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Instrumental and sensory evaluation of cooked pasta during frozen storage

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Summary Food consumption patterns have changed significantly during the last years, showing an increase in the consumption of convenience foods. Frozen foods represent an important segment of this market. The aim of the present paper was to study the influence of frozen storage on the quality of cooked organic *tagliatelle*. Instrumental measurements of different quality parameters (moisture content, colour, textural and rheological characteristics of frozen cooked pasta) were performed during twelve months of storage. The sensory properties of pasta were also evaluated by means of an acceptability study. In general, both instrumental and sensory analysis found that frozen storage affects negatively the acceptability of cooked pasta. The advantages obtained through fast freezing procedures are not maintained along storage, being hardness (instrumental) and consistency (sensory) the most relevant quality indices. Finally, the shelf life of the product was calculated as 3.6 and 3.8 months in the cryogenic device and air-blast tunnel, respectively, based on simple kinetic models.

Keywords Cooked pasta, frozen foods, organic, shelf life.

Introduction

Food consumption patterns have changed significantly during the last years, showing an increase in the consumption of convenience foods, which reflects a trend towards to a reduction of effort and time in preparing meals (Ahlgren *et al.*, 2005). A convenience product can be defined as any partially or totally ready meal, for which a significant fraction of the preparation time, cooking skills and applied energy have been transferred from home to food industry or retailers. Regarding the preservation of these products, freezing is one of the preferred processes, because it maintains almost intact the quality characteristics of foods and extends their shelf life (Kindt *et al.*, 2008).

In starch-based food products, the effects of freezing and frozen storage at −18 °C have been studied for several years (mainly bread dough and also partially baked bread, Le Bail *et al.*, 1999; Ribotta *et al.*, 2003; Bárcenas *et al.*, 2003; Bárcenas & Rosell, 2006; Giannou & Tzia, 2007; Phimolsiripol *et al.*, 2008). In particular, Bárcenas *et al.* (2003) did not detect amylopectin retrogradation, by DSC studies, during frozen storage of par-baked bread. Probably the protein network had been denatured in the previous baking process, although the analysis of ageing indicated that frozen storage produced some structural changes in amylopectin. In general, the results obtained by different authors showed that both freezing and frozen storage, especially with temperature fluctuations, have a significant negative effect on all quality parameters: CO_2 production rate, yeast viability, bread volume after baking, bread crumb firmness and dough weight loss. Also, the hardening rate during ageing was found to be dependent on storage time.

To predict and then control these changes, Giannou & Tzia (2007) proposed a kinetic model to correlate texture data. In the same sense, Vulicevic *et al.* (2004) studied the quality of four varieties of par-baked breads during 9 months of frozen storage and developed a kinetic model to predict shelf life of frozen breads.

On the other hand, the effects of freezing and frozen storage on cooked pasta have been scarcely described. Only a few studies can be found in literature about this subject. Hatcher (2004) investigated the influence of freezing and frozen storage (4 months) on texture of

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cooked noodles and found that the frozen product exhibits inferior textural characteristics than the fresh one, being the cooking time prior to freezing the critical variable of the process. Redmond *et al*. (2005) studied the effects of short- and long-term chilled and frozen storage of lasagne, while Kindt *et al*. (2008) investigated quality aspects of frozen pasta, and proposed quality grades based on the degree of sauce absorption and presence of defects as a result of freezing.

In a previous work, we studied the effect of different freezing methods (slow vs. fast) on the overall quality of cooked organic pasta (Olivera & Salvadori, 2009). Textural and rheological characteristics were measured in fresh cooked and frozen cooked pasta. The experimental results confirmed that freezing produces structural damage in the frozen pasta: elasticity, firmness and water-holding capacity were the more affected parameters. Furthermore, a sensory analysis demonstrated that these instrumental results were detected by consumers.

Therefore, the aim of the present paper was to study the influence of frozen storage on the quality of cooked organic pasta. To accomplish this objective, instrumental measurements of different quality parameters (i.e. moisture content, colour, texture and rheological characteristics) were performed during twelve months of frozen storage. Also, the sensory properties of the product were evaluated by means of an acceptability study carried out with an untrained panel. Finally, the evolution of different quality indices was analysed to define the shelf life of the product.

Materials and methods

Sample preparation and freezing

Cooked *tagliatelle* pasta, formulated with organic ingredients, was elaborated to perform this study. For the detailed procedure for preparation of cooked pasta, the reader should be referred to Olivera & Salvadori (2009). Samples consisted of individual ribbons of $0.01 \times 0.08 \times 0.001$ m. Then, individual aluminium trays of $0.14 \times 0.10 \times 0.045$ m were filled with 0.2 kg of cooked pasta (each 0.04 m height) and covered with a sheet of aluminium paper.

