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PHYSICAL CHANGES OF VEGETABLES DURING FREEZING BY CONVENTIONAL AND IMPINGEMENT METHODS*

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A b s t r a c t. Analysis was made of changes in some physical properties of vegetables treated with the conventional methods and in impingement system at reverse fluidization. French fries of 8x8 mm size, and carrot cubes of 8 mm side were frozen with impingement method and at natural convection conditions, whereas garlic, French fries, carrot and radish were thawed in water bath at the natural and forced convection and in air at the natural and forced convection and impingement system. It was found that the freezing proceeded the fastest at the impingement system despite the highest ambient temperature, and the greater loss of vegetable mass frozen after this method was reported. The thawing time and the properties of the environment of the process affected the extent of material mass loss and had a significant impact on shear test results. The application of the impingement technique in the reverse fluidization system for vegetable freezing and thawing allows to obtain products of higher quality as compared to those treated with other methods.

K e y w o r d s : vegetables, physical properties, freezing methods, thawing

INTRODUCTION

Consumers tend to purchase food of the highest possible quality and with the least altered primary properties, and the producers, in turn, press for continuous optimization of the food processing time. It is evident in the case of refrigeration treatment in particular. Quick freezing (especially at low temperatures) is more expensive than slow freezing as it requires special equipment but assures obtainment of product of higher quality and microbiological purity. Fast frozen products do not lose the basic qualities of a fresh product to any great measure, and after their thawing they present lower mass loss.

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Slow freezing leads to the formation of large ice dendritic crystals in tissues that destroy walls and cell organelles. As a consequence, thawing is followed by a noticeable drip loss and enhanced enzymatic activity. Slow freezing, however, can also cause a marked concentration of still unfrozen tissue fluids and, as a result, some irreversible protein damage [9]. A proper freezing rate determines the material loss reduction as well as its quality improvement after thawing. The modern freezing methods are connected with high freezing rate causing fast transition of a product through the cryoscopic range, the zone of ice crystal formation. That shortens the processing time to a great extent and at the same time a thin ice coat on the product surface develops preventing moisture loss [2]. The choice of an appropriate method and conditions for the process run at food thawing exerts a significant impact on the final quality of the product processed. As regards microbiological contamination and maintenance of easily degradable palatable and medical substances, it is vital to keep low temperature and short thawing time. According to the USA Ministry of Health, e.g. meat should be thawed at up to 5°C temperature [3], while the Canadian regulations TDA state that the thawing process should be completed under 2h [1], beyond this time the meat is unfit for consumption. Such strict regulations concerning both freezing and thawing need new methods of food refrigeration processing.

Over a few years the systems based on the impingement effect have undergone intensive investigations and efficient introduction into food processing.

The term impingement is derived from the medieval Latin word *impingere* and means an opposite stroke – impingement. This technique was employed in the 70’s of the last century to remove dust and flour out of air in mills and bakeries. Its application in baking revolutionized the bakery industry. Currently ovens equipped with impingement system for household use are available at the market. This method is also used in connection with the microwave technique and resistance heating [6,10].

In refrigeration food treatment, this process consists in appropriate passing of air or nitrogen vapour downwards, vertically, out of short or long nozzles at high speed through a layer of product located on a horizontal belt or trough. The gas flux being introduced to the fixed bed from above penetrates it and rebounds from the belt or trough bottom and returns to the environment through the bed [4,5,6] (Fig.1, 2).

The impingement systems presented above were introduced to the industry and are used commonly (among others, hamburgers in McDonald`s and Burger King are frozen according to impingement system), yet its application in the apparatus with fluidization has been still under experimental studies. There are two technical possibilities of the impingement effect application in fluidization. The first consists in an air stream passage through nozzles from below onto a product to induce so-called product boiling occurrence (Fig. 3). Actually, this method does not differ from the conventional fluidization [5,10,11].

