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EFFECT OF CHILLING AND FREEZING ON SELECTED PROPERTIES OF EGGPLANT *SOLANUM MELONGENA* L.

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ABSTRACT

The state of knowledge about eggplant and the methods of its storage is the subject of the paper. In the experimental part, the effect of freezing treatment on eggplant fruits was investigated and the range of its cryoscopic temperature was determined.

Eggplant fruits in the form of cubes with the side of 2 cm were submitted to initial treatment, which consisted in soaking in water solutions of NaCl and $CaCl_2$ and blanching in water solutions of NaCl and $CaCl_2$, and then chilling in icy water with an addition of NaCl, $CaCl_2$ and vitamin C. Freezing was performed in glycol at the temperature of -20 to -45°C, either in the air with the temperature ranging from -10 to -180°C or in liquid nitrogen (-196°C). The samples were frozen and thawed loose and in a vacuum package. Thawing was performed in the air (all samples) with the temperature of 17-20°C or in water (vacuum packed samples) with the

temperature of 20-30°C. The product's temperature during all processes was recorded by electronic thermometers working with a computer set. Before and after each stage of treatment the examined material was weighed.

The studies found out that there is a good possibility of preserving the colour of eggplants, whereas it was very difficult to keep its structure after the treatment. The estimated cryoscopic temperature of eggplant ranges from -0.4°C to -5.3°C.

Key words: eggplant, freezing, cryoscopic temperature, thawing, structure, colour

INTRODUCTION

1. The plant and its origin

Eggplant, *Solanum melongena* L., also called aubergine, madapple or brinjall, belongs to the family of *Solanaceae.* According to Linneus, eggplants came from India, where individuals growing in the wild were found. The plant had already been cultivated in the Middle Ages, mainly for medical reasons, in the area of South and East Asia (China, India). From the Asiatic regions the plant arrived in Europe in the 14th century, and its cultivation for cooking purposes did not spread until the 18th c. [1, 4, 5, 7, 10].

At present, the cultivation of eggplants is popular on all continents, but its greatest European producers include France, Italy, former Yugoslavia and Bulgaria. Unfortunately, in Poland the cultivation of aubergine is limited, although numerous studies have been conducted on the choice of proper cultivars and the application of right agricultural conditions [3, 5, 12, 14]. This state is probably caused by lack of traditions of consuming aubergine fruits.

2. Morphological characteristics of aubergine

Aubergine is a plant with small requirements as for the temperature and the soil, that is why in Polish conditions it is usually an annual plant mostly grown in household gardens, under foil or in glasshouses.

Like the other plants of the family *Solanaceae,* eggplant is a self-pollinating plant. Its root system is rather poorly branched and is found right under the surface of the ground. Fruits, violet in colour, can be distributed singularly, or gathered in grapes with 2-7 plants in each.

The purpose of aubergine cultivation is to get the fruit, which is a berry, whose shape is a characteristic feature of the variety. Eggplant fruits can be spherical, pear-shaped, egg-shaped, oval or prolate, and their weight can reach up to 2000 g in large fruit varieties [3, 5, 10].

The fruit colouring in the period of ripeness is usually dark violet (with different shades), or violet with a brown shade. It can be white, green, grey-green or green with brown streaks (fig. 1).

Fruit should be collected in the stage of physiological unripeness, since with ripening the fruit surface gradually loses its gloss and begins to wrinkle [3].

On the basis of agricultural experiments it was found out that 40-50 day – old fruits are most suitable for treatment. The fruit flesh is then compact, with cream-yellow colour (fig. 2); it does not have any bitter taste, and the content of sugars and protein is the biggest at this stage [3, 10].