Samples were frozen in two different freezers, to test the influence of freezing rate on food quality: (i) a cryogenic cabinet using liquid N_2 (PRAXAIR, Brazil), with chamber temperature of -40 ± 1 °C and (ii) an air-blast tunnel (FRIOTECNOLOGIA, Argentina), with air temperature of -35 ± 3 °C and air velocity of 0.3 m s^{-1}. Freezing rates and times presented in Table 1 indicate that fast and slow freezing rates were successfully obtained, respectively. More details about pasta freezing can be found in Olivera & Salvadori (2009).

Frozen storage

Trays containing frozen cooked pasta were stored in a commercial freezer (Philips Whirlpool Dual model AFG 145, Argentina). Prior to quality assessment during storage, the freezer performance was investigated recording its inner temperature (set to −18 °C) during one month.

Total storage time was 12 months. During the experimental study, samples and freezer temperatures were recorded using DS1921G Thermochron iButton temperature sensors (USA), located in different positions (inside and over several trays), to register storage temperature. Air temperature was -18 ± 2 °C in freezer compartment and -18 ± 1 °C inside the trays containing the frozen product. Similar results were recorded with the same equipment in a previous study (Mascheroni & Salvadori, 2006). It was assumed that the observed fluctuations represented a good temperature control, as stated by other researchers (Phimolsiripol *et al*., 2008).

To perform the whole set of quality analysis (see below), different trays were removed after 1, 2, 4, 6, 8, 10 and 12 months of frozen storage.

Quality analysis

The evolution of several quality aspects of cooked pasta during frozen storage was experimentally studied. Experimental techniques used in this work have been used previously by the authors, so only a brief description is presented here; the reader should be referred to Olivera & Salvadori (2006, 2009) for a detailed explanation of the implemented methodology.

Moisture content

Moisture content of samples at different storage times was determined according to AOAC official method 925.09 (AOAC, 1995):

$$M(\%) = \frac{W_i - W_f}{W_i} \times 100 \qquad (1)$$

where W_i is the initial sample weight, W_f is the final sample weight and M is the percentage moisture content, in wet basis.

Colour

Colour was measured using a portable colorimeter (Minolta CR-300; Konica-Minolta, Osaka, Japan) with a measuring area of 50 mm^2 (diameter 8 mm), which was calibrated before each determination against a white standard plate. This parameter was described by the CIE L^* a^* b^* model, where L^* represents the lightness of colour, a^* its position between red and green (or redness) and b^* its position between yellow and blue (or yellowness). In this colour space, each colour value is

Table 1 Characteristics of freezing methods

	Cryogenic	Air
Freezing rate (°C min^{-1})	0.98	0.32
Freezing time (min)	18.0	68.1

represented by a single point (Gonzalez & Woods, 2002). Six replicates per storage time were recorded.

Texture

Two different texture tests were performed, both using a TA.XT2i Texture Analyzer (Stable Micro Systems, Surrey, UK):

- Cutting-shear test: The probe simulates the bite action of incisive teeth. The sensor cuts the sample, which is placed on the base of the equipment. The parameters recorded in this test are the maximum force, related to sample firmness, and the area beneath the force curve, which is directly associated with the energy required for cutting the sample (Szczesniak, 1987). The assays conditions were sample, one *tagliatelle*; probe, Volodkevich Bite Jaws HDP/VB; test speed, 0.5 mm s^{-1}; strain, 100%.
- Texture profile analysis (TPA): This technique has been extensively applied to different food products; it consists of compressing the sample twice. From the complete compression-relaxation-tension profile, several texture parameters are derived: hardness, adhesiveness, cohesiveness, consistency, springiness and masticability (Szczesniak, 1963; Bourne, 1978). The assay conditions were sample, one *tagliatelle*; probe, 75-mm flat-end aluminium disc P75; test speed, 0.5 mm s^{-1}; strain, 20%.

The recorded data were processed with the software Texture Expert Exceed v.1.2 (Stable Micro Systems). Six replicates for each storage time were done for all measurements.

Rheology

In addition to texture, knowledge about rheological characteristics enables us to perform a comprehensive description of food behaviour. In this work, two complementary assays were performed, involving large and small deformations, respectively:

- Relaxation test: Relaxation curves provide a way of measuring the viscoelastic properties of solids. Previous works confirmed that viscoelastic behaviour of cooked pasta can be characterised by the generalised Maxwell model, combining one elastic ideal element (string) in parallel with various composed Maxwell elements (i.e. a string element with a viscous element in series) (Steffe, 1996; Olivera & Salvadori, 2006). These assays were performed using the texture analyzer previously mentioned, with the following conditions: sample, one *tagliatelle*; probe, 75-mm flat-end aluminium disc P75; test speed, 0.5 mm s^{-1}; strain, 20%; time, 600 s.
- Dynamic oscillatory test: This test employs small deformations to indicate predominance of either viscous or elastic characteristic in a particular material, providing complementary information to the relaxation test. Through the experimental procedure, two parameters are determined: the storage modulus G' and the loss modulus G'', as a function of both time and oscillation frequency. G' indicates the elastic behaviour of the food, while G'' measures the viscous characteristics of food. The loss tangent, tan δ, is a relative measurement of both contributions, viscous and elastic ones, and indicates which characteristic prevails. These tests were performed in a Rheometer RS600 (Haake, Karlsruhe, Germany), with the following conditions: sample, three *tagliatelle*; probe, 35-mm parallel serrated plates (PP35/S) with a gap of 0.8 mm; oscillation frequency, 0.1–100 Hz; strain, 0.1%.

