

# Researches on the freezing of blueberries and green bean pods using an experimental model of a fast freezing equipment

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**Abstract.** In order to conserve perishable food and extend the permissible storage and marketing period, one of the best methods that uses artificial frost is freezing. The action of low temperatures leads to a slowing down of the modifying processes, both nutritionally and organoleptically. The researches presented within the paper aims to determine some specific parameters for the freezing process using an experimental model of a fast freezing equipment with liquid nitrogen. Experimental researches use two species of horticultural products, namely blueberries and green bean pods. The results indicate that the values of total freezing time, average linear freezing rate and liquid nitrogen consumption for quick freezing of blueberries were higher than those recorded for green bean pods. Also, with the lowering of the set temperature inside the freezing chamber, the freezing time from 0 °C to the temperature of -15 °C decreases, resulting in lower freezing times, higher average linear freezing rates and liquid nitrogen consumptions with increasing tendency.

## 1 Introduction

In order to extend the permissible period of storage and marketing of perishable foodstuffs, a number of conservation methods and techniques can be applied [1-6]: preservation by using low temperatures (refrigeration, freezing, modified atmosphere); preservation by using high temperatures (pasteurization, sterilization); conservation by reducing the water content of the product (dehydration, concentration); preservation by the use of inhibitors of

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depreciation phenomena (natural antimicrobials, bacteriocins, sugar addition, acidification, chemical preservatives etc.); preservation by unconventional methods (ionizing radiation, high pressure, high voltage electrical impulses, non-ionizing radiation, ozone, ultrasound, photodynamics, etc.). Of all these processes, the use of artificial cold (refrigeration, freezing) leads to the best results when it is desired to keep the attributes and quality as close as possible to those of the fresh product [7-9].

For long-term storage, in order to use the products in the off-season, freezing is frequently used. By freezing the admissible storage time of the products is increased by over 5 ... 50 times the preservation by refrigeration [10].

Generally, freezing occurs at temperatures between -18 °C and -40 °C. Depending on the temperature at which it occurs, freezing can be:

- slow, carried out at temperatures of -18 °C ... 20 °C for about 80 hours;
- semi-rapid, at temperatures between -20 °C and 40 °C (in cold rooms or freezing tunnels) and lasting about 60 hours;
- fast, conducted at temperatures of -30 °C to -35 °C and lasting up to 24 hours;
- ultrafast, carried out at -35 °C to -40 °C and lasting about 3 hours.

The freezing rate determines the formation of ice crystals as follows: slow freezing ("classic") leads to the formation of a small number of ice crystals having large dimensions, while rapid freezing with cryogenic liquids generates a large number of small size crystals. Large crystals resulting from slow freezing cause deformation, dislocation, and perforation of cell walls, and when defrosting these products, juice losses are high. In the case of rapid freezing with cryogenic fluids, tissue changes due to the formation of ice crystals are less damaging, and defrosting juice losses are lower because much of the water remains in the cells [11, 12].

The quality of frozen fruits and vegetables depends to a certain extent on the characteristics of the raw material used. Compatibility with freezing is a function of the species, climate and soil characteristics when the fruit and vegetables were harvested, crop technologies (fertilization, irrigation etc.). Some species such as lettuce, tomatoes, radishes, table grapes are not suitable for freezing, because during the freezing process there are important losses of turgidity, discoloration and loss of flavor. The conditions that vegetables and fruits have to fulfill to be preserved by freezing are determined by: compatibility with freezing preservation, widespread acceptance by consumers, high technological yields, virus resistance, mold, physiological defects and insects, uniformity of maturation, good handling resistance, pronounced color and flavor, firm texture with as little as possible deformation and softening tendency to thaw, as little juice as possible in defrosting. One of the modern freezing techniques is that of cryogenic freezing using liquid nitrogen (N<sub>2</sub>) as a cooling substance [11, 13, 14]. Compared to conventional freezing techniques, the cryogenic method has the following advantages: rapid freezing, inhibition of bacterial growth, limited dehydration, considerable reduction of quantitative losses, optimal nutritional preservation, maintenance of the appearance and taste of the food.

