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Kinetic modeling of quality changes of chilled ready to serve lasagna

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ABSTRACT

Pre-cooked pasta, in particular lasagna, plays an important role in the market of chilled ready to serve meals. In this work we analyzed the evolution of the most important physical and sensory quality attributes of lasagna sheets during their refrigerated storage, at 0, 4 and 10 °C. The quality of ready meals deteriorates with storage time, and food loses its freshness condition. The same behavior was observed for all analyzed characteristics: as the storage temperature increases, reaction rate (measured by the kinetic constant and activation energy) also increases, confirming the influence of temperature in quality loss. Besides, overall acceptability was the more sensitive attribute to temperature changes, with Q_{10} equal to 4, indicating an indirect but strong dependence of consumers' opinion on storage temperature.

Finally, shelf life models, based on sensory analysis and on microbial spoilage, were compared, showing that the adopted sensory score determines which criterion is more restrictive.

Kinetic data provide a useful tool to control storage, ensuring good safety and sensory quality.

1. Introduction

During the last years, and as a consequence of the changes in lifestyles that affect consumer's behaviors, the market of ready-to-serve meals has experienced a sustained growth. Also, this trend has been encouraged by the development of new products with high levels of innovation (Sorenson and Henchion, 2011).

Although the subject has been tested in a number of studies, in the fields of both market research (HighBeam Research, 2008, 2011) and consumer attitude related studies (Ahlgren et al., 2005; Brunner et al., 2010; Costa et al., 2007), literature regarding the evolution and quality of ready meals is still fairly limited. In particular, after an extensive bibliographic search, only few works that study the quality of ready-to-serve pasta have been found. Redmond et al. (2005) analyze the effect of storage time on the quality of frozen lasagna. In two related papers, Kindt et al. (2006, 2008), propose a quality scale for frozen ready pasta meals, based on moisture and lipid contents, capacity to hold sauce, degree of pulping, wholeness and defects of pasta. Our previous research on the effects of freezing and long-term frozen storage on the quality of cooked *tagliatelle* was reported in Olivera and Salvadori (2009, 2011).

Most of the studies related to the quality of ready meals tend to focalize only in the microbiological aspects (Del Torre et al., 2004; Gombas et al., 2003; McAteer et al., 1995; Tyrer et al., 2004). This is because the rise of the microbial load during refrigerated storage is usually considered the first shelf life limit of these products (Singh et al., 2011). Nevertheless, there are other food attributes, such as freshness, healthiness, sensory or physical quality, convenience, among others, which directly influence consumers' food choice and define the purchase of chilled ready meals (Reed et al., 2000). Therefore, it is interesting to investigate the feasibility of predicting shelf life based on sensory and instrumental quality relationships.

In this context, the aim of this work is to analyze the evolution of distinct quality attributes (moisture content, color, texture, sensory acceptability) during refrigerated storage, considering different storage temperatures. Using simple mathematical models, the quality changes will be correlated, providing characteristic kinetic parameters. Not only do these parameters supply information on the mechanisms that are involved in the quality changes during storage, but they also provide a way of selecting the optimum storage conditions to preserve the desired characteristics onto the final product (van Boekel, 2008). Also, shelf life models, based on sensory analysis and on microbial spoilage, were compared.

2. Materials and methods

2.1. Lasagna preparation

The sample was presented in individual trays and consisted of a traditional lasagna recipe: cooked pasta sheets alternated with a

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filling made with spinach and tomato sauce, the top layer sprinkled with grated cheese. Further details can be found in Olivera and Salvadori (2006). In order to carry out the complete set of determinations, a total of 90 aluminum trays (of 14 cm × 10 cm × 4.5 cm) were used, with 200 g of lasagna each. The trays were also covered with sheets of aluminum paper.

2.2. Refrigerated storage

Three storage temperatures were studied: 0 ± 0.5, 4 ± 0.5 and 10 ± 0.5 °C. The first two values are typical recommended temperatures for refrigerated storage (ISO Standard 7371 recommends 5 °C or less). Although a temperature of 10 °C may be considered as a thermal abuse condition, it can be found in normal operation of domestic refrigerators (Mascheroni and Salvadori, 2011). Thirty trays were assigned to each temperature during a period of 8 days. Samples and refrigerator temperatures were monitored using several DS1921G Thermochron iButton temperature sensors (USA), located in different positions (inside and over several trays).