Six replicates for each storage time were done for all measurements.

Sensory analysis

Increasingly, consumers ask for natural food products, and there exists a clear and favourable stream towards foods that maintain their original sensory properties. From this trend arises the importance of sensory analysis as the only way to know how consumers perceive and value the products. To test the acceptability of frozen cooked pasta, a sensory analysis was carried out using a semi-structured hedonic scale (Meilgaard *et al.*, 2006). A thirty-member panel of untrained consumers was recruited: eighteen women and twelve men, 25–55 years in age, habitual consumers of pasta and food containing whole flour, and with some experience in sensory evaluation.

Frozen samples were heated in an oven at 180 °C for 5 min, served in 60-mL capacity plastic cups, coded in random order and immediately presented (individually) to panellists. Panellists rinsed their mouths with bottled spring water between each sample testing. The assessed attributes were the appearance (related to colour), flavour, consistency (related to texture) and global acceptability. Each panellist received a form sheet to evaluate the mentioned attributes, using a nine-point hedonic scale anchored with 'like extremely' and 'dislike extremely' at each end, with a neutral point labelled as 'neither like nor dislike'. The sensory tests were performed in an isolated room with good illumination and natural ventilation.

Shelf life

According to Taoukis & Labuza (1989a,b), it is necessary to know about the quality loss kinetics of a food to predict its shelf life. This implies measuring the loss of food quality during storage, obtaining the rate of change of quality attributes from kinetic modelling, and finally establishing a critical point or index to define the shelf life. In general terms, a kinetic model for food quality loss can be expressed as:

$$-\frac{dA}{dt} = kA^n \quad (2)$$

where A is the (measured) quality index (e.g. colour, texture, sensory attribute), t is time, k is the reaction rate constant, which is temperature dependent and n is the reaction order. Usually, zero or first-order kinetic models are used (Singh, 2000), i.e., $n = 0$ or 1, respectively.

The quality index A is a critical descriptor, i.e., an attribute that limits the shelf life of the product, because of its either decrease (e.g. vitamin content, additive functionality, crispness, typical aroma) or increase (e.g. browning, microbial load, undesirable flavour), during the commercial life of the product. This critical descriptor was defined analysing the evolution of the different instrumental and sensory quality indices described in previous sections.

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 $P < 0.05$.

Results and discussion

Moisture content

Figure 1 shows the evolution of moisture content in frozen cooked *tagliatelle* with storage time, at a storage temperature equal to −18 °C. As can be observed, moisture content decreased significantly ($P < 0.05$) during the first 4 months of frozen storage. This trend did not depend on the freezing technology that was used. Afterwards, moisture content remained almost constant till the end of storage time. Finally, after 12 months, the average weight loss was 6%. This value suggests that in spite of being covered with an impermeable material, ice frost formation induced a considerable pasta weight loss. Laguerre & Flick (2007) studied the effect of temperature fluctuations and package materials on weight loss of frozen foods stored in a domestic freezer; they also found that small fluctuations induce ice/frost formation and water loss. According to Mascheroni & Salvadori (2006), temperature fluctuations are usual in commercial freezers under conventional operating conditions. These small fluctuations will affect the sensory quality of the frozen foods (texture, drip on thawing, global appearance and probably taste), even though food safety is ensured.

In addition, the influence of the freezing rate on weight loss can be analysed from Fig. 1. The slight difference in moisture content produced by the freezing method, i.e., 62.91% for fast freezing and 61.35% for slow freezing, was maintained during the first 2 months of storage, but this difference gradually disappeared after that period. Similar trends were reported by other researchers in starch-based products: Bárcenas & Rosell (2006) found that the moisture content of par-baked bread significantly decreased during 42 days of frozen storage at −25 °C. Phimolsiripol *et al.* (2008), who studied the frozen storage of bread dough, found that the control sample, stored at −18 ± 0.1 °C, showed a weight loss of 0.5% as well.