Fig. 1. Blooming eggplant with fruit sets and a fruit in the stage of utility ripeness

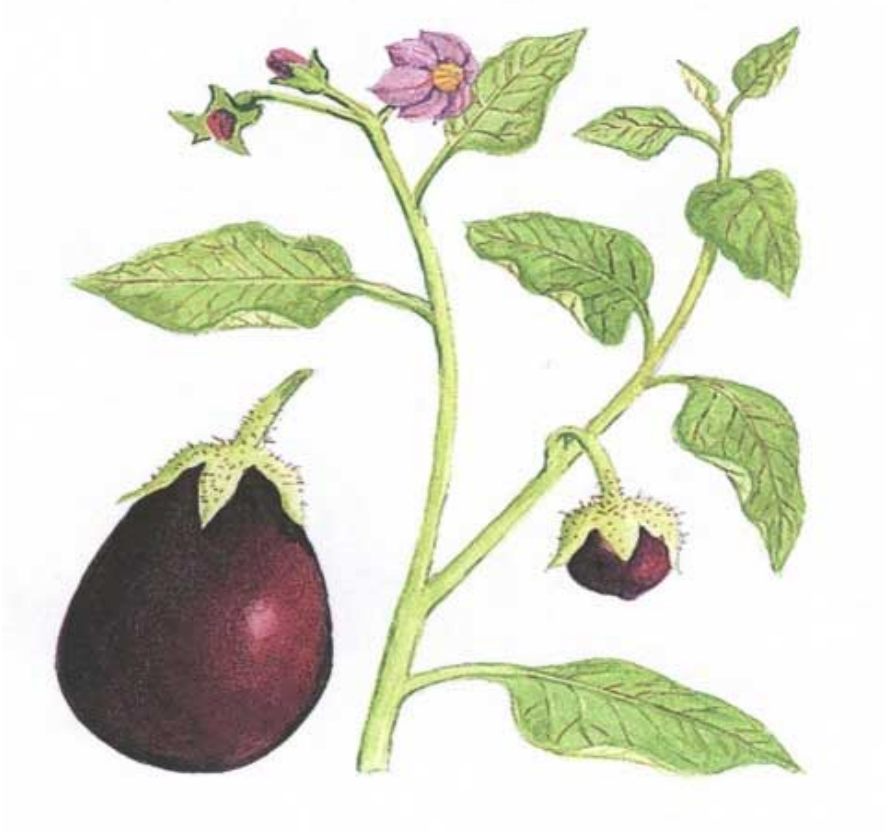
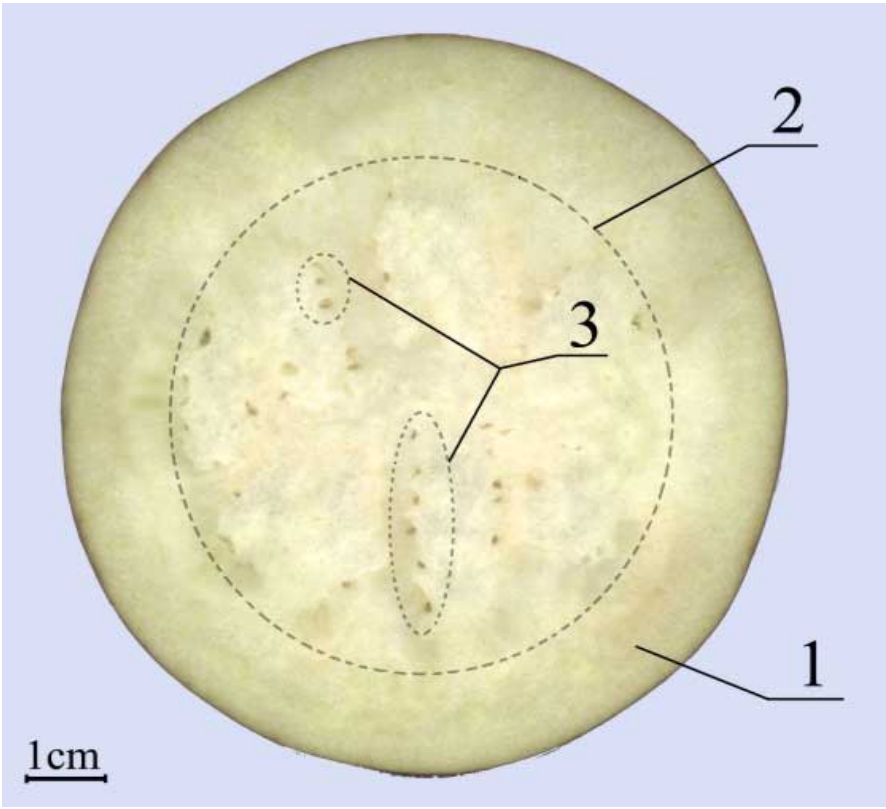