Among the fruit species with the widest use for freezing can be remembered berries, strawberries, cherries, peaches and apricots, and among vegetables: green peas, green beans, spinach and carrots.

## **2 Materials and methods**

Two species of horticultural products, namely blueberries and green bean pods, were used in the experimental research. (Fig. 1).



**Fig. 1.** Species of horticultural products used in the experimental research

For horticultural products fast freezing it has been used an experimental model of fast freezing equipment with liquid nitrogen, ECR-0, intended for cryogenic freezing of different food products (Fig. 2).



**Fig. 2.** Fast freezing equipment – ECR [15]

The equipment is provided with temperature sensors that allow monitoring and permanent control of process parameters, namely:

- Type K Thermocouple (chromel–alumel), probe diameter  $\phi 1.5$  mm, measuring range  $-100$  °C... $+30$  °C, allows temperature measurement in the centre of the product;
- Type K Thermocouple, with temperature transfer element, measuring range  $-100$  °C... $+30$  °C, allows temperature measurement on the external surface of the product;
- Thermal resistance, type TTR Pt 100, measuring range  $-200$  °C... $+30$  °C, allows temperature measurement inside the freezing chamber.

The chamber is provided with an access door, thermal insulated and provided with two sealing gaskets and de-icing resistances to prevent ice formation and to facilitate access to the chamber at the end of the freezing cycle. The locking system is provided with two clamps and a handle to obtain a uniform and firm closing. In order to achieve a forced convection of the atmosphere in the chamber in order to improve the thermal transfer from the product to the thermal agent, a fan was provided inside the chamber. The equipment allows operation in two working modes, namely:

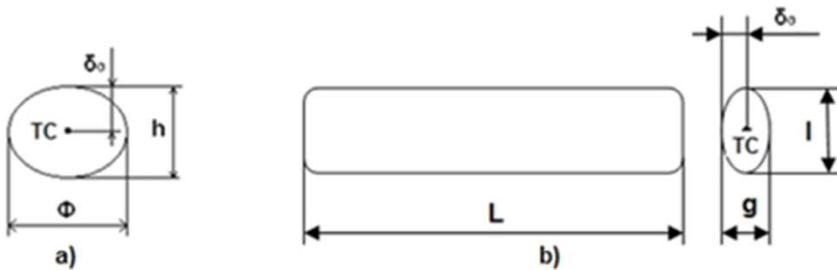
- automatic operation mode, with setting the chamber temperature limit at which ventilation starts and liquid nitrogen purging stops;
- manual operation with continuous liquid nitrogen purging.

All measured parameters during the working cycle were recorded on the SD memory card of the Programmable Logic Controller (PLC) within the automation installation of the equipment.

The weight of each sample was set at 750 g, 250 g on each of the 3 trays. For each sample, the mass and dimensional characteristics were determined as follows:

- for blueberries: the average bean mass, average height and the maximum equatorial diameter were determined as the average of five random measurements from the product;
- for green bean: the pods were fragmented up to lengths between 35 and 65 mm. For these, the average mass, average length, average width and average thickness of the pods fragments were measured as the average of five random measurements from the product.

For products with regular geometric shapes, the thermal center (TC) coincides with their geometric center. The smallest distance between the TC thermal center and the outer surface of the product is noted with  $\delta_0$  and is an important parameter for determining the freezing rate (Fig. 3). For blueberries,  $\delta_0$  was approximated by  $h/2$  and for green bean pods with  $g/2$ .



**Fig. 3.** Dimensional characteristics: a) – blueberries; b) – green bean pods

The freezing process is considered complete when the temperature in the product thermal centre reaches  $-15^{\circ}\text{C}$ .

The parameters followed during the freezing process were as follows:

- Mass of the liquid nitrogen container used for freezing;
- Freezing time from  $0^{\circ}\text{C}$  to  $-15^{\circ}\text{C}$ ;
- Total freezing time.

Following the processing of experimental data, the following energy indexes were determined:

- Average linear freezing rate;
- Liquid nitrogen consumption for a freezing cycle.

