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Quality evaluation of foodstuffs frozen in a cryomechanical freezer

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Abstract

Cryomechanical freezing is recommended for delicate products, with poor mechanical resistance (shrimps, raspberries, strawberries) or those that change their appearance during freezing (chicken, mushrooms, shrimps). The aim of this work is to study the quality aspects related to the application of cryomechanical freezing compared to the use of a conventional mechanical freezer. In order to determine whether or not the use of the combined freezer provokes an improvement in the quality of the final product, different kinds of foodstuffs were chosen and analysed before and after freezing by both methods. The selected products were: chicken escallops, hamburgers, strawberries, asparagus and mushrooms. The quality parameters analysed for this purpose were: drip loss during thawing, texture and colour. The variation in mechanical resistance was also evaluated as a function of the immersion time to determine the hardness of the protective crust formed by the liquid N_2 pretreatment.

Keywords: Cryogenic; Mechanical; Freezing; Quality

1. Introduction

Cryomechanical or combined freezing consists of the association of two freezing systems: an in-line cryogenic freezer (using liquid N_2 (LN) or CO_2) combined with a continuous mechanical freezer (with cold air as heat transfer fluid). Generally, this process uses first a cryogenic step followed by a mechanical one (Groll, 1986; Acharya & Bredencamp, 1989).

During cryogenic freezing, the foodstuffs come into contact with the cryogenic liquid and quick freezing of the outer layers occurs forming a thin crust. This freeze-crusting treatment is said to provide a higher mechanical resistance to the foodstuffs and to prevent small and/or wet products from sticking on the conveyor or between them. The crust frozen locks in moisture and flavours and prevents clumping. When products are frozen more slowly, as in a mechanical freezer, moisture forms an ice bridge between the individual pieces of food and they clump together. With LN, the pieces are individually quick frozen, and there is no time for the bridging to occur.

After the freeze-crusting the product completes its freezing in a mechanical freezer (normally a fluidised bed or a belt freezer) until its thermal centre reaches the required final temperature.

Cryomechanical freezing is specially recommended for delicate products, not having good mechanical resistance (raspberries, strawberries, shrimps, peeled mussels) or other products that change their appearance during freezing (chicken escallops, mushrooms, peeled or cooked shrimps) (Mascheroni, 2000).

Besides, the overall freezing time and the weight loss are reduced compared to those of purely mechanical freezing. This reduction increases the output of the mechanical freezer and may also induce an improvement in the final product quality (Summers, 1984). In a previous work, we have already developed a model for the combined process (Agnelli & Mascheroni, 2001). This model predicts that only a few seconds of immersion in the cryogenic liquid are enough to reduce the freezing time and to form the protective crust.

Notwithstanding, the alleged higher product quality is not definitively verified, especially when the cryogenic stage consists of an immersion pre-freezer, with higher heat transfer rates (and possible damage to the structure of product surface layers) than for a cryogenic aspersion freezer. When studying cryogenic freezing on halved

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strawberries Grout, Morris, and McLellan (1991); found that, after thawing, cryogenically frozen had better texture and flavour than blast frozen ones. When comparing the final quality of meat products frozen by different methods, Löndahl, Göransson, Sundstén, Andersson, and Tornberg (1995), found no noticeable differences between hamburgers frozen in liquid N_2 and by an impingement mechanical freezer but, for other types of freezers that had large differences in the freezing rate, the quality differences were significant. On the other hand, Åström and Löndhal (1969), measuring the difference in drip loss during thawing of beef steaks and strawberries frozen at different rates found this value to be negligible in the first case but important in the second.

In the only study found on immersion pre-freezing, Macchi, Delpuech, Billiard, and Flick (1996), measured a higher mechanical strength of raw pizza dough and strawberries as the crusting period increased. On the other hand, a compact nitrogen-immersion freezer used in-line ahead of an existing fluidised bed mechanical freezer allowed the throughput of frozen blueberries to double, decrease labour costs, eliminate nearly 5% weight loss through dehydration and improve quality (Morris, 1991). According to this paper, the use of the cryogenic tunnel to crust freeze the berries in seconds, prevents internal ice-crystal formation.

