by vectors. Each abscissa and ordinate of a vector is a linear correlation between a sensorial attribute and the first and second principal component, respectively. All attributes were correlated ($p < 0.10$) with the first principal component.

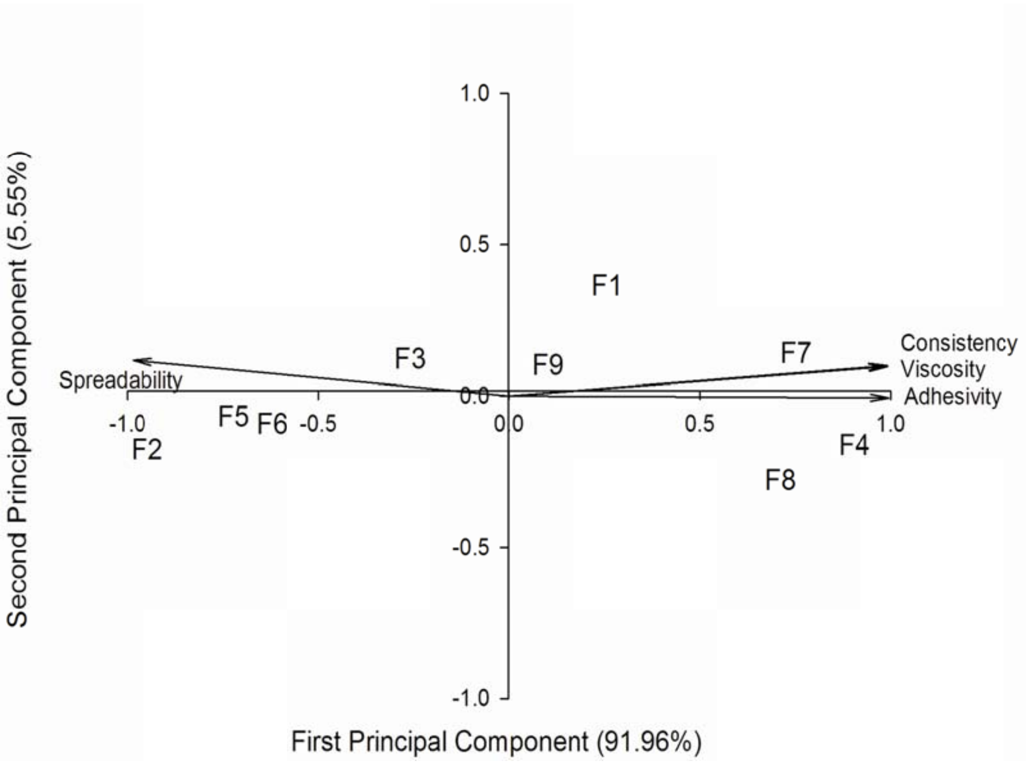


Figure 4. The relationship of the sensorial descriptors and the light processed cheese samples to the two principal components.

Formulations F4, F7 and F8 exhibited greater intensities in consistency, viscosity and adhesivity, which is due to the relationship between the fat and moisture content of the processed cheese and the protein content. The formulations with lower levels of fat and moisture exhibited a high casein content. These formulations caused a hardening of the matrix proteins due to the elevated number of protein-protein interactions, which increased the intensity of these texture attributes (Fox & Guinee, 2000). Formulations F2, F5 and F6 were characterized by spreadability, which exhibits an inverse relationship with consistency and viscosity. The more viscous samples exhibit an inferior spreadability on a cracker (Garruti et al., 2003). The formulations with greater casein percentages (F4, F7 and F8, i.e., lower fat and moisture content) exhibited the opposite behavior. Formulations F1, F3 and F9 were located in the central region of the graph, which indicated an intermediate intensity of these attributes. A reduction in fat and a gradual increase in moisture content produce sensorial similar cheeses (Verma & Gupta, 1981).