Fig. 2. Cross-section of eggplant: 1 – sphere of compact flesh, 2 – sphere of spongy flesh, 3 – seed concentration



3. Chemical composition and nutritive value of eggplant fruits

Due to the specific chemical composition, aubergine fruits are considered to be especially valuable for the people who have to keep low-calorie diets. Unparalleled taste valours of aubergine as well as the presence of a number of phytochemical compounds in its flesh which protect against cancer and atheromatosis make it fully useful in the treatment of old or sick people. Fresh fruits of eggplant contain about 7-11% dry mass, 3-4% carbohydrates (glucose, fructose, sucrose, starch), small quantities of protein and fats, around 1.5% dietary fibre [1, 7, 11]. It is worth mentioning that the white cultivars of eggplant can contain twice as much raw fibre as the violet or green ones.

The bitter taste of unripe fruits is due to the presence of glycoalkaloids, frequently present in plants of the family *Solanaceae*. A representative of alkaloid characteristic of aubergine is solanin M. – called melongene, whose content can reach as much as 20 mg/100 g of dry weight.

Aubergine tissues are also rich in such enzymes as phosphatase, alcohol dehydrogenase, polyphenolooxidase, catalase, lypooxigenase and peroxidase. The activity of particular enzymes is related to the cultivar and the content of mineral elements in them [11]. The phenomenon of the fruit getting brown under the effect of air oxygen takes place faster and is manifested in the violet cultivars. It is associated with a higher activity of polyphenolooxidase in tissues. The green cultivars undergo changes of colour in a smaller degree than the green ones. The situation with peroxidase is different because its higher activity was found in the white cultivar. Also, the activity of lypoxigenase catalysing oxidation of lipids is considered to be the cause of worse quality of fruits that are not blanched [quotation 11].

Eggplant, rich in mineral elements, contains particularly much chlorine salt, phosphorus, calcium, magnesium, potassium and iron (table 1) [1, 11].

Table 1. Content of mineral elements per 100 g of edible material

Element	Content (mg)
Calcium	18
Magnesium	16
Phosphorus	47
Iron	0.9
Sodium	3.0
Copper	0.17
Potassium	2.0
Sulphur	44
Chloride	52

It follows from the experiments of Flick et al. [quotation 8] that the highest content of potassium and chloride is found in the violet cultivars. Owing to big quantities of mineral salts, aubergine fruits are effective in strengthening the heart activity and lowering the level of cholesterol in blood [1, 11].

The content of vitamins in aubergine is small; however, its fruits contain ascorbic acid (mostly, 0.8-19 mg/100 g fresh mass), but also thiamine, riboflavin and -carotene [1].

4. Storing eggplants in low temperatures

Fresh aubergine fruits can be successfully used as a valuable addition to various vegetable salads. Most often, however, its fruits are cooked, roasted, soured, pickled and dried, which does not always have a good effect on the preservation of nutritive values.

Limited durability of fresh aubergine fruits is determined mainly by their susceptibility to storing conditions and to fungi-related diseases. The fact which determines a high quality of the raw material and minimises the losses of valuable nutritive elements is a choice of optimum storing parameters.