2.3. Physical analysis

The evolution of quality on the sheets of cooked pasta was evaluated according to the following instrumental parameters:

- *Water content*: the moisture content of the lasagna sheets was determined by drying 10 g of pasta until the sample's weight remained constant, using a vacuum stove at 70 °C as in Olivera and Salvadori (2009).
- *Pasta surface color*: the color was measured using a portable colorimeter (Minolta CR-300, Japan), which was calibrated before each determination using a white standard plate. Color was described by the *CIE* L^*, $a^*$and b^* model, where L^* represents the lightness, a^* the redness or greenness, and b^* the yellowness or blueness. In this space, each value is represented by a single point (Gonzalez and Woods, 2002). Ten replicates per storage time and temperature were recorded.
- *Texture*: this property was evaluated by means of a cutting-shear test, performed with a texture analyzer (TA-XT2i; Stable Microsystems, Stable Micro Systems, Surrey, UK). In this test, the probe (Volodkevich Bite Jaws) simulates the bite action of incisive teeth cutting the sample, which is located in the base of the equipment. The parameters recorded are the maximum force, related to sample firmness, and the area beneath the force curve, which is directly associated with the energy required to cut the pasta (Szczesniak, 2002). Ten replicates for each sample were registered.

2.4. Microbiological analysis

The microbiological determinations were performed with pasta samples of 10 g each, which were dissolved with 90 ml of peptone, utilizing a Stomacher 400 to guarantee an aseptic homogenization. Two dilutions in 9 ml of peptone 0.1% were performed from this sample, and 0.1 ml of each of these were seeded in Agar PCA (incubation at 37 °C for 24–48 h) for total mesophile count and in Agar YGC (30 °C, 5 days) for mold and yeast count.

Triplicate tests were done for each time and temperature. The counts were expressed as $\log N$ (N: Colony Forming Units/g (CFU/g)).

2.5. Sensory analysis

A sensory analysis was carried out to evaluate the acceptability of chilled stored lasagna using a semi-structured hedonic scale (Meilgaard et al., 2006).

A total of 50 regular consumers took part in the consumer panel. The consumer's selection criteria were that they liked pasta and filled pasta and that they presented a minimum consumption frequency of once a week ("moderate").

Sensory tests were carried out in three sessions, one for each storage temperature. In each session, the panelists received 5 samples of lasagna (one fresh and 4 at different storage times). Four attributes: appearance, flavor, consistency and overall acceptability were evaluated, according to a scale anchored in the following steps: "dislike very much", "indifferent" and "like very much". The samples were presented to the evaluators in individual trays, immediately after being taken out of the oven. They were arranged randomly, coded with 3 digit numbers.

2.6. Mathematical modeling of quality changes

The kinetics of food quality loss can be represented by the following equation:

$$-\frac{dA}{dt} = kA^n \tag{1}$$

where A indicates the measured quality factor (color, texture, sensory attribute, etc.), t is time, k is the reaction rate constant and n represents the reaction order.

To evaluate the dependence of the reaction rate constant k on temperature T, we use Arrhenius law:

$$k = k_{ref} \exp\left(-\frac{E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \tag{2}$$

where k_{ref} is the constant of the reaction rate at the reference temperature T_{ref} (in K), E_a is the activation energy (in J/mol), and R is the general gas constant (8.31 J/mol K). Another frequently used parameter is the value Q_{10}, which is defined as (van Boekel, 2008):

$$Q_{10} = \frac{\text{reaction rate at temperature } (T+10)}{\text{reaction rate at temperature } (T)} \tag{3}$$

In other words, this parameter represents the sensitivity of a reaction to temperature changes; in this work it estimates how much quality changes are accelerated by an increase of 10 °C in the storage temperature.

2.7. Statistical analysis

Analysis of variance and pairwise comparisons were computed using SYSTAT software (SYSTAT, Inc., Evanston, IL, USA). Differences in means and F-tests were considered only when $P < 0.05$.

