Faster freezing times, which can be achieved by using cryogenic processes, lead to better organoleptic characteristics, with water retention capacity being closely linked to other qualitative descriptors of meat such as tenderness and juiciness.

Table 3 quantifies the losses at freezing and defrosting according to the freezing technique used. Here, there are significantly higher losses when using a mechanical freezing tunnel (+625% at -20°C and +300% at –40°C) compared to the test carried out using cryogenic freezing.

• **Dehydration**

During the freezing process, products may suffer high levels of dehydration due to the sublimation of surface water. This dehydration may lead to a significant loss of weight, up to 10% in certain cases, as well as affecting the taste of the product. Using cryogenic freezing processes enables a significant reduction of this dehydration (up to 10 times less dehydration) (Löndahl et al., 1195) compared to mechanical freezing.

The level of dehydration is directly linked to the tangential velocity of the gas (air, N_2 or CO_2) in contact with the product. Mechanical freezing requires a high tangential velocity in order to limit the length of time required for the freezing process, resulting in significant dehydration for certain foodstuffs.

Table 3: Loss of weight (in %) with different freezing/defrosting processes for ham

Freezing x defrosting	Freezing loss	Defrosting loss (microwave)
-20°C tunnel x microwave	0.50	0.80
-40°C tunnel x microwave	0.24	0.70
Liquid nitrogen x microwave	0.08	0.58

(1) From Jacquet et al. (1976)

The efficiency of the thermal transfer is also dependent on the difference in temperature between the surface of the product and the freezing gas. Since cryogenic freezers work at lower temperatures, a higher tangential velocity is not the only way of achieving rapid freezing.

In addition, the saturated vapour pressure (pressure at which the gaseous phase and solid phase are in equilibrium) is approximately halved for every decrease in temperature of 10°C. Since cryogenic freezers work at a lower temperature, the saturated vapour pressure at this temperature is lower and dehydration is consequently less.

4. Conclusion

Various studies on changes in the state of food products have shown the impact of the quality of freezing and storage methods on the organoleptic properties of the products after defrosting. Freezing rate is the key parameter for ensuring optimal freezing. Cryogenic freezing is a particularly good way of preventing organoleptic deterioration (loss of texture and dehydration) in sensitive foodstuffs such as seafood, fruit and meat.

5. Tell me more

About the author

A graduate of ENSIA (Ecole Nationale Supérieure des Industries Alimentaires), Adrien Agoulon has been Director of Agro-Hall since 2010, after heading up Research & Development at the technology center for eight years.

Based in Evreux (France), Agro-Hall was formed in 1986 to provide companies with tailored support for their R&D and innovation projects.

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Air Products
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Crewe CW1 6AP
United Kingdom
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Unit 950, Western Industrial Estate
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Ireland
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ieinfo@airproducts.com

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Impact of freezing parameters on the characteristics of food

Adrien Agoulon
Director, Agro-Hall

Abstract :
Various studies on changes in the state of food products have shown the impact of the quality of freezing and storage methods on the organoleptic properties of the products after defrosting. Freezing rate is the key parameter for ensuring optimal freezing. Cryogenic freezing is a particularly good way of preventing organoleptic deterioration (loss of texture and dehydration) in sensitive foodstuffs such as seafood, fruit and meat.

1. Introduction

Sales of frozen foods are on the increase globally. Freezing protects the quality of food at a competitive price. The freezing technique itself, just like the frozen food market, is developing to become faster, more efficient and more cost-effective. In order to continue to serve the interests of consumers, who demand high-quality products, both in terms of taste and nutrition, but who are willing to spend less and less time preparing meals, we need to have a better understanding of the fundamentals of this process and its effect on food. This article aims to present the existing scientific data on the impact of freezing technologies on the organoleptic characteristics (e.g. taste, texture, smell and appearance) of sensitive foodstuffs such as meat, fruit and vegetables or even seafood.

2. The freezing process

Contrary to what is widely thought, frozen food is not entirely stable. Although it is microbiologically stable, the product remains susceptible to physical and biochemical reactions, which may compromise its organoleptic qualities. This is more easily understandable if we look at the proportion of frozen water that we find in various frozen foods. Let us take animal products as an example, as in Table 1.