Aubergine fruits are susceptible both to the effect of the environment with lowered (5-10°C) and raised temperatures. Storing the fruits at the temperature below 10°C can cause chilling injuries usually shown in spots and hollows on the surface and in the darkening of seeds and fruit flesh [2, 11]. Concellón et al [6] observed that exposition to 0° and 5°C injured the fruits whereas exsposition to 10°C did not cause damage. Rodrigez et al [13] stored aubergine fruits at 3°C and observed chilling injury with manifestation of piting. The susceptibility of aubergine to this kind of chilling injuries depends in a considerable degree on the cultivar properties as well as on the degree of ripeness and period of harvest. The fruit gathered in summer can be preserved at the temperature of 12°C for about one week, and this period gets longer by ten days in the autumn period [2].

Pantisco et al. [quotation 11] recommend storing fruit in the air temperature of 10-12.8°C and relative humidity of 92% for about 2-3 weeks, while according to Ryall and Lipton aubergine can be stored in the same temperature conditions but in 95% relative humidity.

Satisfactory results in lengthening the durability of eggplants are achieved storing the fruit packed in polyethylene foil bags, in proper temperature and relative humidity conditions.

The fruit packed in PE foil bags should be carefully placed in compact layers in wooden or plastic boxes [6]. During storage, the tissues lose their turgor and the fruits get wrinkled, that is why it is advisable to place parchment paper between the layers of fruit, which prevents the fruit from drying. As follows from Aubert and Pochard's experiments [quotation 8], foiled fruits can be then stored up to several days in the air temperature of 7-10°C and relative humidity of 90-95%.

Mohamed and Sealy [quotation 11] also observed that eggplants can be stored in the air temperature of 8-9°C for more than ten days, preserving perfect commercial quality as long as the fruits are packed in shrinkable foils of LDPE, HDPE foils. The storage time of packed fruits can be extended to 40-50 days keeping the air temperature within the range of 3-8°C and relative humidity of 85-90°C.

The use of optimum storing conditions allows for a remarkable reduction of the weight losses of the material, which has a positive effect on preservation of its original quality. However, if the package coating is little pervious or perforated, aubergine fruits can be threatened by anaerobic decay processes and rapid drop of commercial quality [2, 11].

So far, there are no accessible experimental data on the freezing methods of lengthening the durability of aubergine. Therefore, experiments were undertaken whose purpose was to establish the cryoscopic temperature and range, and to estimate the possibilities of freezing eggplant fruits. In case of encouraging results, the studies would also attempt to optimise this process in order to obtain the final product with satisfying sensory quality.

MATERIALS AND METHODS

The material were fresh aubergine fruits, cultivars Long Violet and Long Purple, which slightly differed in terms of their colour and tissue structure. At the stage of technological ripeness the material is characterised by compact and uniform flesh with light colouring. The fruits selected for studies were fresh, with no sign of infection by disease or insects.

The material was submitted to initial treatment, which consisted in washing the fruits, removing the bitter peel, crumbing the flesh to make cubes with the dimensions of 2 cm× 2 cm×2 cm, soaking and blanching. After such preparation, the product was frozen and thawed.

The purpose of the initial treatment was to prevent the flesh from getting brown and to keep its tissue structure. The colour can be kept through soaking the crumbed aubergine in water solution $CaCl_2$ and NaCl. Before the process of soaking, particular samples were weighed exact to ±0.001 g. $CaCl_2$ concentration was changed in subsequent solutions by 0.1%, and the proportion of $NaCl_2$ by 1% for each repetition until the optimum value was achieved, which was determined on the basis of organoleptic estimation of colour and flesh structure. The process took place in solutions with room temperature of about 20°C, in the time between 5 to 30 minutes (each time lengthening the period of soaking by about 5 minutes). Next, the crumbs were blanched in a water bath, which modified the composition of the blanching solutions with an addition of NaCl, $CaCl_2$ and citric acid. Because of the delicate structure of the material, the blanching temperature was set within the range of 60-95°C, and the temperature of solutions was changed by 5 K in subsequent repetitions. The period of contact between the material and the blanching solution was within the range of 5 to 90 seconds. Chilling after blanching was performed in icy water with an addition of NaCl, $CaCl_2$ and ascorbic acid. After the processes of blanching and chilling had been completed, the samples were weighed in order to determine the weight change.