3.4 Correlation: Sensory and Instrumental

Visual Texture - Figure 5 presents the Principal Component Analysis of the rheological measurements at 10ºC and the sensory texture attributes that were evaluated visually (e.g., consistency and spreadability). Only one dimension was considered because the first component explained 99.7% of the data variance. Consistency, apparent viscosity, initial stress, G', G", gumminess, firmness, elasticity and chewiness were positively correlated ($p < 0.10$) with the first principal component, which indicated that these attributes exhibit the same linear trend. These results also suggest a direct correlation between these attributes because they are positively correlated with the same main component, which has been suggested by Bleibaum et al. (2002), Salvador et al. (2009) and Silva et al. (2012). The sensory attribute spreadability and instrumental measures were inversely correlated ($p < 0.10$) with the first principal component. The Pearson correlation coefficient confirmed the correlations that were suggested by the PCA, and significant correlations ($|r| > 0.50$ and $p < 0.05$) were observed for all of the comparisons mentioned above. A positive correlation ($p < 0.01$) between the viscoelasticity (G' and G'') and consistency of cheese textures has been previously observed (Pereira et al., 2005).

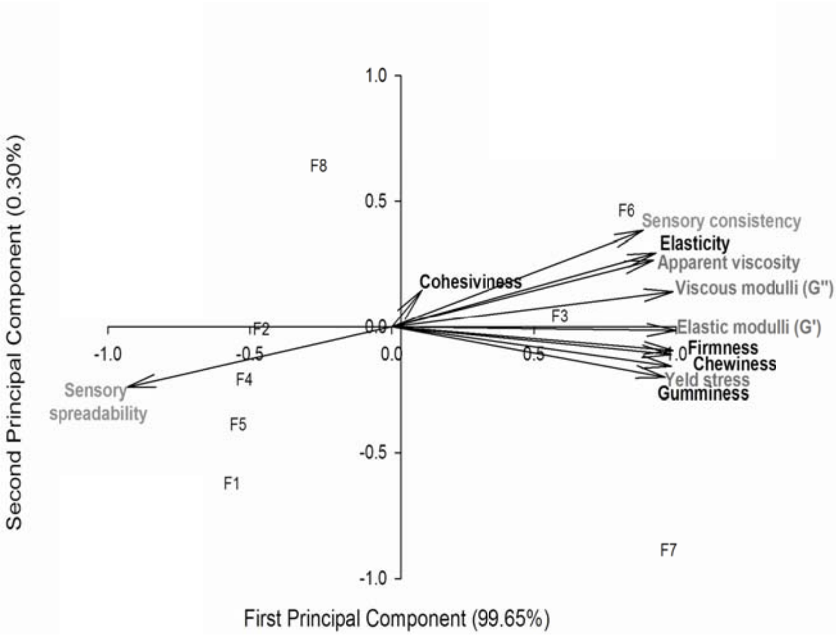


Figure 5. Correlations of sensory and instrumental properties of texture measurements at

10ºC.

Oral Texture – Figure 6 presents the Principal Component Analysis (PCA) of the rheological measurements at 25ºC and the orally evaluated sensory texture attributes (viscosity and adhesiveness). Only one dimension was considered because the first component explained 99.9% of the variance. Viscosity and adhesiveness were positively correlated ($p < 0.10$) with the first principal component, and therefore, these attributes can be directly associated with initial tension, viscosity, G' and G". The Pearson correlation analysis confirmed the correlations between the sensory and instrumental measurements at 25ºC. The correlation between oral viscosity and apparent viscosity at 10 s^{-1} confirmed the proposal of Shama and Sherman (1973), which suggested that the value of apparent viscosity at a strain rate of 10 s^{-1} is a sensory consistency index of semisolid products.