3. Results and discussion

3.1. Physical parameters: kinetic models of quality loss

3.1.1. Moisture

When the moisture content of the pasta sheets was evaluated, we observed a significant increase in such parameter ($P < 0.05$) at the beginning of the storage period (Fig. 1). However, moisture remained almost constant for the rest of the storage time. This initial rise is expected since the pasta, which has a moisture content of approximately 62% when prepared, engages in a water flux relation with the filling (from the filling toward the pasta sheets), which has 92% moisture.

Different authors relate water displacement with product aging. In this sense, Gonzalez et al. (2000) studied moisture redistribution in cooked lasagna, and concluded that water migration was one of the most important mechanisms responsible for the loss of the

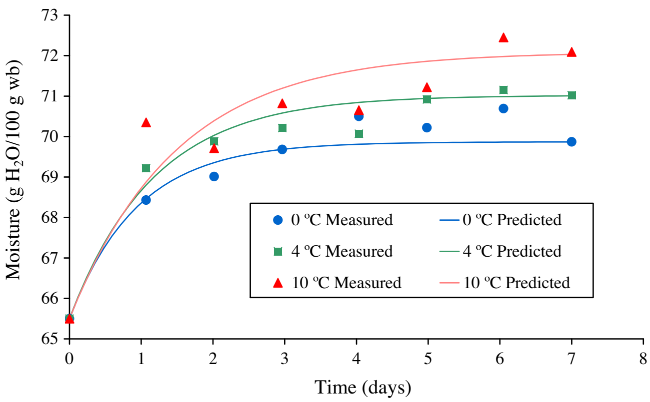

Fig. 1. Moisture content of lasagna sheets, during refrigerated storage.

"*al dente*" mechanical characteristics of pasta (Redmond et al., 2005). In a study of a different multicomponent product (cheese sandwiches), Barret et al. (2005) observed that migration and redistribution of moisture between the different components (cheese, crumb and crust) are two of the main causes of aging and sensory changes during storage at ambient temperature.

Moisture migration in cooked pasta has been previously studied in relation to dry pasta rehydration (Cunningham et al., 2007), hydration of fresh pasta during cooking and overcooking (Cafieri et al., 2008) and moisture distribution in lasagna post cooking (Horigane et al., 2006; McCarthy et al., 2002). These works confirm that water migration in cooked pasta can be entirely modeled using Fick's law of diffusion, which originates an exponential variation of the average moisture content with time. Following this theory, the changes of moisture content in the pasta sheets were correlated with modified first order kinetics (Eq. (4)):

$$\frac{M_t - M_0}{M_f - M_0} = \exp(-kt) \tag{4}$$

where M_0, M_f and M_t are the moisture contents of the samples (g H_2O 100 g^{-1} w.b.) at initial, final and t storage times, respectively, and k is the reaction rate constant, which is the function of the storage temperature.

In Fig. 1 we include experimental data and predicted results based on Eq. (4), for each storage time. Detailed kinetic data (kinetic constant, activation energy) are presented in Table 1 and discussed in Section 3.1.4.

3.1.2. Color

Simple observation of the color evolution on pasta sheets indicates a progressive darkening of the samples, due to absorption of juices from the filling and sauce. This trend can be translated into a significant decrease in the lightness parameter, L^*, during refrigerated storage (Fig. 2a). Besides, a^* values decreased during