The aim of this work is to study the quality aspects related to the application of cryomechanical freezing compared to the use of a conventional mechanical freezer. In order to determine whether or not the use of the combined freezer provokes an improvement in the quality of the final product, different kinds of foodstuffs were chosen and analysed before and after freezing by both methods. The selected products were: chicken escallops, hamburgers, strawberries, asparagus and mushrooms. The gain in mechanical resistance due to the crust formation during immersion in LN was also evaluated.

2. Experimental

2.1. Freezing methods

Products were frozen in a conventional air-blast tunnel and in a purpose-fitted pilot cryomechanical freezer. The latter results from the combination of a Dewar flask in which liquid N_2 (LN) is stored and an air-blast freezer and is schematically described in Fig. 1. In the case of cryomechanical freezing, products were first submerged for a given time in LN (a few seconds). After that, they were immediately transferred to the air-blast tunnel until the core temperature reached −20°C.

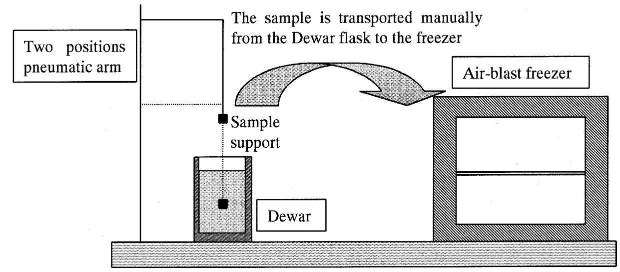

Fig. 1. Experimental facilities used for the simulation of the cryomechanical freezer.

Core temperature evolution with time was followed by means of a type T thermocouple connected to a data acquisition system Keithtley DAC-500. The duration of the immersion time in LN was dependent on the product. The immersion time used on each product in the present case is given in Table 1. These times were short enough to prevent product damage as a consequence of too fast freezing. Otherwise, if immersion is prolonged, products may crack.

2.2. Drip loss evaluation

Frozen products were laid over a weighed absorbent paper and let to thaw at room temperature, except for hamburgers that were kept at 4°C. Drip loss was then evaluated by periodically weighing the absorbent paper until a constant value is reached and expressed as

$$DL = \frac{\omega_t - \omega_0}{\omega_S} \times 100 \ (\%),$$

where ω_0 is the weight of the dry absorbent paper (g), ω_t is the weight of the wet absorbent paper at time t (g) and ω_S is the weight of the frozen sample (g).

2.3. Texture tests

Firmness of the thawed products was measured by simple compression between two flat surfaces in an INSTRON texturometer (Model 1011) supplied with transducers of 500 and 50 N which can operate at different crosshead speeds. For this purpose, the products were size selected to ensure certain uniformity in the

Table 1
Immersion times in LN for the different products tested

Product	Hamburger	Chicken escallop	Strawberry	Mushroom	Asparagus
Time (s)	20	20	20	10	10

results. The rate of advance of the compression plug was 30 mm/s. The force–distance diagram was registered during the run. The first marked break in the slope of the diagram indicates the point of internal fracture and was taken as the parameter to measure flesh firmness.

On the other hand, puncture tests were performed in the case of strawberries and chicken escallops to assess the hardness of the crusted surface. After immersion in LN, the sample is punctured normally to the frozen crust. Experiments were run with a metal probe of 2 mm diameter, and a rate and depth of penetration of 30 mm/s and 20 mm, respectively. In this case, the maximal force of the force–distance plot was evaluated to characterise the mechanical resistance of the crusted surface after different times of immersion in liquid N_2.