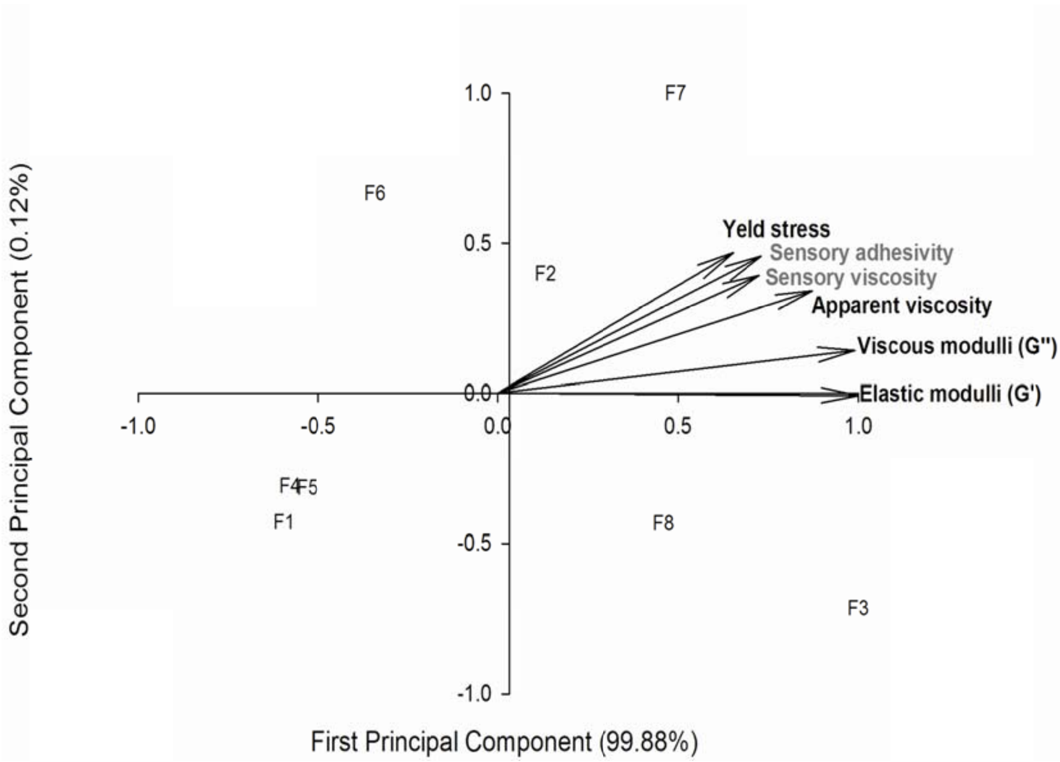


Figure 6. Correlations of sensory and instrumental properties of texture measurements at 25ºC.

Firmness or consistency is the best predictor of sensorial attributes using an evaluation of the cheese surface instrumentally or in the mouth (Drake et al., 1999). Consistency exhibited the highest correlation ($r = 0.9467$) with instrumental measurements in this study, which was predicted by the apparent viscosity at a strain rate of 10 s^{-1}.

The instrumental parameter apparent viscosity (η_{ap}) exhibited a stronger correlation with sensory consistency (r = 0.9467), sensory viscosity (r = 0.9318) and sensory adhesiveness (r = 0.9331) than the other instrumental measurements. The instrumental measurement elasticity was also a better predictor of sensory spreadability (r = -0.9450) than the other mechanical parameters. Therefore, regression models established a prediction model of sensory attributes from these instrumental texture measurements in processed cheeses (Table 4).

Sensory evaluations from a properly trained panel can correlate with instrumental measurements and provide practical information for the food industry. The mechanical properties can predict the consistency, viscosity, sensory spreadability and adhesiveness of the cheeses, which is advantageous for the industry due to the rapid acquisition of instrumental measurements.

Instrumental measurements present an interesting alternative to sensory evaluation, but sensory evaluation is not dispensable. Sensory evaluation must calibrate and measure the correlations between human perception and instrumental detection (Wilkinson & Yuksel, 1997). Therefore, the mechanical properties of light processed cheeses can be used routinely, but these processes are not permanent substitutes for sensory evaluation.

Table 4. Prediction model of sensory attributes from instrumental measurements of texture in the processed cheese

Attribute	Model		R^2	MSE
Consistency	Intercept	1.4037	0.9279	0.5739
	Slope	0.0432		
Viscosity	Intercept	1.1069	0.9342	0.5633
	Slope	0.0450		
Adhesivity	Intercept	0.6741	0.9609	0.3823
	Slope	0.0487		
Spreadability	Intercept	7.0109	0.9097	0.8513
	Slope	- 0.8426		

R^2: coefficient of determination; MSE: mean square error.

4. Conclusions

Low-fat cheeses that are formulated with little water yield an excessively rigid protein matrix and elevated rheological parameters. These properties may present difficulties in product flow in industrial pipes and low sensory acceptance due to the extremely rigid texture. Therefore, fat reduction in processed cheeses should be coupled to a concomitant increase in water content during processing to dilute the matrix protein. The resulting product may exhibit satisfactory sensory and mechanical parameters.