Table 1:
Influence of temperature on the percentage of frozen water in meat

	Frozen water (%)		
Temperature (°C)	Poultry (muscle)[1]	Lean beef [1,2]	Fish (cod)[1,2]
-5	74	74	77
-10	83	82	84
-15		85	87
-20	88	87	89
-25			
-30	89	88	91

(1) From Reidel (1957), cited by Desrosier and Tressler Fundamentals of Food Freezing, ix, 629p., AVI Pub. Co. (1977).
(2) IIF (1986)
(3) Leistner and Rodel (1976), cited by Daudin, Technologie de la viande et des produits carnés, Chapitre 1 (1988)

In a product such as meat, at a stabilized temperature of -20°C, the percentage of non-frozen water is still over 10% of the total water content of the product. This liquid portion has specific characteristics. It is progressively enriched with various dissolved substances as more and more of the water forms ice crystals. This is referred to as the freeze-concentrated phase, during which a high number of changes occur as frozen products age. Essentially, this phase allows the regrouping of enzymes and their substrates within a restricted volume of liquid, which can accelerate certain reactions despite the retardant effect of low temperatures.

The kinetics of the decrease in temperature during the freezing process (and therefore the freezing technique used) will influence the characteristics (number and size) as well as the growth of crystals:

- Nucleation rate. This is the number of nuclei formed per unit of time. This parameter increases with faster cooling rates. For example, each degree of subcooling multiplies the nucleation rate by 10.
- Growth rate of crystals. The growth of crystals is linked to the capacity to remove heat where the ice crystals are forming (related to the characteristics of the product and temperature of the medium).
- Size of crystals. This depends on the two previous factors. The formation of a large number of nuclei, as well as a rapid growth rate, encourages the formation of small crystals.

In many cases, deterioration caused by ice can be explained by the rigidity and the size of crystals within the cellular structure of the food. This results in mechanical pressure that can damage the cellular structure of products such as meat, fruit and vegetables. Figure 1 shows the size and distribution of crystals depending on the freezing kinetics.

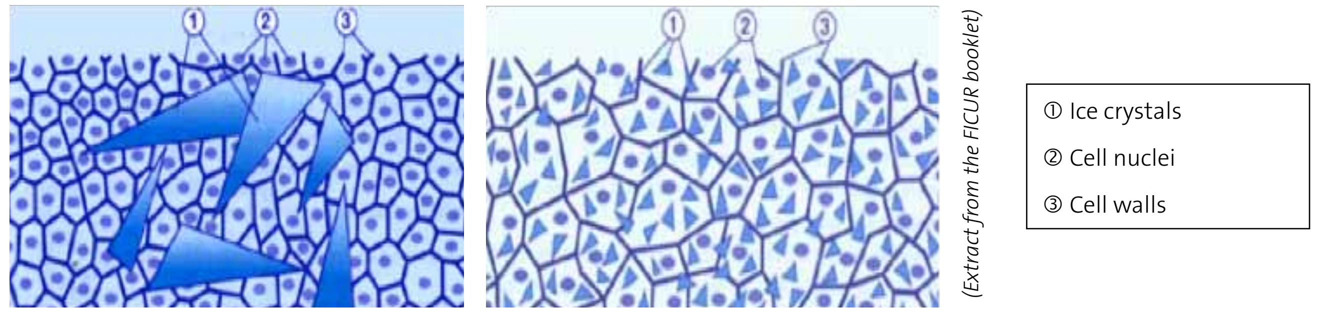

Figure 1: Illustration of crystal formation according to freezing kinetics

3. Impact of freezing on food structure

3.1. Characteristics of the different freezing technologies

Before looking in more detail at the impact of freezing technologies on food structure, it is necessary to recall the principal characteristics of the technologies used at an industrial level.

- Mechanical cooling: this is the term used to describe traditional vapour compression cycle freezers, which normally operate at a temperature of between -20°C and -50°C.
- Cryogenic freezing is achieved using cryogenic liquids such as nitrogen or carbon dioxide, and normally operates at under -70°C.