2.4. Colour characterisation

For the representation of colour in the three-dimensional space, the CIE 1976 $L^*a^*b^*$ system was adopted (L^* represents the luminosity, $\pm a^*$ the redness or greenness and $\pm b^*$ the yellowness or blueness). Colour difference values ΔL^*, Δa^*, Δb^* are calculated according to:

$$\Delta L^* = L^* - L_t^*, \quad \Delta a^* = a^* - a_t^*, \quad \Delta b^* = b^* - b_t^*,$$

where t represents colour taken as reference, the fresh product, in our case.

The total difference colour is defined by the equation: $\Delta E_{ab} = \sqrt{\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}}$.

Other parameters corresponding to the CIE L*C H^0 colour system can be calculated. In this system, L^* is the lightness, C is the chroma (saturation) and H^0 is the hue angle (colour). Their defining equations are:

$$L^* = L^*, \quad C = \sqrt{a^{*2} + b^{*2}} \quad \text{and} \quad \mathrm{H}^0 = b^*/a^*.$$

Colour difference is expressed by the values of ΔL^* and $\Delta C = \sqrt{\Delta a^{*2} + \Delta b^{*2}}$. Determination of chromatic co-ordinates was done by means of a Minolta CR100 analyser.

3. Results and discussion

3.1. Crust hardness

Strawberries and sliced chicken were selected for this test, as they are particularly sensitive to the freezing process considering the tenderness of their flesh.

The results obtained for strawberries are shown in Fig. 2, curve (a) where the maximal force (from puncture test force–distance diagram) has been plotted against the duration of the immersion in LN. It can be noted that for an immersion time of 20 s, the necessary force to break the surface layer is 4.3 N while for the fresh strawberries this force is about 0.8 N. The surface hardness has been then increased by five times. For higher immersion times, the force continues increasing, as the crust becomes thicker, but for times greater than 30 s the surface began to crack. Similar results were obtained for sliced chicken (Fig. 2, curve (b)). In this case, the surface hardness is increased by about three times in 20 s, but no surface crack was observed even if immersion continues until core freezing. Thus, the crust formed during immersion in LN constitutes a protective layer which prevents the product from damage.

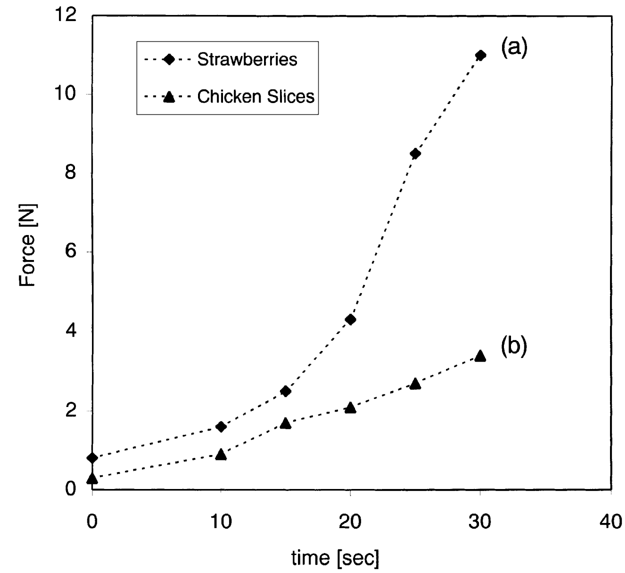

Fig. 2. Maximal force (from puncture test force–distance diagram) against time of the immersion in LN for: (a) strawberries and (b) chicken escallops.

The hardness enhancement can be related to the thickness of the frozen crust by making use of the model for heat transfer during freezing proposed by Agnelli and Mascheroni (2001). For example, as it was shown by Agnelli and Mascheroni (2001) for strawberries, 20 s of immersion leads to a frozen crust of about 1.6 mm thickness.

3.2. Quality attributes of frozen products

3.2.1. Strawberries

Two kinds of strawberries were analysed: strawberries cultivated in the field (F) and in greenhouse (G). Thus, the influence of the initial flesh firmness could also be evaluated.