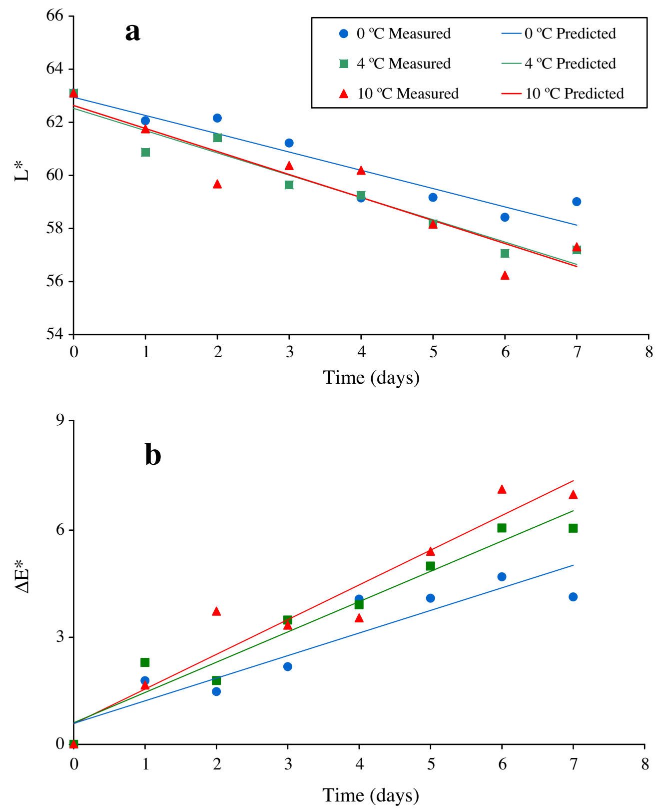

Fig. 2. Color variation of lasagna sheets, during refrigerated storage. (a) Lightness L^*, (b) color difference ΔE^*. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

storage at 4 and 10 °C. However, when the storage temperature is set at 0 °C, such parameter did not present large differences ($P > 0.05$). The decrease in a^* indicates the loss of the red color, replaced by tones with greater percentage of gray components (Feillet et al., 2000).

No significant differences were registered in the b^* parameter for the conditions essayed in this work. The obtained results are comparable to those stated by Redmond et al. (2005), who study refrigerated storage of fresh lasagna, and reported L/b values which are similar to those obtained in this work for 7 day-long refrigerated storage at 4 °C.

The total color difference in lasagna sheets was quantified as ΔE^* (Eq. (5)), as a function of parameters L^*, a^* and b^*, obtained during the refrigerated storage period, considering as reference values the magnitudes corresponding to the beginning (day 0) of storage.

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2} \tag{5}$$

Table 1
Kinetic data for instrumental quality of lasagna.

	Moisture			Shear force			Color L^*			Color ΔE^*		
	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C
Order		First			First			Zero			Zero	
k (day^{-1})	0.69	0.85	1.06	0.62	0.92	0.99	0.69	0.84	0.87	0.62	0.84	0.89
r^2	0.92	0.96	0.93	0.99	0.99	0.99	0.94	0.93	0.98	0.98	0.96	0.92
E_a (kJ/mol)		29.11			26.58			13.94			26.68	
r^2		0.99			0.90			0.99			0.99	
Q_{10}		1.54			1.62			1.26			1.45	

Note: In all cases, storage temperature accuracy: ±0.5 °C.

The results of ΔE^* showed that the color of pasta sheets is highly influenced by storage conditions. Greater refrigeration temperatures induce a larger variation in the color of cooked pasta (Fig. 2b). For example, after 7 days of storage at 10 °C, the value of ΔE^* was 7.30, while at 0 °C it was 4.13.

The changes in the color of lasagna sheets, represented by L and ΔE^*, were described from zero-order kinetics (Fig. 2a and b respectively), since it was the one which best adjusted to the experimental results. Again, the detailed values of the kinetic parameters are provided in Table 1 and are discussed in Section 3.1.4.

3.1.3. Texture

Fig. 3a shows the results obtained from the cutting-shear test for pasta sheets.

The initial firmness of the pasta (day 0) was determined at 2.22 N, a value that drops progressively during storage for the three studied temperatures, showing a greater change rate at the beginning of the storage. When the effect of storage temperatures is analyzed, a more notorious firmness decrease pattern is observed at higher temperatures. Nevertheless, the evolution of this quality parameter follows first-order kinetics for the three essayed temperatures. Values of $R^2 > 0.93$ confirm a good correlation between experimental and predicted values (Table 1).

Given the analogous behavior observed in the evolution of both moisture and firmness contents, a possible correlation between these quality factors was studied. The results showed in Fig. 3b state a strong dependence between the two, which is independent of the storage temperature.