To characterize a freezing process in terms of cooling intensity, it is considered as criterion, the average linear freezing rate given by the relation:

$$w_m = \frac{\delta_0}{\tau_0}, [cm/h] \quad (1)$$

where:  $\delta_0$  is the smallest distance between the thermal centre and the outer surface of the product, [cm];

$\tau_0$  - the freezing time from a uniform initial temperature of  $0^{\circ}\text{C}$  to the temperature to be achieved in the thermal centre, [h].

Depending on the average freezing rate,  $w_m$ , the International Institute of Refrigeration recommends the following classification of freezing methods [16]:

- slow freezing  $w_m < 0.5 \text{ cm/h}$ ;
- fast freezing  $w_m = 0.5 \dots 3 \text{ cm/h}$ ;
- very fast freezing  $w_m = 3 \dots 10 \text{ cm/h}$ ;
- ultrafast freezing  $w_m = 10 \dots 100 \text{ cm/h}$ .

Liquid nitrogen consumption for a freezing cycle was determined by the difference between the mass of the liquid nitrogen container before and after the freezing process was completed.

### 3 Results and discussion

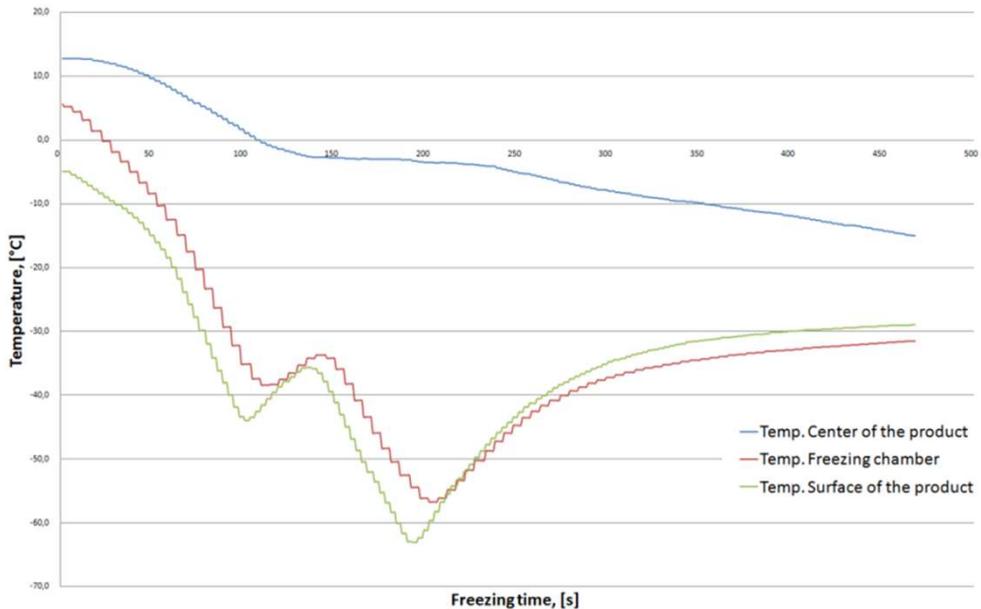
Following the processing and interpretation of the experimental data, the following results were obtained regarding the characterization of the two species of horticultural products used:

**Table 1.** Characteristics of the analysed products

No.	Characteristic	UM	Value of parameters determined in the tests	
			Blueberries	Green bean pods
1.	Sample mass	g	250x3=750	200x3=600
2.	Average mass of a product	g	1.72	1.29
3.	Maximum equatorial diameter (for blueberries), $\Phi$	mm	15.30	-
4.	Bean average height (for blueberries), $h$	mm	12.07	-
5.	Average length of the pod fragment (for green bean pods), $L$	mm	-	48.77
6.	Average width of the pod fragment (for green bean pods), $l$	mm	-	8.79
7.	Average thickness of the pod fragments (for green bean pods), $g$	mm	-	6.75
8.	The smallest distance between the thermal centre and the outer surface of the product, $\delta_0$	mm	6.04	3.38

Process parameters, during the freezing process, can be determined by direct reading on the touch screen of the command and control panel or by post-processing the data recorded on the SD memory card. Freezing times were determined based on the data recorded on the SD memory card (Fig. 4), as follows:

- the freezing time from  $0^\circ\text{C}$  to  $-15^\circ\text{C}$  was determined by the difference between the total timer recorded at the end of the freezing process ( $-15^\circ\text{C}$ ) and timer recorded when the temperature reached  $0^\circ\text{C}$  in the product's thermal centre;
- the total freezing time was determined by direct reading of the total timer recorded at the end of the freezing process.