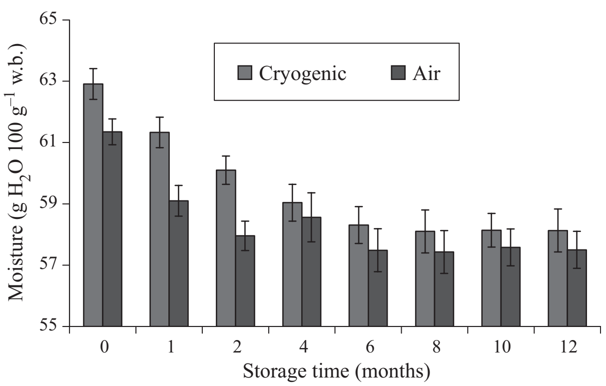

Figure 1 Variation of moisture content of cooked pasta during frozen storage.

Colour

Table 2 presents L^* a^* b^* colour parameters registered throughout 12 months of frozen storage; each value is

Table 2 Variation of colour parameters during frozen storage

Time (months)	L^*		a^*		b^*	
	CRY	AIR	CRY	AIR	CRY	AIR
0	60.59[a]	62.77[a]	4.22[a]	4.37[a]	20.89[a]	21.48[a]
1	62.44[b]	64.18[b]	4.15[a]	4.07[a]	20.13[a]	20.45[a]
2	64.25[c]	65.27[bc]	3.99[a]	3.58[b]	19.48[a]	19.25[a]
4	65.32[cd]	66.31[c]	3.75[ab]	3.54[b]	19.15[a]	19.08[a]
6	66.06[d]	66.61[c]	3.62[b]	3.50[b]	18.76[b]	17.86[b]
8	66.08[d]	66.42[c]	3.65[b]	3.66[b]	19.22[ab]	18.64[a]
10	66.31[d]	65.30[bc]	3.54[b]	3.55[b]	19.39[ab]	18.02[a]
12	65.87[cd]	66.09[c]	3.53[b]	3.62[b]	19.31[ab]	18.27[a]

Mean values of each parameter followed by same letter do not differ (α = 0.05).
CRY, cryogenic freezing; AIR, air-blast freezing.

the average of six determinations. The most noticeable change was observed in lightness (L^*), which increased 8% to the end of the process. In a few isolated cases, some lighter zones could also be observed, indicating a marked dehydration (moisture content of 35% approximately) that negatively affects the overall lightness of pasta. These samples were discarded because they were not representative of the general trend and hence, were not taken into account in the average results presented in Table 2. Kindt *et al.* (2006, 2008) also reported the presence of white points at the surface of different types of frozen storage pasta, which were identified from macroscopic observation of samples. These authors associated these defects with surface dehydration generated when water migrates from food surface to storage ambient by ice sublimation, producing a visible damage to pasta. Damage area presents lighter colour because of microscopic cavities (pores) previously occupied by ice crystals, which modify the length wave of reflected light.

With respect to other parameters of CIE $L^* a^* b^*$ system (also reported in Table 2), it was found that a^*, which is associated with redness, diminished during frozen storage. On the other hand, b^*, that is related to yellowness, did not present significant differences in the tested conditions; only a slight decrease during the sixth months of storage was observed. In consequence, the samples tend to a hue with more proportion of grey components.

Texture

As it was stated by different researchers, texture characteristics are of vital importance for defining the quality of cooked pasta, either organic or not (Edwards *et al.*, 1993; Sozer *et al.*, 2008; Olivera & Salvadori, 2009). In addition, the combined analysis of the results provided by different techniques offers a complete description about the texture of the studied product (Serra Síster *et al.*, 1986).

Cutting-shear test

Results for the cutting-shear tests for different frozen storage times and both freezing rates are shown in Fig. 2; the value of maximum force can be correlated directly with the hardness of analysed samples. Maximum force diminished during the first 2 months of storage, and then no significant variations were detected during the remaining time. In addition, regarding the freezing method, the differences achieved by using fast freezing were only maintained for the first 2 months of storage.

Similarly, de Kock *et al.* (1995) observed that the slight advantage obtained by fast freezing in non-cellular par-cooked starchy convenience foods (prebaked pizzas) was lost during frozen storage. Additionally, freezing and frozen storage may be detrimental to these convenience foods. According to Hatcher (2004), who measured 'bite' as maximum cutting stress, freezing and frozen storage of optimally cooked noodles results in a product with inferior texture attributes.

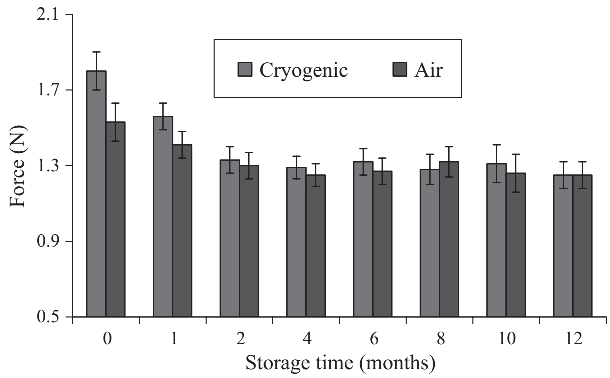

Figure 2 Variation of maximum cut force of cooked pasta during frozen storage.