These notable differences in temperature result in very different freezing kinetics between the two technologies. Figure 2 shows the typical freezing time (the time required for the temperature at the center of the product to drop from -1°C to -7°C) of a steak of beef (200 g, 2 cm thick) according to the freezing technique used.

The large temperature difference between product and freezing medium of the cryogenic technique results in significantly shorter freezing times than mechanical freezing. These cooling kinetics are to a large extent responsible for the differences in levels of deterioration seen in the finished product when we compare the impact of the freezing technology with the quality of the food.

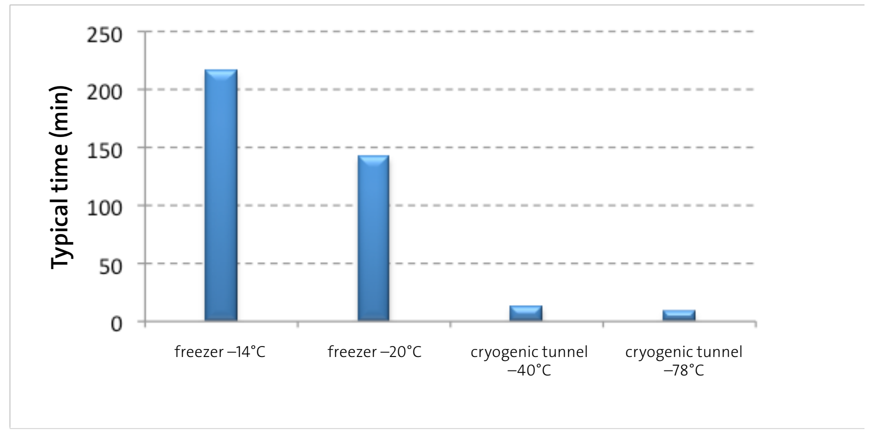

Figure 2: Typical freezing time of a steak of beef according to freezing technique

3.2. Impact of freezing on food quality

• Freeze-concentration

Slow freezing (freezing front advances at a speed of less than 0.2 cm/h) leads to the formation of ice crystals in the less concentrated extracellular space. The progressive concentration of the extracellular space (freeze-concentration) results in the dehydration of the cells via osmosis. The leaking of intracellular liquid results in a weakening of the tissue and a loss of turgidity in plant tissue. Table 2 shows the qualitative differences observed between cryogenic freezing with liquid nitrogen, ventilated mechanical freezing and non-ventilated mechanical freezing.

In the case of green beans, deterioration, which was very minor under cryogenic freezing, was most noticeable when the time required for the centre to reach -20°C exceeded 30 minutes.

Table 2: Effect of freezing rate on the sensory properties of green beans

Time required for centre to reach -20°C	Sensory characteristics of cooked product	Type of freezing
< 30 minutes	No loss of firmness, colour and taste as normal	Cryogenic freezing (liquid nitrogen)
30 minutes-2 hours	Loss of texture, colour and taste as normal	Ventilated mechanical freezing
> 12 hours	Loss of texture, colour and taste deteriorated	Non-ventilated mechanical freezing

CJ Kennedy, GP Archer, 1999. Maximising Quality and Stability of Frozen Foods, Report 2, 14.

Loss of texture, resulting from the loss of cell turgidity, occurs first. Due to the rapidity of cooling in cryogenic freezing, freeze-concentration is limited and ice crystals are formed in both the intracellular and extracellular spaces. This is because the amount of cold transferred cannot be absorbed by the formation of crystals in the extracellular spaces alone, so nuclei form in a homogeneous manner throughout the matrix (cf. Figure 1). The homogeneity of the nucleation sites therefore limits the effects of osmotic pressure which would cause loss of texture.

Deterioration of colour and taste varies widely according to storage conditions and the nature of the frozen product. Nevertheless, it is clear that the presence of enzymes and their substrates in a confined volume of liquid creates conditions for fast-acting, damaging reactions, despite the low temperatures. Rapid freezing (i.e. cryogenic freezing) stabilizes the environment by limiting the flow of matter through the tissue. Liquid phases therefore retain lower concentrations of dissolved substances, resulting in slower enzymatic deterioration (oxidation, hydrolysis and decarboxylation, for example).