However, the sensory evaluations of a properly trained panel provide measurements that correlate with instrumental measurements. The correlations between instrumental and sensory measurements provide practical information for the food industry because the sensory texture attributes of processed cheeses can be more quickly and economically predicted from the rheological parameters (τ_o, η_{ap}, tan δ) or textural properties.

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References

Alves, R. M. V., Van Dender, A. G. F., Jaime, S. B. M., Moreno, I., & Pereira, B. C. (2007). Effect of light and packages on stability of spreadable processed cheese. *International of Dairy Journal*. 17 (4), 365-373. http://dx.doi.org/10.1016/j.idairyj.2006.04.004

Ares, G., Giménez, A., & Gámbaro, A. (2006). Preference mapping of texture of dulce de leche. *Journal of Sensory Studies*. 21 (6), 553–571. http://dx.doi.org/10.1111/j.1745-459X.2006.00082.x

Bleibaum, R.N., Stone, A, H., Tanb, T., Labrecheb, S., Saint-Martin, E., & Isz, S. (2002). Comparison of sensory and consumer results with electronic nose and tongue sensors for apple juices. *Food Quality and Preference*. 13 (6), 409–422. http://dx.doi.org/10.1016/S0950-3293(02)00017-4

Bower, J., & Whitten, R. (2000). Sensory characteristics and consumer liking for cereal bar snack foods. *Journal of Sensory Studies*. 15 (3), 327-345. http://dx.doi.org/10.1111/j.1745-459X.2000.tb00274.x

Bourne, M. C. (1978). Texture profile analysis. *Food Technology*. 32 (7), 62–66.

Bourne, M. C. (2002). *Food Texture and Viscosity: Concept and Measurement* (2nd ed.). London: Elsevier Science & Technology Books.

Brown, J. A., Foegeding, E. A., Daubert, C. R., & Drake, M. A. (2003). Changes in rheological and sensorial properties of young cheeses as related to maturation. *Journal of Dairy Science*. 86 (10), 3054–3067. http://dx.doi.org/10.3168/jds.S0022-0302(03)73905-8.

Bryant, A., Ustunol, Z., & Steffe, J. (1995). Texture of Cheddar cheese as influenced by fat reduction. *Journal of Food Science*. 60 (6), 1216-1219. http://dx.doi.org/1216–1219. 10.1111/j.1365-2621.1995.tb04559.x

Cunha, C. R. (2007). Papel da gordura e do sal emulsificante em análogos de requeijão cremoso. Tese (Doutorado em Engenharia de Alimentos) – Universidade Estadual de Campinas – UNICAMP, Campinas.

Cunha, C. R., Viotto, W. H., & Viotto, L A. (2006). Use of low concentration factor ultrafiltration retentates in reduced fat ‘‘Minas Frescal’’ cheese manufacture: Effect on composition, proteolysis, viscoelastic properties and sensory acceptance. *International of Dairy Journal*. 16 (3), 215–224. http://dx.doi.org/10.1016/j.idairyj.2005.03.004

Damásio, M. H., & Costell, E. (1991). Análisis sensorial descriptivo: generación de descriptores y selección de catadores. *Revista Agroquimica de Technologia de Alimentos*. 31 (2), 165-78.

Dong, Q. (2009). BP neural network for evaluating sensory texture properties of cooked sausage. *Journal of Sensory Studies*. 24 (6), 833–850. http://dx.doi.org/10.1111/j.1745-459X.2009.00240.x

Drake, M. A., Gerard, P. D., Truong, V. D., & Daubert, C. R. (1999). Relationship between instrumental and sensory measurements of cheese texture. *Journal of Texture Studies*. 30 (4), 451–476. http://dx.doi.org/10.1111/j.1745-4603.1999.tb00230.x

Engelen, L., De Wijk, R. A., Prinz, J. F., Janssen, A. M., Weenen, H., & Bosman, F. (2003). The effect of oral and product temperature on the perception of flavor and texture attributes of semi-solids. *Appetite*. 41 (3), 273-281. http://dx.doi.org/10.1016/S0195-6663(03)00105-3

Floury, J., Camier, B., R, F., Lopez, C., Tissier, J., & Famelart, M. (2009). Reducing salt level in food: Part 1. Factors affecting the manufacture of model cheese systems and their structure–texture relationships. *Food Science and Technology – LWT*. 42 (10), 1611–1620. http://dx.doi.org/10.1016/j.lwt.2009.05.026

Fox, P. F., & Guinee, T. P. (2000). *Cheese Rheology and Texture: Fundamentals of Cheese Science*. Gaithersburg, Maryland: Aspen Publishers, Inc.