Texture profile analysis

From the analysis of force vs. time curves, the independent parameters hardness, consistency, cohesiveness, elasticity, adhesiveness and resistance, and the dependent parameter masticability can be evaluated (Szczesniak, 1963; Bourne, 1978).

Figure 3 shows the evolution of different TPA parameters during frozen storage (note that only those that presented significant differences are shown). In general terms, a similar behaviour can be observed for the different TPA parameters: a significant decrease was registered with time, which was more pronounced during the first 2 months of storage.

As it was mentioned, in a previous work, the influence of the freezing method was investigated. No significant differences were found when comparing the TPA parameters of the unfrozen cooked pasta and cryogenic frozen sample, except for adhesiveness. However, the TPA results of the samples frozen in air-blast tunnel indicate that slow freezing produces pasta with less hardness, less consistency and consequently, less masticability than the unfrozen product (Olivera & Salvadori, 2009). The initial difference between samples frozen with cryogenic equipment and air-blast tunnel was reduced as storage time increased. Therefore, as it was mentioned earlier, the slight advantages achieved by using a fast freezing rate (i.e. cryogenic device) are lost during frozen storage. In this sense, the same trends were found by Giannou & Tzia (2007) in their study of quality characteristics of frozen dough products: during the first 2 months of frozen storage, its quality decayed rapidly, and then remained stable, presenting rather satisfying quality characteristics even after 9 months of storage.

In particular, hardness of pasta samples decreased with storage time. Our results present an opposite trend

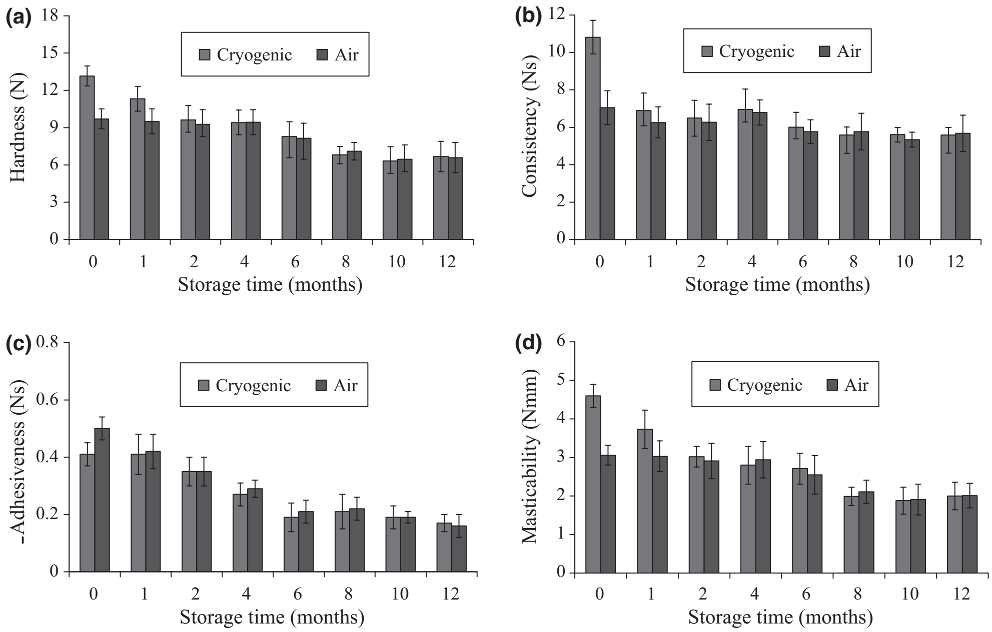

Figure 3 Evolution of hardness (a), consistency (b), adhesiveness (c), and masticability (d) of pasta, obtained by Texture profile analysis (TPA), during frozen storage. Parameters of TPA of the cooked pasta, prior to freezing: hardness 14.42 N, adhesiveness −0.99 Ns, consistency 11.99 Ns, masticability 4.77 (Olivera & Salvadori, 2009).

to that obtained for frozen dough and par-baked bread. In bread baked from frozen dough and par-baked frozen bread, crumb firmness increased gradually with frozen storage time, indicating that some undesirable changes are produced during the frozen storage (Bárcenas *et al.*, 2003; Phimolsiripol *et al.*, 2008). Furthermore, a gradual decrease in adhesiveness was observed until the sixth storage month, probably as a consequence of surface dehydration.