Freezing non-packed and vacuum packed crumbed eggplants was performed straight after the initial treatment with the use of the following chilling media:

- air – direct contact with non-packed and vacuum packed product (temperature of the environment between -15°C and -180°C, difference between subsequent tests 10 K)
- glycol – only vacuum packed material (temperature between -20°C and -45°C, difference between subsequent tests 5 K)
- liquid nitrogen – direct contact between the agent and the material (temperature -196°C).

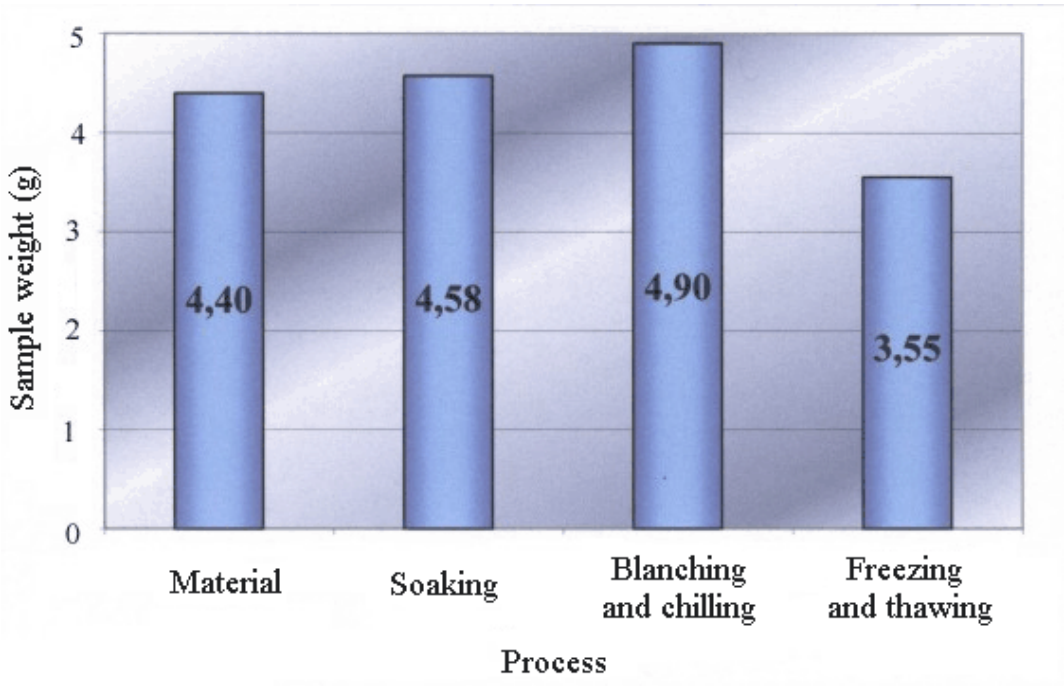
Thawing was performed in the way which reflected the household methods of proceeding with the frozen food. The frozen material was thawed in the air temperature of 20°C, and the vacuum packed material in the water temperature of 30°C.

RESULTS

In order to estimate the usefulness of freezing as a method of lengthening the durability of aubergine fruit, all stages of the procedure should be analysed. Initial preparation of the material, including soaking and blanching, was to keep the flesh colour and structure. It can be stated on the basis of the experiments, that the solutions that were used fulfilled the assumed aim in a considerable degree. A positive effect on the preservation of sensor properties of the fresh material was exerted by the solutions containing 1.5% $CaCl_2$ and 2% citric acid. It should be pointed out that all the stages of the initial treatment should proceed possibly fast because of considerable kinetic of enzymatic changes with polyphenolooxidase.

The next stage meant to secure the material against unfavourable changes was blanching. The problem of optimisation in terms of the choice of parameters was solved in a complex manner, using differentiated composition of solutions as well as different temperatures and periods of treatment. As a result of experimental choice of parameters, blanching in a 10% NaCl solution with the temperature of 65°C, in the time of 30 seconds was considered the most favourable. At each stage, an analysis of changes in the weight of the samples was conducted (fig. 3).