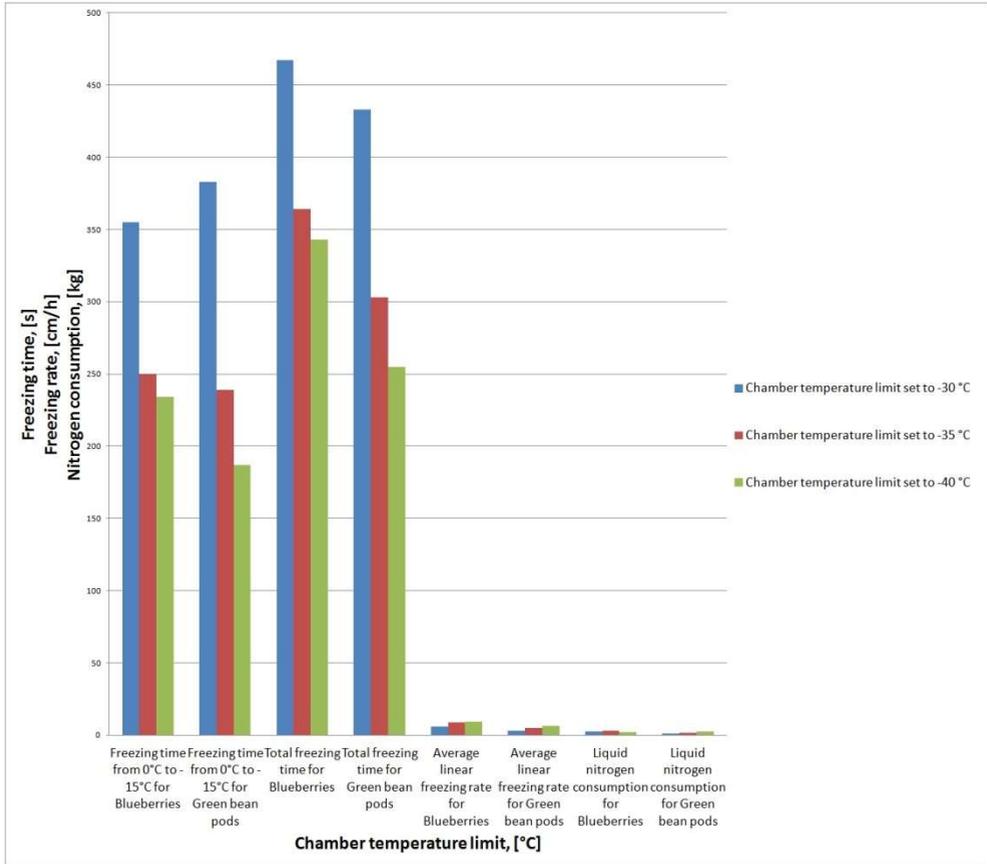
**Fig. 4.** Determination of the process temperatures based on data recorded by sensors

The parameters followed during the freezing process and the energetic indexes of fast freezing equipment are shown in Table 2.