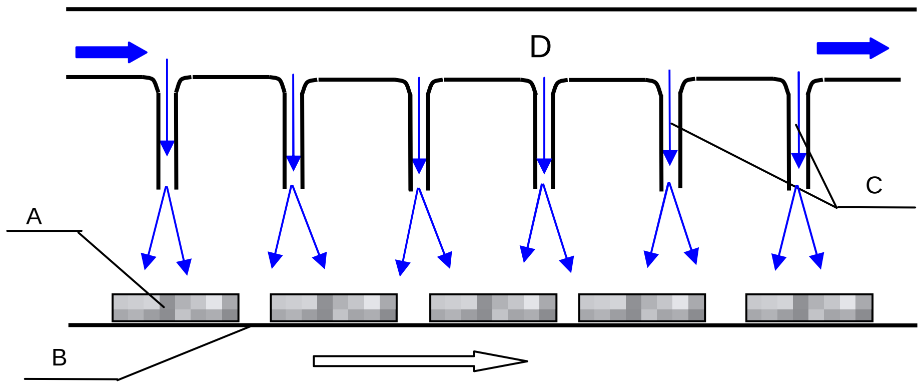

Fig. 1. Apparatus using impingement effect, A – product, B – belt, C– nozzles, D – compressed air chamber

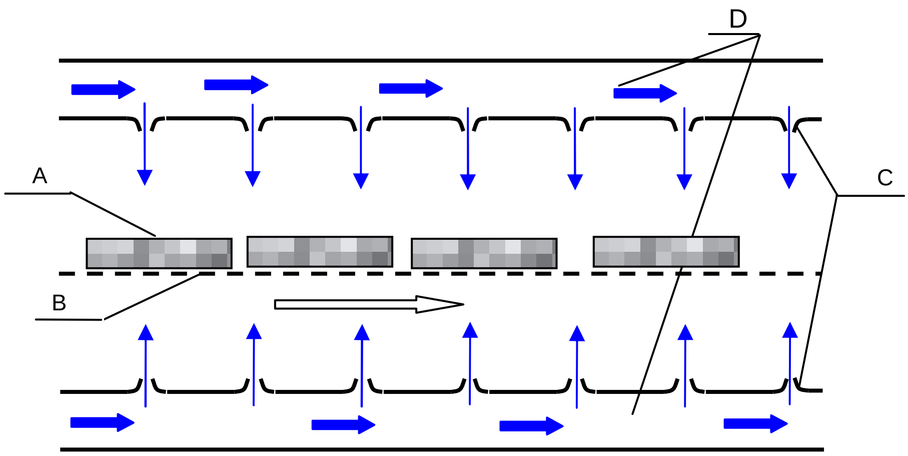

Fig. 2. Impingement method application in binary system with short nozzles system use, A – product, B – belt, C – nozzles, D – compressed air chamber

The other method consists in inducing reverse fluidization through pointing the air stream onto a product from above, its rebound from the bottom resulting in product boiling (Fig. 4). This method is very promising due to the high quality of the product obtained [4,5].

The objective of the work was to analyse the changes of some physical properties of vegetables treated, at refrigeration processing including freezing and thawing with conventional methods in a device with the use of the impingement method.

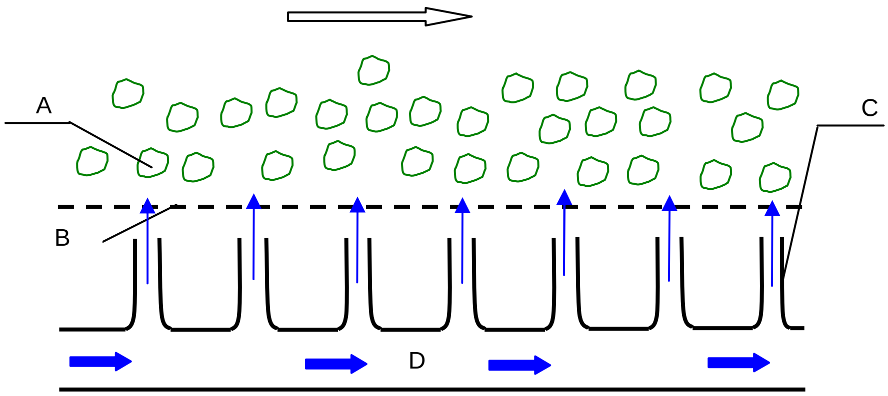

Fig. 3. Impingement effect application in fluidization process, A – product, B – belt, C – nozzles, D – compressed air chamber

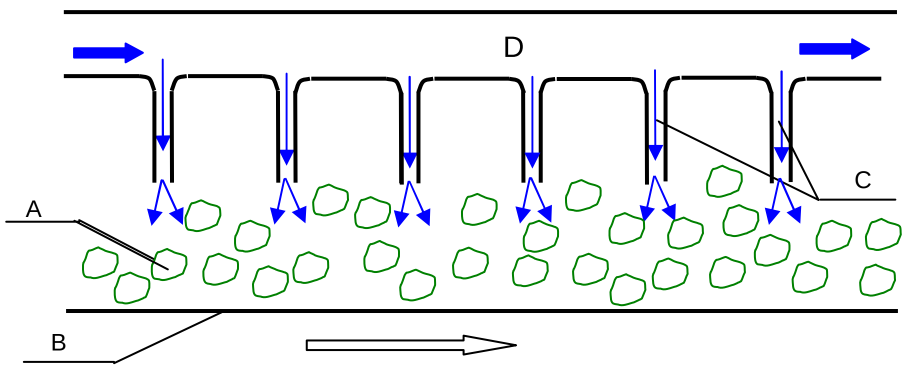

Fig. 4. Apparatus using reverse fluidization effect, A – product, B – belt, nozzles, D – compressed nitrogen vapour chamber