The drip losses during thawing for F and G strawberries are presented in Fig. 3. F strawberries frozen in the combined freezer showed much lower thaw-drip loss than conventionally frozen ones. Up to a 60% reduction in drip loss was obtained. However, in the case of G strawberries the results are quite different, as drip loss is practically the same for the two freezing methods.

Similar results were found as regards texture experiments. Fig. 4 shows the compression force at the

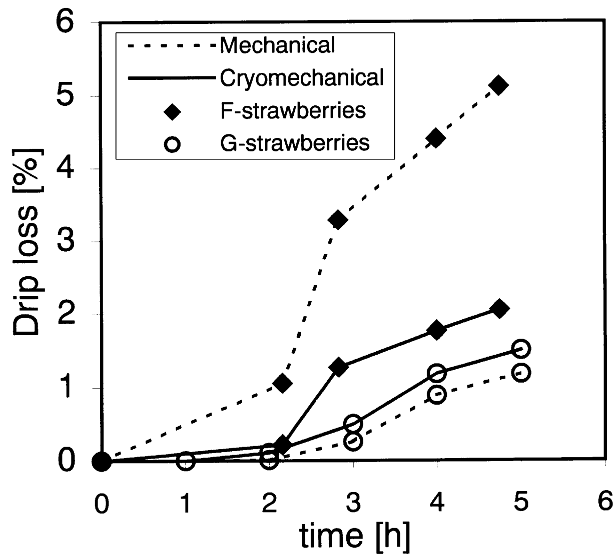

Fig. 3. Drip loss of whole strawberries after thawing at room temperature: (◆) strawberries cultivated in the field (called *F*) and (◯) strawberries cultivated in greenhouse (called *G*).

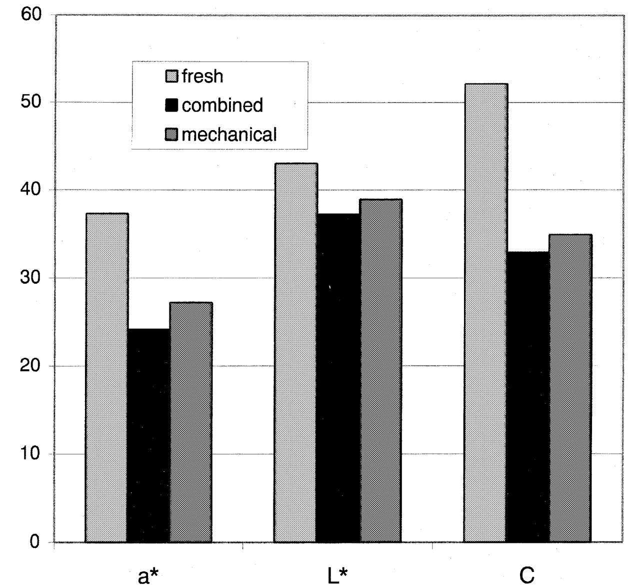

Fig. 5. Colour reflectance parameters a^* (redness), L^* (lightness) and C (saturation index) for fresh and combined and mechanical frozen strawberries.

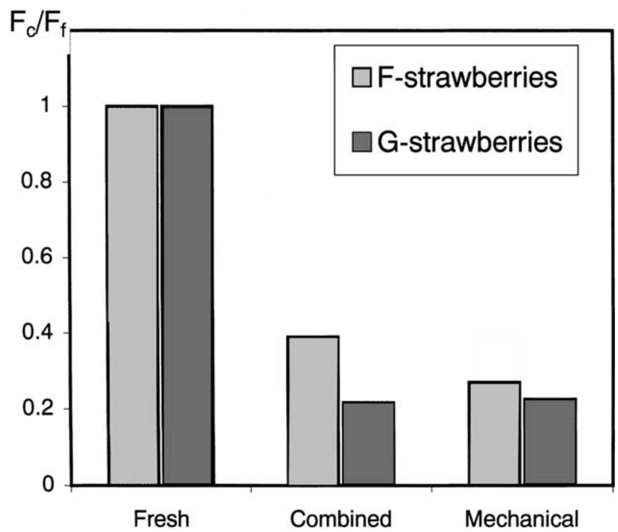

Fig. 4. Compression force at the breaking point for fresh and mechanical and cryomechanical frozen strawberries normalised with the value for fresh fruits: (▨) strawberries cultivated in the field (called *F*); (▩) strawberries cultivated in greenhouse (called *G*).