Fig. 3. Changes in the weight of samples in particular stages of the treatment



The soaking process caused weight increase by about 3-5%, and blanching resulted in another 7-12% in reference to the mass of samples after crumbing. When optimum parameters of initial treatment were established, the next stage was to freeze eggplants. Using a few methods gave an initial, but explicit evaluation of the possibilities of preserving aubergine fruits in low temperatures.

An experimental analysis of the freezing process consisting in drawing a freezing curve (in many repetitions) made it possible to obtain the initial value of cryoscopic temperature of aubergine, which is equal to T_{cri} = -0.4°C for the studied cultivars (table 2). Fig.4 shows changes in the temperature of the product during the freezing process of eggplant in differentiated conditions. The method for estimation of cryoscopic temperature is presented in fig. 5 [8, 9].

Table 2. Cryoscopic range for aubergine frozen in the air with different temperatures

Conditions for freezing (°C)	Cryoscopic temperature	
	initial T_{cri} (°C)	final T_{crf} (°C)
-50	-0.4	-3.6
-70	-0.4	-4.8
-90	-0.4	-3.9
-120	-0.4	-5.3

Fig. 4. Temperature profiles of aubergine in different freezing processes

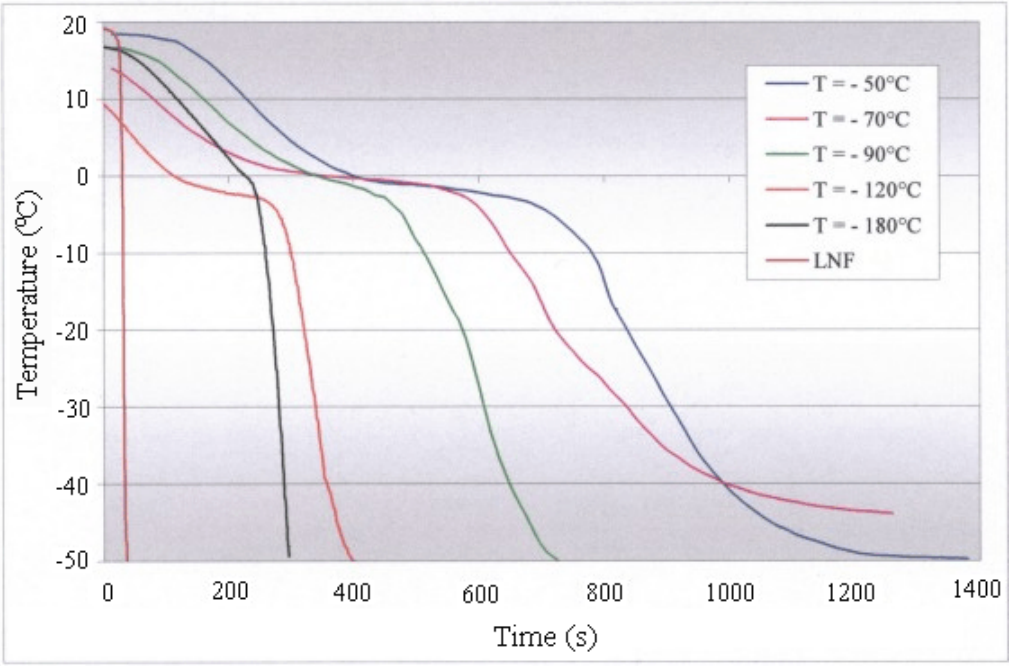
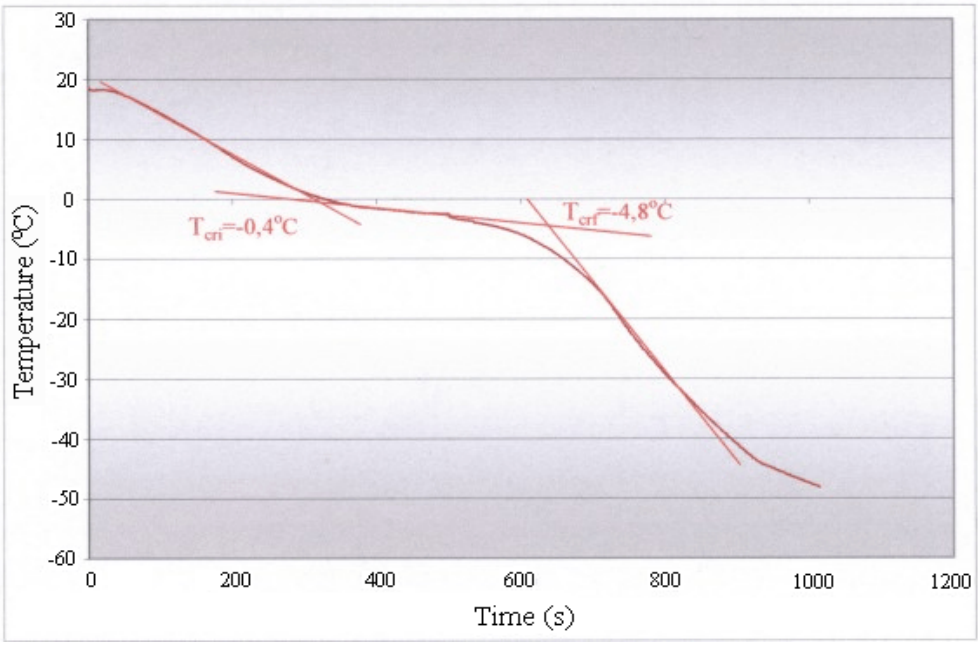
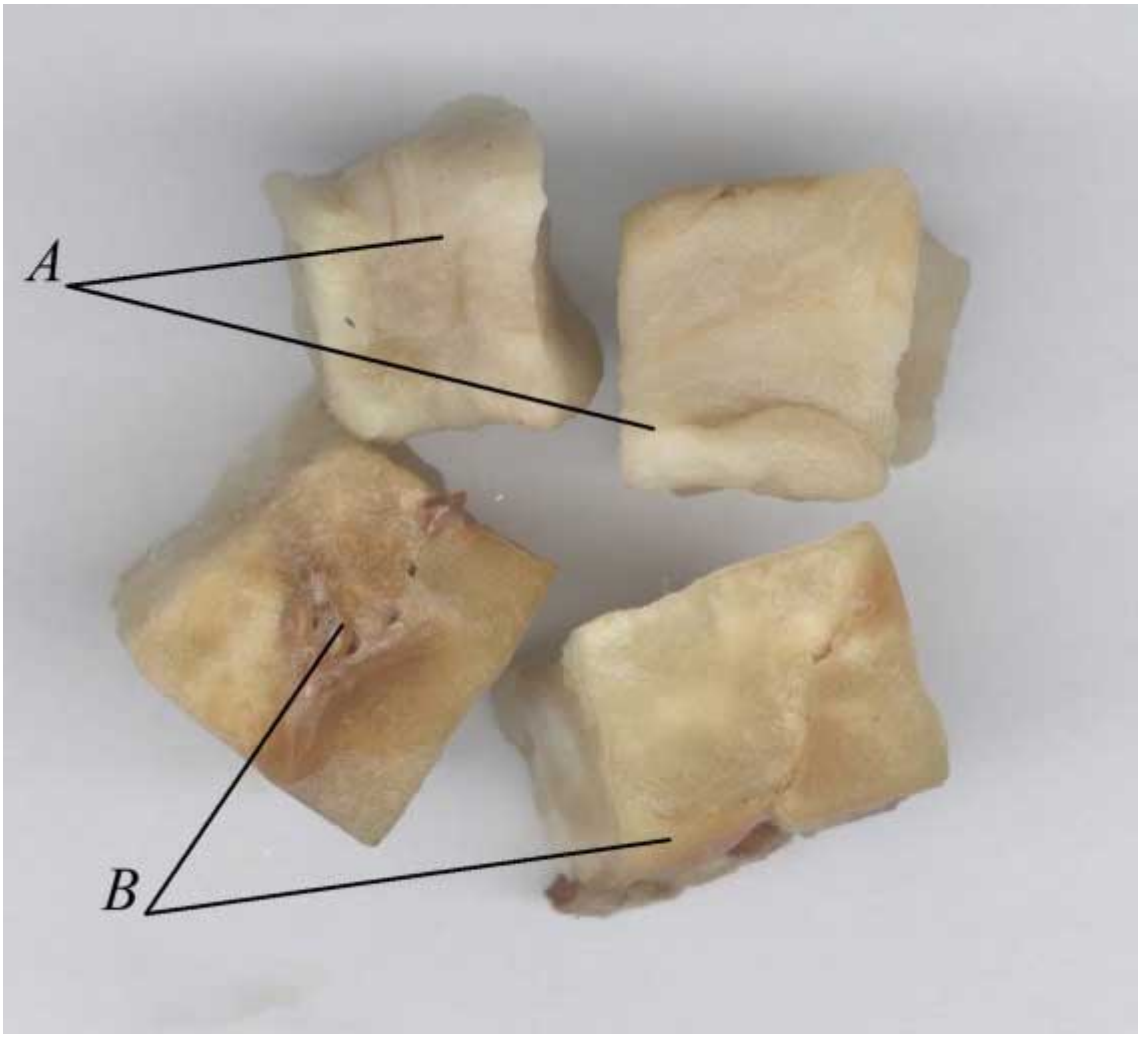