3.1.4. Kinetic data analysis

Table 1 summarizes the values of the kinetic constants that model quality loss during refrigerated storage. The same behavior was observed for all four analyzed physical characteristics (moisture content, lightness, total color variation and texture): as

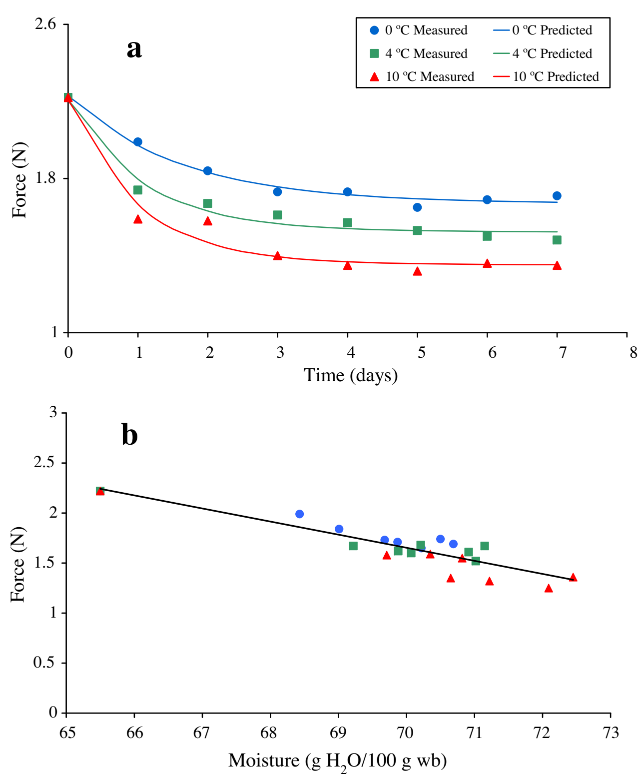

Fig. 3. (a) Hardness of lasagna sheets, during refrigerated storage. (b) Relationship between hardness and moisture content, for the three storage temperatures.

the storage temperature increases, reaction rate also increases (i.e. kinetic constant k increases), confirming the influence of the temperature in quality loss.

Arrhenius law (Eq. (2)) was used to determine the activation energy corresponding to each kinetic; values are reported in the same table. For moisture migration, the calculated E_a is similar to that informed by Martínez Navarrete et al. (1998) for water diffusion in semolina and hard wheat pasta (22–25 kJ/mol).

As it was mentioned, Q_{10} measures the sensitivity of the quality loss kinetics in relation to temperature. The values presented in Table 1 confirm that the moisture migration and hardness are more sensible than color variation to an increase in the temperature of refrigerated storage.

3.2. Microbiological shelf life

The determination of the microbiological shelf life *MSL* is essential in order to ensure food safety, especially when initial food characteristics and storage conditions allow microbial growth.

Table 2 summarizes the total mesophile count and mold and yeast count on lasagna, at different storage times and temperatures. The initial counts were very low (<2 log CFU/g), indicating a good practice in product manufacture (Martins and Leal Germano, 2008). Similar values were informed for cooked ricotta-filled ravioli (Gianuzzi, 1998) and meat lasagna (Martins and Leal Germano, 2008; Redmond et al., 2005).

From the experimental results, the microbiological shelf life *MSL* of the prepared meal, defined as the time required for spoilage microorganisms to reach a value of 10^4 CFU/g (ANMAT, 2004), was estimated. This value also agrees with the PHLS guidelines for the microbiological quality of ready-to-eat food (PHLS, 2000). In this document ready-to-eat meals and ready-to-eat pasta are categorized in group 2, being 10^4 CFU/g an index reflecting a borderline limit of good microbiological quality.

For the essayed storage temperatures *MSL* were 8, 6 and 4 days for 0, 4 and 10 °C respectively. As it was expected, the higher the storage temperature is, the lower the *MSL*. In the context of this work, *MSL* also determines the maximum storage times within which sensory analysis can be performed.

3.3. Sensory analysis: kinetic models of quality loss

As consumers are the ultimate judge of food quality, the knowledge of kinetics of sensory quality loss is very important in every study about food storage (Hough, 2006).

First, the surveyed consumers rated fresh lasagna appearance with 6.9 points, in a scale where point 1 represents the minimum acceptability and 9 the maximum acceptability. This attribute did not change significantly ($P > 0.05$), for the different temperature–time essayed schemes. Despite being related to surface color, the

Table 2
Microbiological counts on lasagna during storage.