MATERIALS AND METHODS

The investigated material was constituted by single unpacked cloves of garlic without hulls, of similar size and medium thickness of 15.4 mm, French fries of 8 x 8 mm intersection and various lengths, carrot cubes of 8 mm side, radishes without tops and roots of 1 cm in diameter. The sampled vegetables did not have any visible damage or signs of any disease. The material under study was weighed at ±0.1g accuracy and then frozen with two methods.

The first method, i.e. reverse fluidization, proceeded in the laboratory apparatus for the impingement investigations constructed by the present authors [7] (Fig. 5). The process conditions were as follows: air flow speed 20 m s^{-1}, air temperature –10ºC. The material quantity treated each time was 0.5 kg.

Fig. 5. View of the laboratory impingement stand

The other method consisted in freezing the material of 0.5 kg weight in a cabinet freezer. The material was put in the freezer chamber centre on a wire net shelf. The process was run at –32ºC in the natural convection conditions.

The thawing was performed in a water bath by using the natural and forced convection, and in air under the conditions of natural convection and reverse fluidization (impingement). The reverse fluidization process was realized at the laboratory stand which was used for freezing before. Prior to thawing the material was frozen only in the cabinet freezer so that the very thawing method impact on physical properties changes could be compared.

Ambient temperature during the thawing process was maintained at a constant level of 15ºC and the process was run till 10ºC was obtained in the sample thermal centre (Fig. 6). During each thawing treatment the changes of temperature in the sample thermal centre were measured and recorded by multi–channel temperature meter equipped with NiCrNi thermocouples. The sampling frequency was 1 measurement per second. On the basis of the registered results the mean freezing and thawing rates were determined through the obtained curves of the process course.

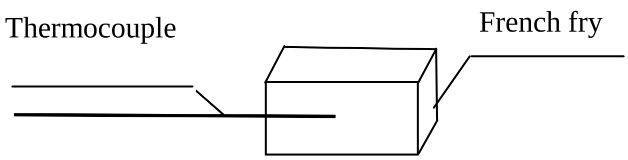

Fig. 6. Method of temperature measurement in thermal centre of French fry

The physical properties changes of the processed garlic were estimated through: texture characteristics, on the basis of valuation of maximal force in the shear tests performed on a Zwick ZO20 testing machine. The shear test was made with a knife of the Warner–Bratzler type [12] and was run till a garlic clove got cut across completely. The garlic was cut perpendicularly to the clove axis and the maximal shear force was considered the highest force value read out from the shear curve diagram.

The weight change after the refrigeration treatment induced by moisture loss due to freezing and thawing drip was calculated from the difference between sample weight prior to and after processing, and expressed as a percentage.

The final general evaluation of the products was performed by means of the organoleptic test when colour, texture and taste were assessed according to the 4–point preference scale. The colour scale evaluation went as follows;

1. product did not change its colour after treatment,
2. product colour changed slightly and took on very light brown stains all over the surface,
3. product colour changed for light brown,
4. product got dark and took on a brown colour.

Texture evaluation included four points;

1. product did not change its texture after treatment,
2. product surface changed slightly with delicate creases and folds on some part of the surface,

3. product top layer got creased all over the surface,
4. product surface was folded to a very great extent.

The taste scale referred to radish and carrot only, and comprised four points:

1. taste did not change significantly compared to a fresh product,
2. product taste changed delicately, lost its sweetness but bitterness was not detectable,
3. bitter after–taste noticeable
4. product taste characterized by substantial bitterness with sweet after–taste loss that disqualifies such a product.

RESULTS AND DISCUSSION

The freezing kinetics studied exhibited that, despite a threefold lower temperature obtained in the cabinet freezer, the process proceeded slower as compared to the impingement system use. Application of this system for freezing caused the occurrence of overchilling (Fig. 7) and its lack when the process was carried out in the cabinet freezer.