Rheology

Relaxation test

The results of the relaxation test were fitted to eqn (3), i.e., the generalised Maxwell model (Steffe, 1996; Olivera & Salvadori, 2009). In all cases, a very good regression performance ($r^2 > 0.99$) was obtained considering one simple element and two composed elements:

$$F(t) = F(t)/F_0 = A_\infty + A_1 \exp(-t/\tau_1) + A_2 \exp(-t/\tau_2) \tag{3}$$

From the regression coefficients A_i, the elasticity modules (E_i) were calculated:

$$E_i = \frac{A_i F_0}{a\varepsilon} \tag{4}$$

Figure 4 shows the values of viscoelastic properties calculated from the parameters of the generalised Max-

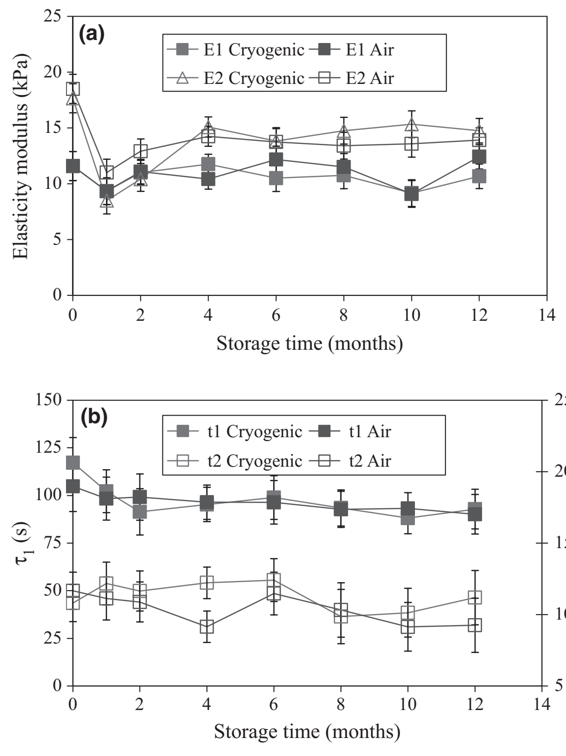

Figure 4 Variation of elasticity modulus (a) and relaxation time (b) of cooked pasta during frozen storage.

well model as a function of storage time, i.e., elastic modules, E_1 and E_2 (Fig. 4a), and relaxation times, τ_1 and τ_2 (Fig. 4b). The elastic modules are related to the solid characteristics of the sample and the relaxation times to the viscous ones. As stated by Sozer *et al.* (2008), the elastic behaviour is associated with gluten content and the viscous behaviour is related to starch content. The modulus E_1 did not present differences with respect to the freezing method, conversely as it was detected in the texture tests previously discussed. The modulus E_2 decreased rapidly during the first month of storage but then partially recovered its original value; a slight difference was observed because of the freezing technique during the first stage of storage (month 1), indicating an elasticity loss in the tested samples. Afterwards, no significant differences were detected. These results support the ones obtained in the cutting-shear test and TPA, i.e., ice recrystallisation and subsequent damage to the food structure are inevitable consequences of frozen storage (Zaritzky, 2006). Besides, no significant differences in relaxation times were observed in relation to freezing method or storage time (Fig. 4b).

Dynamic oscillatory test

Figure 5a shows the variation of elastic modulus during the frozen storage of cooked pasta. This parameter presented an important decrease in the first stage of storage for the case of cryogenic freezing, confirming again that the advantages achieved using high freezing rates are lost almost completely during the first months of frozen storage. This decrease in elasticity gives an idea of the modifications suffered by the pasta structure because of ice crystals formation and recrystallisation (Laguerre & Flick, 2007). For longer storage times, no significant differences were found in the elastic modulus.

Also, the variation of modules G' and G'' during storage was reflected in the change of the tangent of the deformation angle, tan δ (Fig. 5b). This parameter is an index of the elastic characteristic of food; its value diminishes with stiffness of food matrix. During pasta frozen storage, tan δ increased significantly, independently of the freezing method, showing the loss of elastic characteristic because of the structural damage produced by enlargement of ice crystals. By the end of the storage period, this parameter had duplicated its initial value.