Storage time (days)	Total mesophile count (log CFU/g)			Total mold and yeast count (log CFU/g)		
	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C
0	<2	<2	<2	<2	<2	<2
2	<2	2.15	2.05	–	2.47	
4	2.00	3.30	**3.91**	1.80		3.61
6	2.80	**4.00**	5.29	2.02	3.83	4.69
8	**3.85**	4.25	–	3.00		–
10	4.33			3.35		–

Note: Values in bold defines microbiological shelf life. In all cases, storage temperature accuracy: ±0.5 °C.

tendency of this attribute on the sensory analysis does not agree with instrumental color variation (see Section 3.1.2).

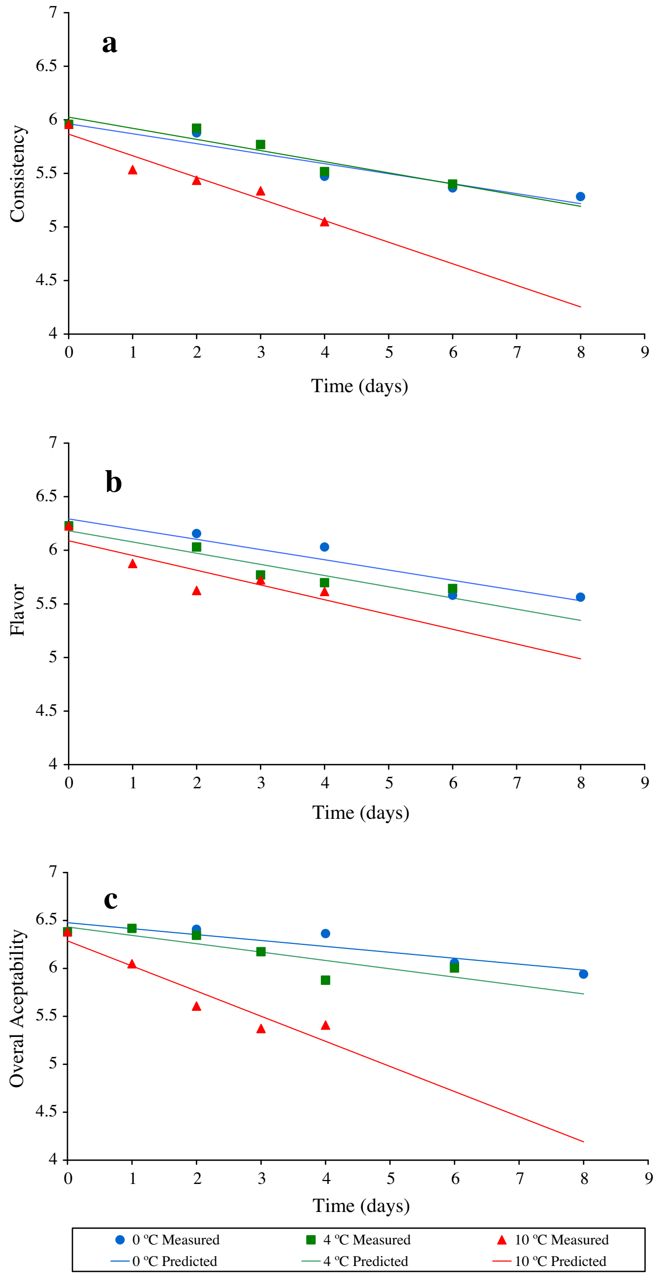

Fig. 4. Sensory analysis of lasagna sheets, during refrigerated storage. (a) Consistency, (b) flavor, (c) overall acceptability.

On the contrary, consumers found significant differences in the other three evaluated attributes. Fig. 4a–c shows the evolution of consistency, flavor and overall acceptability, respectively.

For the three essayed storage temperatures, the acceptability of consistency and flavor diminishes with storage time. These changes can be correlated with the evolution of moisture content and hardness, detailed in previous sections. Also, these negative tendencies directly affect the fourth sensory attribute, overall acceptability, which evolves in the same direction.

From the sensory analysis results, kinetic data were obtained, which are reported in Table 3. As it can be inferred from the experimental results shown in Fig. 4, the three sensory attributes follow zero-order kinetic, for the three temperatures. A high correlation was obtained in the regression of experimental values ($R^2 > 0.97$).