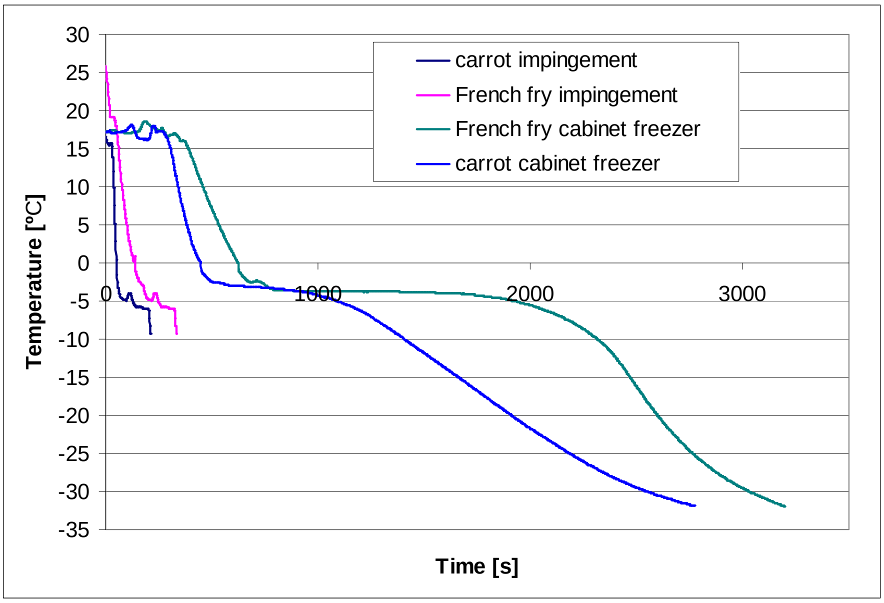

Fig. 7. Freezing curves of carrot and French fry in cabinet freezer and impingement method

The calculated freezing rate (Tab. 1) reached 8.88 cm h^{-1} for French fries and 14.8 cm h^{-1} for carrot cubes The weight measurement taken before and after the freezing treatment showed higher weight loss of vegetables frozen after the impingement method (Tab. 2). This was likely to result from greater intensity of air flow around the frozen material and, as a consequence, its surface drying. However, the assumptions that a quickly developing ice coat on a product could diminish weight loss proved false, which may have been caused by too high air temperature at freezing with impingement system.

Table 1. Process rates

Process	Environment	Method	Product	Process rate (cm min^{-1})
Freezing	Air	impingement	carrot cube	14.8
			French fries	8.88
		natural convection	carrot cube	2.05
			French fries	1.25
Thawing	Water	forced circulation	clove	3
		natural convection	carrot cube	4.66
			French fries	2.09
			radish	2.62
			clove	0.57
	Air	impingement	carrot cube	2.93
			French fries	2.42
			radish	3.67
			clove	0.45
		natural convection	carrot cube	0.46
			French fries	0.4
			radish	0.42
			clove	0.04

Table 2. Freezing weight loss of potato French fries (%)

Method	Mean weight loss at successive series (%)					Mean (%)
Impingement	6.8	6.4	6.7	8.8	3.4	6.42
Cabinet freezer	2.44	3.2	4.2	2.2	2.1	2.82

Short freezing time is of primary importance due to some palatability attributes maintenance, as well as positive impact on product quality as the possibility of microflora development on the product surface is inhibited. On account of that, the most advisable method for this process run is one which assures the shortest treatment time. Analysing the thawing kinetics it was found that the use of the reverse fluidization method leads to serious shortening of the process time and obtainment of thawing rate near that in water bath without forced water circulation. The process lasted the longest in the natural convection conditions, whereas it was the shortest in the water bath with forced water circulation (Fig. 8).