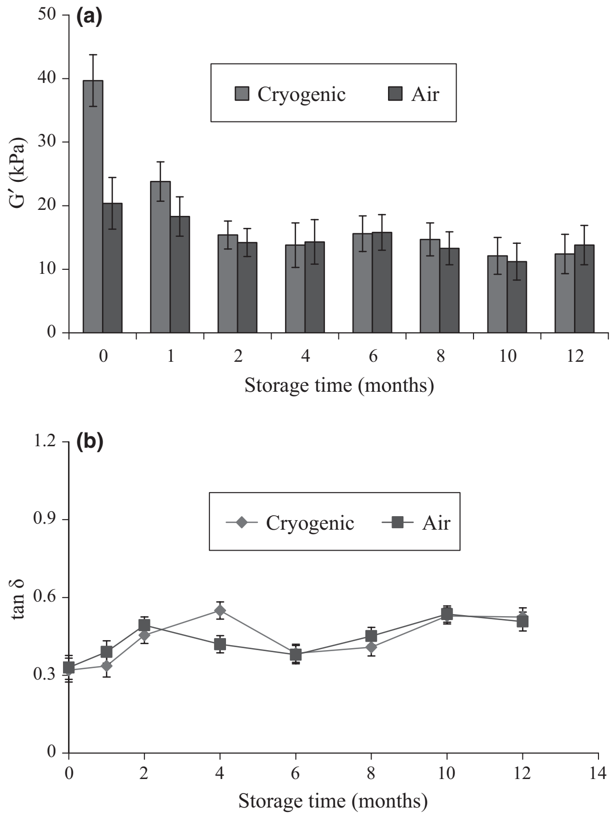

Figure 5 Variation of elastic modulus (a) and tangent of deformation angle (b) during the frozen storage of cooked *tagliatelle*.

Sensory analysis

Results of sensory acceptability tests for frozen storage of pasta are presented in Table 3. From the statistical analysis of such values, it can be stated that consumers found significant differences in all evaluated attributes during the frozen storage. Previous studies on the influence of the freezing methods indicate that cryogenic freezing does not affect any of the four sensory attributes, but low freezing, on the other hand, has a negative impact in all of them, except the appearance (Olivera & Salvadori, 2009).

Appearance (related to surface colour) decreased between the second and fourth storage month; towards the end of storage (months 8 and 10), it diminished again. During frozen storage, surface colour turned lighter, as can be seen from Table 2, and probably consumers rejected the pale appearance because the tested product is formulated from whole flour. Also, the results could be because of the loss of concentration or intuition of panellists (Meilgaard *et al.*, 2006).

According to consumers, the difference between freezing methods regarding the consistency could not be detected after the first month of storage, demonstrating once again that advantages obtained through the fast freezing procedure are not maintained along storage. Consistency decreased again between the fourth and sixth month of storage, remaining constant for the rest of the storage time tested in this work. Considering the flavour and overall acceptability of samples, we found that both attributes presented a behaviour similar to that of consistency.

Table 3 Sensory analysis on acceptability of frozen cooked pasta

Time (months)	Appearance		Consistency		Flavour		Global acceptability	
	CRY	AIR	CRY	AIR	CRY	AIR	CRY	AIR
0	6.83[a]	6.70[a]	6.60[a]	5.93[b]	7.00[a]	6.46[b]	6.87[a]	6.40[b]
1	6.77[a]	6.76[a]	5.83[b]	5.68[b]	5.72[b]	5.63[b]	5.88[b]	5.80[b]
2	6.73[a]	6.74[a]	5.65[b]	5.76[b]	5.62[b]	5.86[b]	5.68[b]	5.78[b]
4	6.06[b]	5.92[b]	5.47[b]	5.45[b]	4.71[c]	4.93[c]	5.73[b]	5.61[b]
6	5.80[b]	5.86[b]	4.72[c]	4.96[c]	4.73[c]	4.58[c]	4.99[c]	4.85[c]
8	5.97[b]	5.81[b]	4.53[c]	4.37[c]	4.95[c]	4.83[c]	4.82[c]	4.74[c]
10	5.42[c]	5.17[c]	4.43[c]	4.55[c]	4.80[c]	4.75[c]	4.88[c]	4.99[c]
12	5.28[c]	5.35[c]	4.55[c]	4.60[c]	4.72[c]	4.69[c]	4.98[c]	4.79[c]

Mean values of each parameter followed by same letter do not differ ($\alpha = 0.05$).
Sensory analysis of the cooked pasta, prior to freezing: appearance 6.73, consistency 6.97, flavour 6.83, global acceptability 7 (Olivera & Salvadori, 2009).
CRY, cryogenic freezing; AIR, air-blast freezing.

Shelf life

During frozen storage, the hardness of pasta was the parameter that showed the most important variation, which can be deduced from the results of texture and rheological tests previously discussed. Moreover, such differences were detected by regular consumers and certainly affected the acceptability of the product. Therefore, hardness was selected as the critical quality index for frozen storage of cooked pasta, and then, the quality loss kinetic model was obtained for the tested conditions. In this way, from the experimental data of instrumental (hardness) and sensory (consistency) texture, the corresponding quality loss kinetics was calculated. In both cases, experimental values were well adjusted using a modified first-order kinetic model (Martins *et al.*, 2008):

$$A = a + b\exp(-kt) \quad (5)$$

where t is the storage time (months), A is the instrumental or texture value evaluated at storage time t, and a, b, and k are kinetic constants.