Besides, values of E_a and Q_{10} are presented in Table 3. These values indicate that overall acceptability is the more sensitive parameter in relation to temperature changes. As a consequence, from a sensory point of view, we can state that this attribute will determine the sensory shelf life *SSL*.

3.4. MSL vs. SSL

Microbiological shelf life depends on the maximum microbial count that ensures food safety. On the other hand, sensory shelf life is defined by an acceptability score which ensures consumers' satisfaction (Gimenez et al., 2007).

As the kinetic model of sensory quality loss is provided, *SSL* of ready lasagna can be predicted, in the function of storage temperature. Based on kinetic data, *SSL* vs. storage temperature *T* is represented in Fig. 5. As it was stated by previous works of Labuza and co-workers (Fu and Labuza, 1997), when the temperature range is narrow, a simple linear relation between the logarithm of shelf life and temperature is observed. The ordinate of the line depends on the score value adopted.

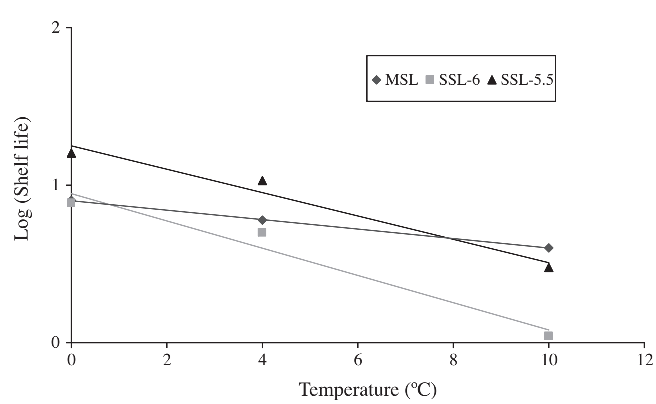

Fig. 5. Lasagna shelf life vs. storage temperature.

Table 3
Kinetic data for sensory quality of lasagna.

	Consistency			Flavor			Overall acceptability		
	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C	0 °C	4 °C	10 °C
Order		Zero			Zero			Zero	
k (day^{-1})	0.09	0.11	0.22	0.09	0.10	0.14	0.06	0.09	0.26
r^2	0.92	0.93	0.93	0.90	0.89	0.90	0.92	0.85	0.99
E_a (kJ/mol)		50.77			24.51			94.75	
r^2		0.95			0.97			0.97	
Q_{10}		2.52			1.47			4.26	

Note: In all cases, storage temperature accuracy: ±0.5 °C.

Therefore, for an acceptability score equal to 6, the *SSL* of chilled lasagna is 7.7, 5.0, and 1.1 days, for 0, 4 and 10 °C respectively. These values are smaller than the *MSL* values presented in Table 2, indicating that the sensory criterion is more restrictive. On the contrary, if the adopted acceptability score is equal to 5.5, the microbiological safety determines the shelf life, for 0 and 4 °C; for 10 °C the sensory acceptability again marks the end of this ready meals' shelf life.

4. Conclusions

The results obtained in this work showed that variations in the moisture content, color and texture of lasagna sheets during storage depend strongly on the storage conditions. High temperatures have a negative influence on the analyzed quality attributes. On the contrary, lower temperatures provide a better storage environment.

Storage associated changes were adequately modeled by first-order kinetics in the case of moisture and instrumental texture and zero-order kinetics for superficial color and for the attributes corresponding to the sensory analysis.

Also, we found Arrhenius law adequate in order to describe the dependence of the kinetic spoilage constants on temperature, and to consequently obtain the respective activation energies.

Once the limits of the quality indexes that define acceptability are established, these models enable the determination of the shelf life. Therefore, it is interesting to investigate the feasibility of predicting shelf life based on sensory quality relationships.

Microbiological and sensory shelf lives were determined and correlated with storage temperatures. The results presented in this work indicate that not always does the microbiological safety criterion determine the shelf life of this particular type of product. When high acceptability values are pursued, it is the sensory analysis that defines the shelf life of the product.

Finally, even if no specific results are presented, the calculated kinetic models provide an important tool for predicting and monitoring the quality of prepared foods during the different stages of the cold-chain: manufacture, transport and distribution, intermediate storage stages, as well as domestic storage.

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