Garruti, D. S., Brito, E.S., Brandão, T.M., Uchôa Jr., P., & Silva, M.A.A.P. (2003). Desenvolvimento do perfil sensorial e aceitação de requeijão cremoso. *Ciência e Tecnologia de Alimentos*. 23 (3), 434-440. http://dx.doi.org/10.1590/S0101-20612003000300024

Gallina, D. A., Van Dender, A. G. F., Yotsuyanagi, K. & De Sá P. B. Z. (2008). Influence of storage temperature on the texture profile and color characteristics of UHT *Requeijão cremoso*. *Brazilian Journal of Food Technology*. 11 (3), 169-174.

Gonzalez, R., Benedito, J., Cárcel, J.A., & Mulet, A. (2001). Cheese hardness assessment by experts and untrained judges. *Journal of Sensory Studies*. 16 (3), 277-285. http://dx.doi.org/10.1111/j.1745-459X.2001.tb00301.x

Gonzalez-Vinas, M. A., Poveda, J., Ruiz, A. G., & Cabezas, L. (2001). Changes in chemical, sensory and rheological characteristics of manchego cheeses during ripening. *Journal of Sensory Studies*. 16 (4), 361-371. http://dx.doi.org/10.1111/j.1745-459X.2001.tb00307.x

Guillermin, P., Dupont, N., Le Morvan, C., Le Quere, J.M., Langlais, C., & Mauget, J.C. (2006). Rheological and technological properties of two cider apple cultivars. *Food Science and Technology – LWT*. 39 (9), 995-1000. http://dx.doi.org/10.1016/j.lwt.2006.02.025

Guinee, T.P., Auty, M.A.E., & Fenelon, M.A. (2000). The efect of fat content on the rheology, microstructure and heat-induced functional characteristics of Cheddar cheese. *International of Dairy Journal.* 10 (4), 277-288. http://dx.doi.org/10.1016/S0958-6946(00)00048-0.

Hennelly, P. J., Dunne, P. G., O'Sullivan, M., & O'Riordan, E. D. (2006). Textural rheological, and microstructural properties of imitation cheese conitaing inulin. *Journal of Food Engineering. 75* (3), 388-395. http://dx.doi.org/10.1016/j.jfoodeng.2005.04.023

Irigoyen, A., Castiella, M., Ordonez, A. I., Torre, P., & Ibarez, F. C. (2002). Sensory and instrumental evaluations of texture in cheeses made from ovine milks with differing fat contents. *Journal of Sensory Studies.* 17 (2), 145-161. http://dx.doi.org/10.1111/j.1745-459X.2002.tb00339.x

ISO (1981). Sensory analysis vocabulary. Part 4. International Organization for Standardization, Geneva.

ISO (1988). Sensory analysis: Guide to design of test rooms for sensory analysis of food. International Organization for Standardization, Geneva.

Jack, F. R., & Paterson, A. (1992). Texture of hard cheeses. *Trends in Food Science and Technology*. 3, 160-164. http://dx.doi.org/10.1016/0924-2244(92)90178-Y

Lassoued, N., Delarue, J., Launay, B., & Michon, C. (2008). Baked product texture: Correlations between instrumental and sensory characterization using Flash Profile. *Journal of Cereal Science.* 48 (1), 133–143. http://dx.doi.org/10.1016/j.jcs.2007.08.014.

Lemay, A., Paquin, P., & Lacroix, C. (1994). Influence of microfluidization of milk on cheddar cheese composition, color, texture, and yield. *Journal of Dairy Science*. 77 (10), 2870-2879. http://dx.doi.org/10.3168/jds.S0022-0302(94)77227-1.