breaking point for fresh and frozen *F* strawberries (for blast and combined freezers) normalised with the value for fresh fruits. Data for *G* strawberries are also presented in Fig. 4.

It can be noted from this figure that *F* strawberries frozen in the cryomechanical freezer maintained firmness to a greater extent than those frozen in the mechanical one. On the other hand, the type of treatment did not affect *G* strawberries.

Colour measurements on the thawed products after freezing by both methods were done on *F* and *G* strawberries. Fig. 5 shows the results obtained for *F* strawberries. The a^*, L^* and C index levels of the frozen ones are lower than the fresh ones but no significant differences are found as regards colour between both freezing methods. Similar results were observed for the *G* strawberries. Finally, ΔE, the total difference in colour, also confirms this tendency as the calculated values were 21 and 19 for the combined and the mechanical methods, respectively.

However, the general aspect observed by simple visual inspection of the frozen strawberries treated in the cryomechanical freezer showed a better colour than those frozen in a conventional way. Indeed, they showed a brilliant and light red aspect while those frozen in the air-blast were darker. This result can be ascribed to the formation of very small crystals of ice that reflect light differently.

From the analysis of these quality parameters it can be inferred that cryomechanical freezing leads to better products for *F* strawberries, but for *G* strawberries no final quality improvements are detected. The unique consequence is an increase in the mechanical resistance of the frozen crust. This fact may be the outcome of the difference in the initial texture. The compression force at the breaking point for fresh *F* strawberries reaches 30 N, while for *G* strawberries this drops to 10 N. So, the initial flesh firmness seems to be an important variable to bear in mind at the moment of choosing the freezing technology.

3.2.2. Hamburger

The drip loss during thawing of hamburgers at 4°C is presented in Fig. 6. It can be noted that those frozen in

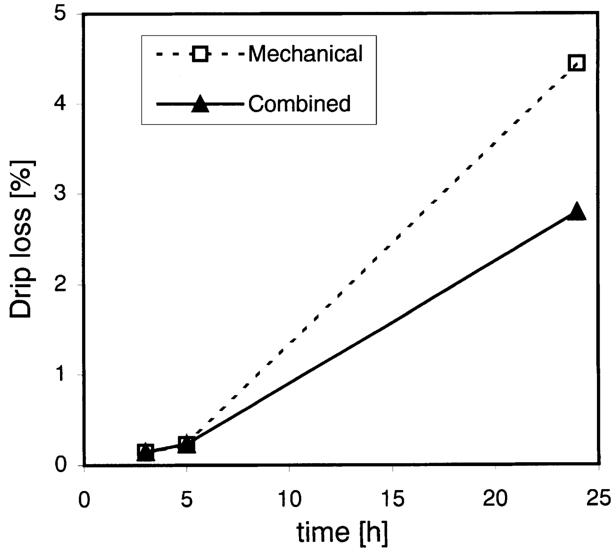

Fig. 6. Drip loss of hamburgers (at $T = 4°C$) frozen in the combined and mechanical freezers.

the combined freezer showed much lower thaw-drip loss than conventionally frozen ones. The difference was found to be 37% lower.

The results of colour tests on fresh and frozen hamburgers are depicted in Fig. 7. Hamburgers frozen in the conventional freezer present a considerable decrease in a^* (redness), L^* (lightness) and C (saturation), typical of the discolouration suffered by meat after the freezing and thawing cycles (Lanari et al., 1989). Cryomechanical freezing decreases colour deterioration as it is clearly demonstrated by all the parameters. The total difference in colour ΔE with respect to the colour of fresh hamburgers was calculated to be 11.6 for the conventionally frozen hamburgers against 5.4 for the cryomechanical frozen ones, confirming that in the last case, colour is closer to that of the fresh ones.