Figure 6a,b shows the results of kinetic modelling for hardness and consistency, respectively, including experimental values; kinetic constants obtained from regression of eqn (5) are presented in Table 4. Shelf life was determined by establishing a limit of sensory acceptability equal to 5.4 of consistency attribute. This value was determined by means of a complementary test utilising a survival analysis (not detailed in this work) and corresponded to the point when 25% of panellists rejected the pasta samples after asking them: 'Would you consume this pasta regularly'? (Ares *et al.*, 2008; Olivera, 2009).

Consequently, sensory shelf life of frozen cooked pasta in the cryogenic device and air-blast tunnel was calculated as 3.6 and 3.8 months, respectively. As both values are similar, it can be stated that the freezing method does not have any influence on the shelf life of stored pasta. Similar values were reported for par-baked frozen bread, where shelf life was restricted to 12–20 weeks, i.e., 3–5 months (Vulicevic *et al.*, 2004). Finally, the values of hardness limiting the shelf life according to the obtained kinetic model based on

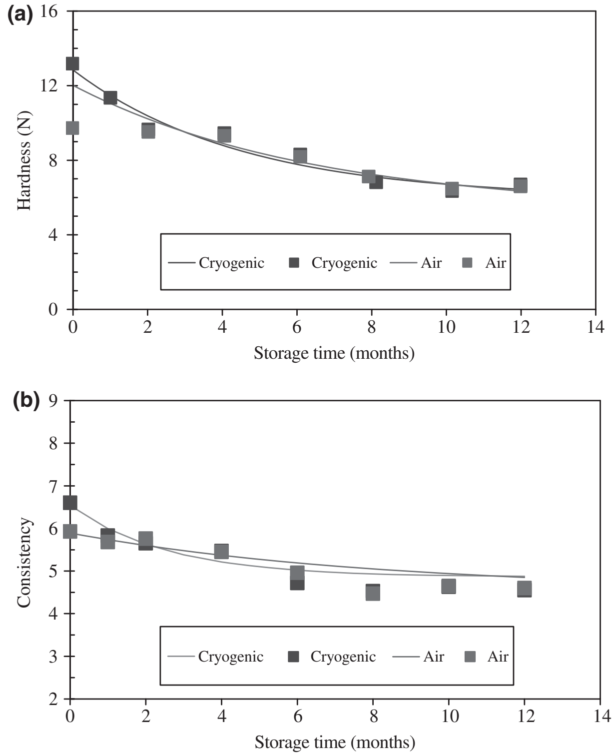

Figure 6 Quality kinetic model: hardness (a) and consistency (b). Lines corresponded to predicted values and symbols to experimental ones.

Table 4 Regression results for kinetic modelling of shelf life

	Hardness (N)		Consistency	
	CRY	AIR	CRY	AIR
a	5.95	5.32	4.86	4.53
b	6.89	6.70	1.68	1.36
k (per month)	0.22	0.16	0.30	0.12
r^2	0.96	0.98	0.97	0.93

CRY, cryogenic freezing; AIR, air-blast freezing.

consumers' perceptions were calculated: 9.06 and 8.96 N for frozen pasta by cryogenic method and air-blast tunnel, respectively.

Sensory shelf life strongly depends on the limit value of sensory acceptability, which is determined by the probability of consumer rejection; the most common values of this probability are 25% and 50%. The choice between 25% and 50% is influenced by several factors, such as the commercial turnover of the product and the brand positioning in the market, among others (Hough *et al*., 2006).

Another important aspect to be considered is the effect of storage temperature, not only for the prediction of shelf life but also to evaluate the effect of the different stages of product distribution, from food manufacturer to consumers' freezer. The dependence of shelf life on storage temperature can be predicted if Q_{10} parameter is known, but the available data in literature are limited on this subject. Further research is necessary to study the dependence of kinetic rate on temperature.

Conclusion

In this work, frozen storage of cooked pasta (*tagliatelle*) was studied with the aim of characterising its moisture content, texture, rheology and sensory acceptability as a function of storage time and freezing method. It was determined that moisture content of frozen pasta presents a significant decrease during the first months of storage, independently of the freezing method. The analysis of texture, viscoelastic and sensory characteristics showed a decrease in the maximum cutting force, hardness and consistency of the studied pasta during frozen storage. These changes were more significant at the beginning of storage and represent the evidence of the increase in average size of ice crystals during storage.

Regarding the influence of the freezing method on the quality of the prepared product, it was determined from texture, viscoelastic and sensory tests that slight advantages were initially obtained by using a fast freezing method but were not maintained after frozen storage. On the other hand, the sensory analysis revealed that frozen storage negatively affects the acceptability of cooked pasta. Finally, from an exhaustive analysis of the variation of quality indices during frozen storage, it could be determined that instrumental as well as sensory texture is the most representative indices of product quality loss, and therefore, they allow the quantification of the food's shelf life, which resulted independent of the freezing method.

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