Lim, S. Y., Swanson, B. G., Ross, C. F., & Clark, S. (2008). High hydrostatic pressure modification of whey protein concentrate for improved body and texture of low fat ice cream. *Journal of Dairy Science.* 91 (4), 1308–1316. http://dx.doi.org/10.3168/jds.2007-0391

Martínez-Cervera, S., Salvador, A., Muguerza, B., Moulay, L., & Fiszman, S. M. (2011). Cocoa fibre and its application as a fat replacer in chocolate muffins. *Food Science and Technology – LWT.* 44 (3), 729-736. http://dx.doi.org/10.1016/j.lwt.2010.06.035

Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2006). *Sensory evaluation techniques* (4th ed.). Boca Raton, FL: CRC Press.

Meullenet, J., Lyon, B. G., Cerpenter, J. A., & Lyon, C.E. (1998). Relationship between sensory and instrumental texture profile attributes. *Journal of Sensory Studies.* 13 (1), 77-93. http://dx.doi.org/10.1111/j.1745-459X.1998.tb00076.x

Messens, W., Walle, D. V., Arevalo, J., Dewettinck, K., & Huyghebaert, A. (2000). Rheological properties of high-pressure-treated Gouda cheese. *International of Dairy Journal*. 10 (5-6), 359-367. http://dx.doi.org/10.1016/S0958-6946(00)00066-2

Murray, J. M., & Delahunty, C. M. (2000). Selection of standards to reference terms in a Cheddar cheese flavor language. *Journal of Sensory Studies.* 15 (2), 179–199. http://dx.doi.org/10.1111/j.1745-459X.2000.tb00264.x

Olson, N. F., & Price, W. V. (1961). Composition and bacterial grouth as factors affecting the body of pasteurized process cheese spread. *Journal of Dairy Science.* 44 (8), 1394-1404. http://dx.doi.org/10.3168/jds.S0022-0302(61)89900-1

Pearce, J. (1996). Effects of milk and fermented dairy products on the blood cholesterol content and profile of mammals in relation to coronary heart disease. *International of Dairy Journal*. 6 (7), 661-672. http://dx.doi.org/10.1016/0958-6946(95)00011-9

Pereira, R. B., Bennett, R. J., Hemar, Y., & Campanella, O. H. (2001). Rheological and microstructural characteristics of model processed cheese analogues. *Journal of Texture Studies.* 32 (5-6), 349–372. http://dx.doi.org/10.1111/j.1745-4603.2001.tb01242.x

Pereira, R. B., Bennett, R. J., & Luckman, M. S. (2005). Instrumental and sensory evaluation of textural attributes in cheese analogs: a correlation study. *Journal of Sensory Studies*. 20 (5), 434–453. http://dx.doi.org/10.1111/j.1745-459X.2005.00038.x

Perera, N., Gamage, T. V., Wakeling, L., Gamlath, G. G. S., & Versteeg, C. (2010). Color and texture of apples high pressure processed in pineapple juice. *Innovative Food Science Emerging Technology*. 11 (1), 39–46. http://dx.doi.org/10.1016/j.ifset.2009.08.003

Prakash, M., Ravi, R., Sathish, H. S., Shyamala, J. C., Shwetha, M. A., & Rangarao, G. C. P. (2005). Sensory and instrumental texture measurement of thermally processed rice. *Journal of Sensory* Studies. 20 (5), 410–420. http://dx.doi.org/10.1111/j.1745-459X.2005.00036.x

Rosenberg, M., Wang, Z., Chuang, S. L., & Shoemaker, C. F. (1995). Viscoelastic property changes in cheddar cheese during ripening. *Journal of Food Science*. 60 (3), 640–644. http://dx.doi.org/10.1111/j.1365-2621.1995.tb09846.x

Rudan, M. A., Barbano, D. M., Yun, J. J., & Kindstedt, P. S. (1999). Effect of fat reduction on chemical composition, proteolysis, functionality, and yield of Mozzarella cheese. *Journal of Dairy Science.* 82 (4), 661–672. http://dx.doi.org/10.3168/jds.S0022-0302(99)75282-3

Salvador, A., Varela, P., Sanz, T., & Fiszman, S.M. (2009). Understanding potato chips crispy texture by simultaneous fracture and acoustic measurements, and sensory analysis. *Food Science and Technology – LWT.* 42 (3), 763–767. http://dx.doi.org/10.1016/j.lwt.2008.09.016