**Table 2.** The parameters followed during the freezing process

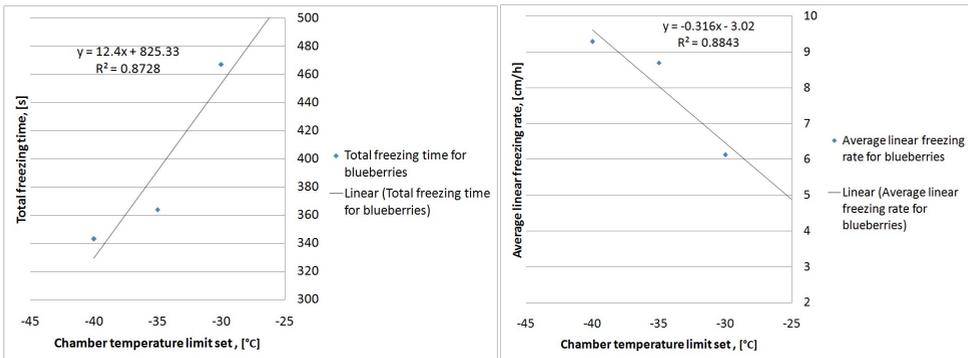
No.	Characteristic	U.M.	Value of parameters determined in the tests					
			Blueberries			Green bean pods		
			The chamber temperature limit set to [°C]					
			-30	-35	-40	-30	-35	-40
1.	Freezing time from 0°C to -15°C	s	355	250	234	383	239	187
2.	Total freezing time	s	467	364	343	433	303	255
3.	Average linear freezing rate for an operating cycle	cm/h	6.13	8.70	9.29	3.18	5.09	6.51
4.	Liquid nitrogen consumption for an operating cycle	kg	2.30	3.06	2.16	0.90	1.60	2.50

Graphical representation of the results is shown in Fig. 5.

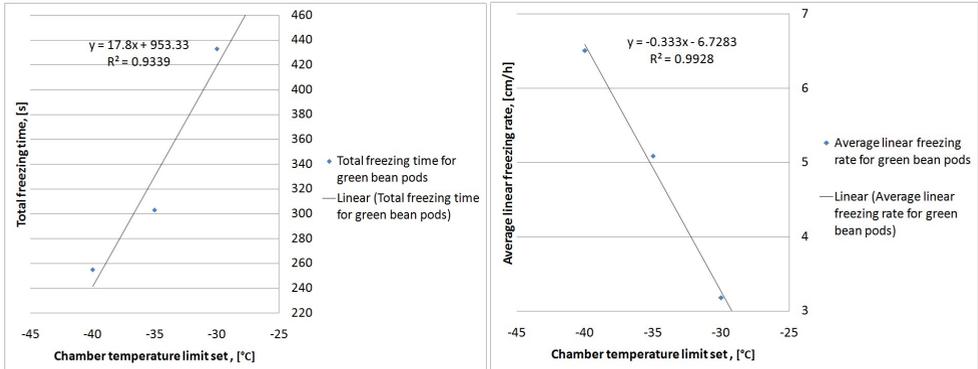


**Fig. 5.** Graphical representation of the results

The total freezing times and the average linear freezing rates depending on the selected temperature limits within the chamber, are presented, both for blueberries and green bean pods, in Fig. 6 and 7.



**Fig. 6.** The total freezing times and the average linear freezing rates depending on the selected temperature limits within the chamber, for blueberries



**Fig. 7.** The total freezing times and the average linear freezing rates depending on the selected temperature limits within the chamber, for green bean pods

Linear regressions performed using Excel, allowed the identification of some linear functions, which estimate the variation of the total freezing time and the average linear freezing rate depending on the selected temperature limit within the chamber, with coefficients of determination varying from 0.87 to 0.99.

Samples aspect before and after freezing is shown in Table 3:

**Table 3.** Samples aspect during the experimentation

	The chamber temperature limit set to		
	-30 °C	-35 °C	-40 °C
<b>Blueberries</b>			
Fresh product			
Quick frozen product			
<b>Green bean pods</b>			
Fresh product			
Quick frozen product			

## 4 Conclusions

Following the determinations made during the experimentation and data processing, the following results were obtained:

- with the lowering of the set temperature inside the freezing chamber, the freezing time from 0 °C to the temperature of -15 °C decreases, resulting in lower freezing times;
- with the lowering of the set temperature inside the freezing chamber, higher average linear freezing rates are obtained;
- with the lowering of the set temperature inside the freezing chamber, the liquid nitrogen consumptions record an increasing tendency;
- the total freezing time for blueberries was higher than the freezing time for green bean pods, regardless of the set temperature inside the freezing chamber;
- the average linear freezing rate for blueberries was higher than the freezing rate for green bean pods, regardless of the set temperature inside the freezing chamber;
- the liquid nitrogen consumption for freezing blueberries was, overall, higher than the nitrogen consumption for green bean pods.

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