Besides, the general aspect of the frozen hamburgers was better for the cryomechanically frozen ones for the same reasons described for strawberries.

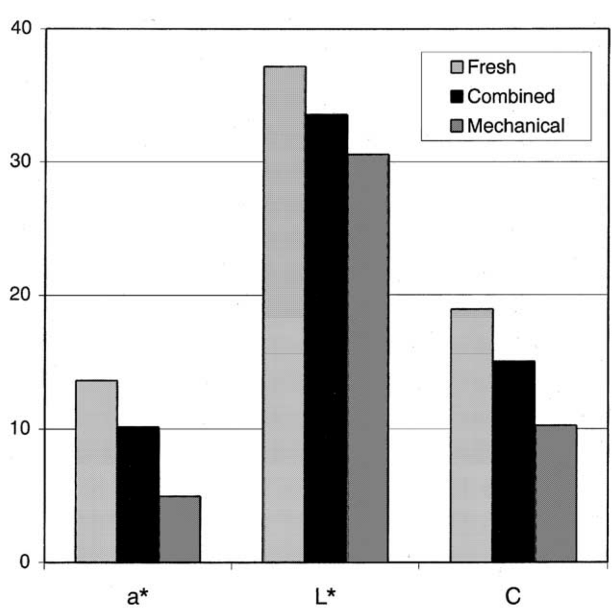

Fig. 7. Colour reflectance parameters a^* (redness), L^* (lightness) and C (saturation index) for fresh and combined and mechanical frozen hamburgers.

3.2.3. Chicken escallops

Although very limited, the drip-loss of chicken escallops frozen in the mechanical freezer is higher by 85% than that observed for cryomechanically frozen ones (Fig. 8). However, the most important feature is the effect on colour. Fig. 9 presents the differences found in colour. A decrease in L^* and an increase in a^* and C is observed for chicken escallops frozen in the air-blast tunnel, indicative that the surface becomes brown and darker. Meanwhile, escallops frozen with the combined method had a colour similar to fresh ones. The total difference in colour ΔE is 3.1 for the combined method and 8.5 for the conventional method. So, in this case, the use of the cryomechanical freezer is highly positive as the final appearance is really improved.

3.2.4. Mushrooms

The drip loss of mushrooms frozen in the cryomechanical freezer was found to be a 33% higher than that of conventionally frozen mushrooms (Fig. 8). Besides, most of them cracked during the immersion period in LN even for short times of treatment. Texture measurements showed that the compression at the breaking point is practically the same for both types of freezing. Fig. 10 presents the results normalised with the value for

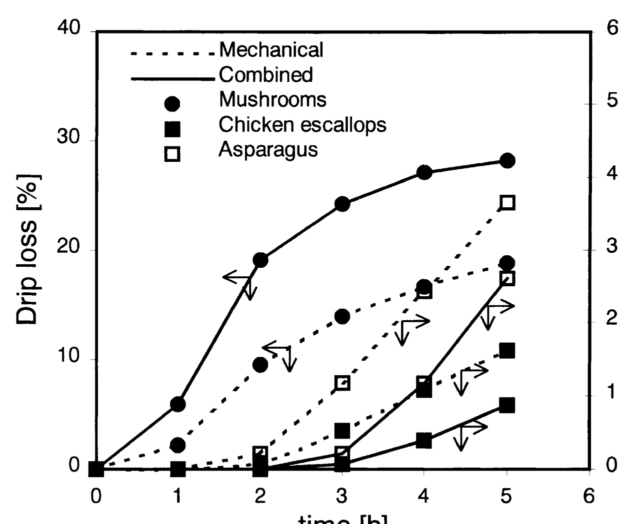

Fig. 8. Drip loss of: (■) chicken escallops, (●) mushrooms and (□) asparagus, frozen in the combined and mechanical freezers, during thawing at room temperature.