Sandoval-Castilla, O., Lobato-Calleros, C., Aguirre-Mandujano, E., & Vernon-Carter, E. J. (2004). Microstructure and texture of yogurt as influenced by fat replacers. *International of Dairy Journal*. 14 (2), 151–159. http://dx.doi.org/10.1016/S0958-6946(03)00166-3

Shama, F., & Sherman, P. (1973). Identification of stimuli controlling the sensory evaluation of viscosity. II. Oral methods. *Journal of Texture Studies.* 4 (1), 111–118. http://dx.doi.org/10.1111/j.1745-4603.1973.tb00657.x

Sheehan, J. J., & Guinee, T. P. (2004). Effect of pH and calcium level on the biochemical, textural and functional properties of reduced-fat Mozzarella cheese. *International of Dairy Journal*. 14 (2), 161–172. http://dx.doi.org/10.1016/S0958-6946(03)00167-5

Silva, R. C. S. N., Minim, V. P. R., Simiqueli, A. A., Moraes, L. E. S., Gomide, A. I., & Minim, L. A. (2012). Optimized Descriptive Profile: a rapid methodology for sensory description. *Food Quality and Preference*. 24 (1), 190-200. http://dx.doi.org/10.1016/j.foodqual.2011.10.014

Silva, R. C. S. N., Minim, V. P. R., Vidigal, M. C. R. T., Silva, A. N., Simiqueli, A. A., & Minim, L. A. (2012). Sensory and instrumental consistency of processed cheeses. *Journal of Food Research*. 1 (3), 204-213. http://dx.doi.org/10.5539/jfr.v1n3p204

Soares, F. M, Fonseca, L. M, Martins R. T., Machado, E. C., PereirA JR. F. N., & Fonseca C. S. P. (2002). Influência do concentrado protéico de soro na composição do requeijão em barra com teor reduzido de gordura. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*. 54 (6), 1-7. http://dx.doi.org/10.1590/S0102-09352002000600014

Stone, H., & Sidel, J.L. (2004). *Sensory evaluation practices* (3rd ed.). London: Academic Press, Inc.

Stone, H., Sidel, J. L., Oliver, S., Woolsey, A., & Singleton, R. C. (1974). Sensory evaluation by quantitative descriptive analysis. *Food Techonology*. 28 (1), 24-33. http://dx.doi.org/10.1002/9780470385036.ch1c

Szczesniak, A. S. (2002). Texture is a sensory property. *Food Quality and Preference*. 13 (4), 215–225. http://dx.doi.org/10.1016/S0950-3293(01)00039-8

Tamime, A. Y., Muir, D. D., Shenana, M. E., Kalab, M., & Dawood, A. H. (1999). Processed Cheese Analogues Incorporating Fat-Substitutes. *Food Science and Technology – LWT*. 32 (1), 50-59. http://dx.doi.org/10.1006/fstl.1998.0510

Van Hekken, D.L., Tunick, M.H., Malin, E.L., & Holsinger, V.H. (2007). Rheology and melt characterization of low-fat and full fat Mozzarella cheese made from microfluidized Milk. *Food Science and Technology – LWT*. 40 (1), 89-98. http://dx.doi.org/10.1016/j.lwt.2005.08.005

Verma, B. B., & Gupta, S.K. (1981). Effect of heat processing on the body and texture of milk and milk products. *Indian Dairyman*. 33 (6), 361-365.

Wang, R., Zhou, W., & Isabelle, M. (2007). Comparison study of the effect of green tea extract (GTE) on the quality of bread by instrumental analysis and sensory evaluation. *Food Research International*. 40 (4), 470–479. http://dx.doi.org/10.1016/j.foodres.2006.07.007

Wilkinson, C., & Yuksel, D. (1997). Using artificial neural networks to develop prediction models for sensory-instrumental relationships; an overview. *Food Quality and. Preference*. 8 (5-6), 439-445. http://dx.doi.org/10.1016/S0950-3293(97)00016-5

Zalazar, C. A., Zalazar, C. S., Bernal, S., Bertola, N., Bevilacqua, A., & Zaritzky, N. (2002). Effect of moisture level and fat replacer on physicochemical, rheological and sensory properties of low fat soft cheeses. *International of Dairy Journal*. 12 (1), 45-50. http://dx.doi.org/10.1016/S0958-6946(01)00130-3