The acceleration of these enzymatic reactions in slow cooling also leads to a second alteration mechanism based on the mechanical pressures caused by the ice crystals.

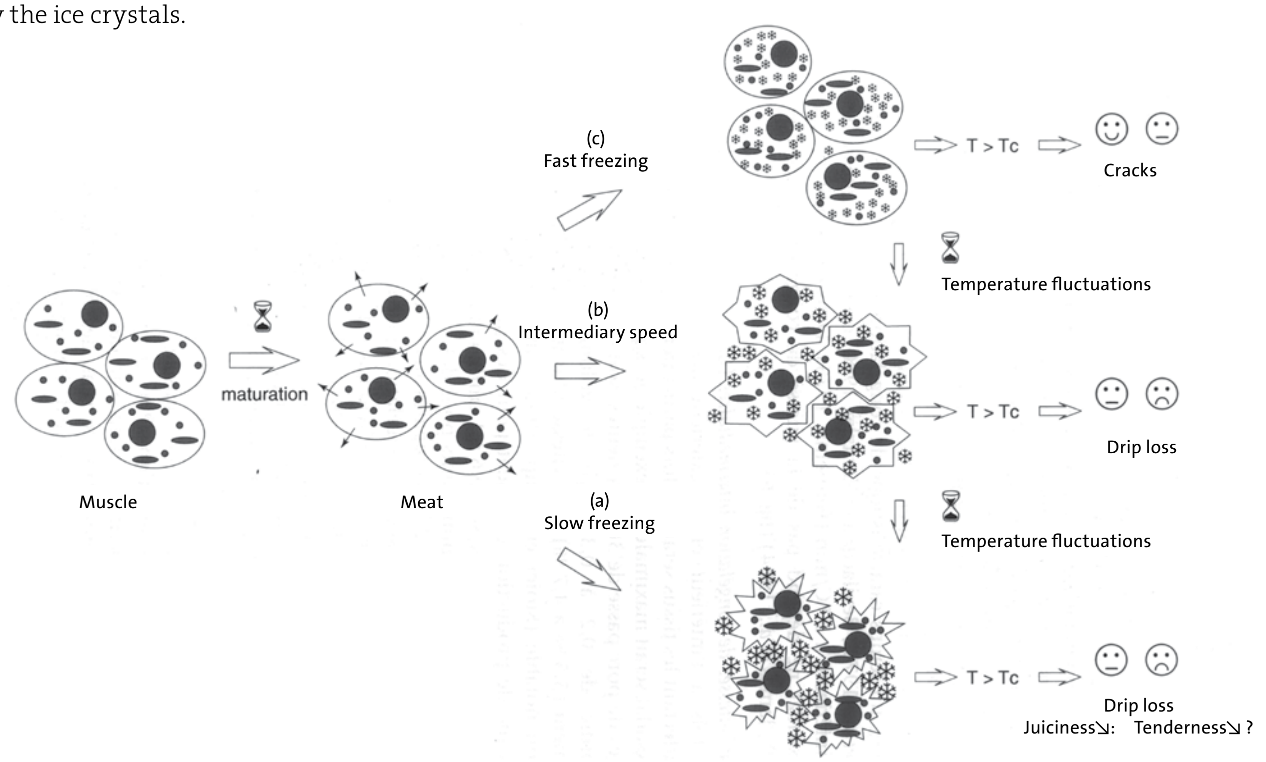

Figure 3: Illustration of the impact of the freezing rate on the quality of meat
Illustration taken from Congélation et Qualité de la Viande, Claude Genot, INRA Edition, 2000.

• Mechanical alteration

Slow freezing techniques, where the freezing front advances at a rate of less than 0.2 cm/h, impacts on the size and number of crystals. Figure 3 illustrates the impact of the freezing rate on cells, and consequently on organoleptic properties.

The large crystals that form under slower freezing conditions generate mechanical pressure and sharp edges that damage all cellular components (e.g. organelles, cell membranes etc.). This damage results in bringing together enzymes and substrates that were previously separated, and therefore leads to differing enzymatic reactions. The organoleptic qualities of the meat that are affected by the freezing method are essentially the tenderness, the juiciness and the water retention capacity.