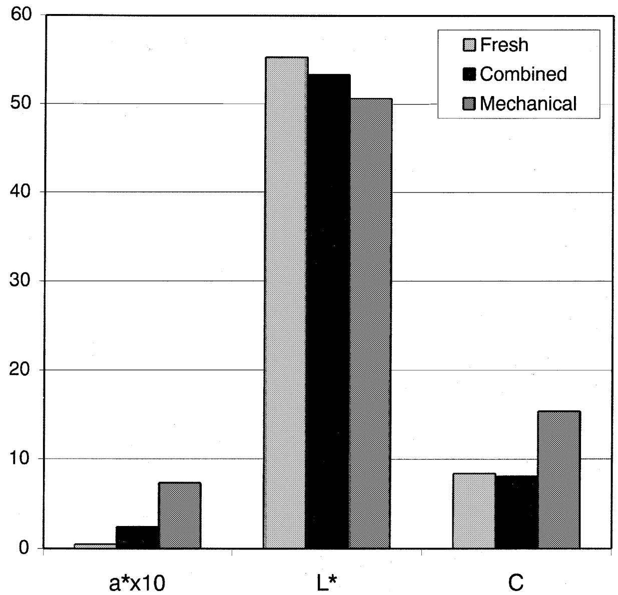

Fig. 9. Colour reflectance parameters a^* (redness), L^* (lightness) and C (saturation index) for fresh and combined and mechanical frozen chicken escallops.

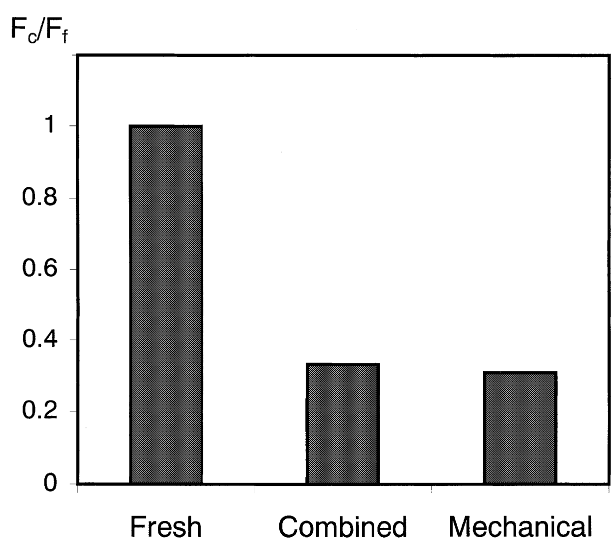

Fig. 10. Compression force at the breaking point for fresh and mechanical and combined frozen mushrooms normalised with the value for fresh ones.

fresh ones. Fig. 11 reports data of colour tests on the fresh and thawed mushrooms. These results indicate that mushrooms frozen in the mechanical freezer showed less browning than those frozen in the combined freezer. Although the difference has statiscally proved significant, it is rather small. The values of ΔE lead to the same conclusion as it is 28 for the combined freezer and 21 for the mechanical freezer.

In addition, even for short times of immersion, there is always a fraction of mushrooms whose surface cracked under LN. Briefly, the application of cryomechanical freezing is not recommended for mushrooms as the final product not only does not improve quality but at least a part of them become fissured.