Fig. 5. Average freezing curve for aubergine frozen in the air temperature T_m = -70°C



Freezing in the temperature of the environment ranging from -10 to -40°C did not result in any colour changes in the case of the material which underwent thermo-chemical treatment. After freezing, however, the tissue structure was much worse, which was accompanied by drip loss reaching as much as 20% of the sample weight before the treatment. In the case of freezing eggplants at the temperatures lower than -40°C, remarkable changes of colour appeared already during the process and they were connected with enzymatic and not enzymatic browning (fig. 6).

Fig. 6. Visualisation of eggplant samples after thawing: samples exposed (A) and not exposed (B)



It proved impossible to preserve the tissue structure even with direct freezing in liquid nitrogen. The delicate structure of the flesh cells got destroyed under the effect of freezing, which was a direct cause of the outflow of cell liquids.

CONCLUSIONS

Storing eggplants in controlled atmosphere was worked out as early as the middle of the 1990's. These methods make it possible to lengthen the period of storing eggplants even up to six weeks. The main shortcoming of storing fruits and vegetables in controlled atmosphere is the high cost of equipment.

A short period of industrial and consumptive ripeness and high sensitivity of aubergine to transportation (rapid enzymatic changes resulting from abrasions and injuries) limit the possibilities of transporting it. Methods of freezing aubergine will make its longer storage and transport with conventional means possible.

The studies did not result in a chilling technology which would provide a thawed product with satisfying properties including proper colour and structure. Studies on preservation of aubergine colour were successful, while those on preserving its structure failed.

Nevertheless, the experiments provided important information on the reaction of aubergine tissue to low temperature during the contact with different chilling media and materials, for example freezing with liquid nitrogen causes intensive changes of colour caused by cryolysis, the browning of the material in contact with iron metals while freezing it in temperatures lower than –60°C.

As follows from the studies, the initial cryoscopic temperature of eggplants has a constant value which is equal to -0.4°C. The situation looks different in the case of the final cryoscopic temperature, which – as follows from the studies – changes together with the rate of freezing and the temperature of the chilling environment.

Although these and not other results were achieved, studies on the freezing methods of lengthening the durability of aubergine are still continued taking into consideration further aspects.

There is no doubt that intensive development of modern methods and technologies of preserving and storing various little known materials and agricultural products can contribute to the spread of their cultivation and consumption.

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