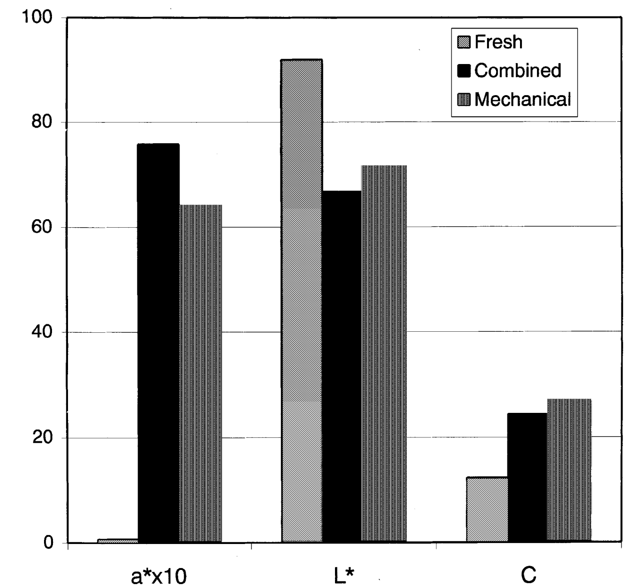

Fig. 11. Colour reflectance parameters a^* (redness), L^* (lightness) and C (saturation index) for fresh and combined and mechanical frozen mushrooms.

3.2.5. Asparagus

The drip loss of conventionally frozen asparagus was found to be higher by 40% than that observed for the cryomechanically frozen ones (Fig. 8). Fig. 12 presents the values of the colour parameters, in this case, $-a^*$

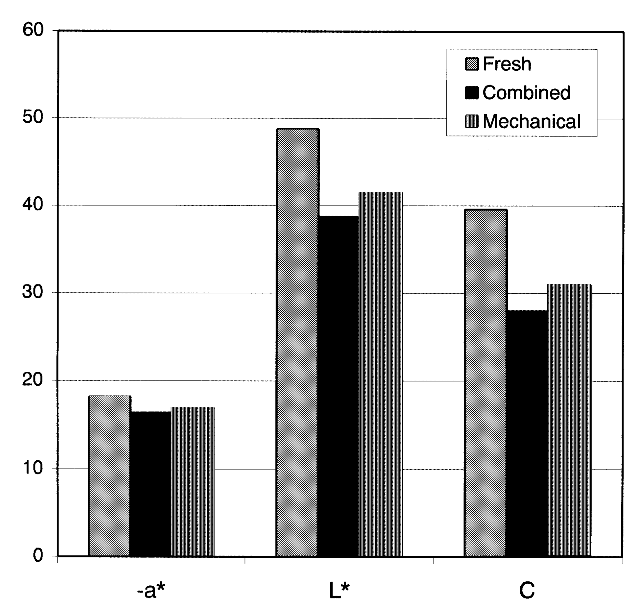

Fig. 12. Colour reflectance parameters a^* (redness), L^* (lightness) and C (saturation index) for fresh and combined and mechanical frozen asparagus.

(greenness), L^* and C. It can be noted that after freezing asparagus become more pale for both freezing techniques but no noticeable differences are found between them. The total difference in colour ΔE would favour the mechanical freezing technique as the thawed asparagus seem to be, as regards colour, closer to the fresh ones (17 against 12). However, these differences are only slightly bigger than experimental error (within 3%).

In this particular case, the application of cryomechanical freezing can be recommended as the gain in drip loss using this freezing method is more important in comparison to the loss in colour.

4. Conclusions

The principal feature of cryomechanical freezing is the protective crust formed during immersion in liquid N_2. A few seconds of immersion provokes an increase in surface hardness of many times its initial value.

Hamburgers, chicken escallops and asparagus exhibit benefits in quality when frozen in the combined freezer. On the contrary, the quality of frozen mushrooms is not only not improved by the use of the cryomechanical freezing but their surface cracks during the fast freezing of the LN immersion step. In the case of strawberries, the results are also dependent on its initial texture. Strawberries with high initial firmness showed a better quality when they were frozen in the cryomechanical freezer but no improvement was observed for strawberries with low initial firmness.

As it can be seen, the results are highly dependent on the product. No general conclusion can be made about the use of the cryomechanical freezing to improve product quality. Besides, an economical evaluation should be done for products that show an improvement by this freezing technique in order to estimate if its use is justified.

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