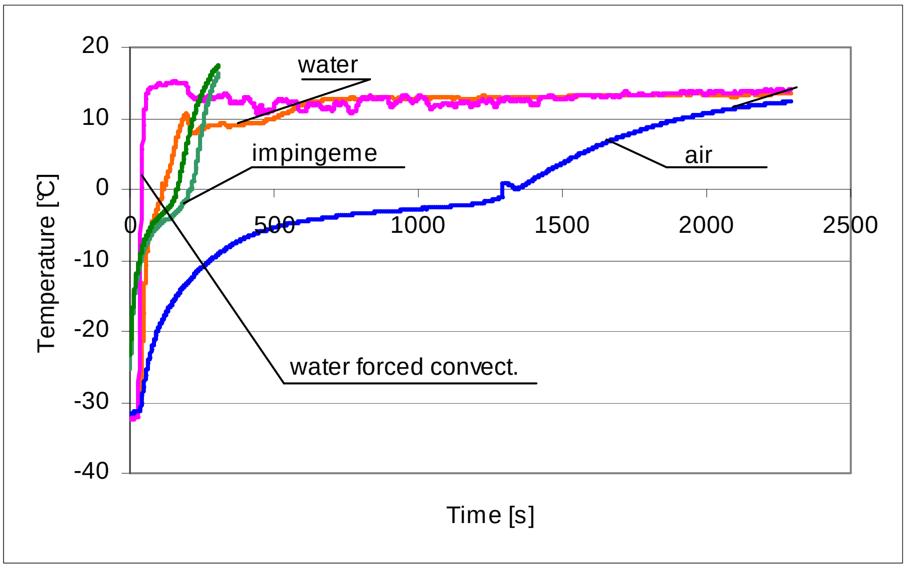

Fig. 8. Comparison of garlic thawing curves in water and impingement method

However, consideration of only the process rate analysis may result in a wrong method choice. The fastest method can bring irreversible changes of the physical properties and, in turn, the material quality deterioration. On the grounds of the investigations on weight changes it was reported that thawing in air under natural convection conditions causes losses up to 1.28% of initial material weight, while the thawing process realized at reverse fluidization technique reduces the losses to 0.74% (Fig. 9).

Substantial material weight losses at thawing in air are induced by the long processing time and, in connection with that, material drying occurrence. Thawing in water at natural convection gives rise to garlic weight increment by 1.96% on average, whereas at forced convection the increase observed was 1.79%. The material weight increment in this case was induced by garlic water absorption. A lower weight gain at bath thawing at forced convection is determined by shorter process time. It was found that the impingement method application leads to lower weight losses brought about by drip loss. In the case of radish the weight losses decrease from 1.3% for thawing in air to 0.9% of initial weight with reverse fluidization technique. Thawing in water at natural convection causes material weight increment by 2%, while at forced convection this increase was smaller – 1.8%. The thawing drip for radish develops similarly.

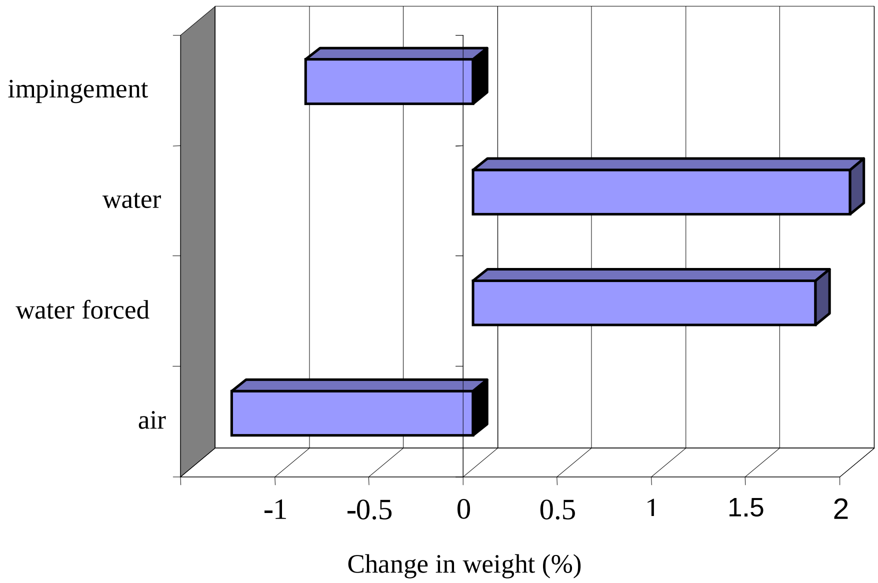

Fig. 9. Weight changes of garlic after thawing

Another comparative method of estimation of the quality of material obtained after processing is the shear test performed by means of a strength apparatus. There were shear force tests of garlic thawed by different methods, and the test values were compared to those for unfrozen garlic. The maximum shear force values of raw garlic and after thawing with reverse fluidization technique are close and reach 17.37 N and 17.39 N, respectively. In the other cases of thawing the values of this property maintain the level of over 20 N and are differentiated significantly (Tab. 3).

The low values of the test prove higher hardness of the material – one of the most often evaluated quality attribute. When thawing proceeds in air, garlic hardness is low due to weight loss. However, at water conditions the shear force increment is probably caused by the water absorption of garlic.

Table 3. Maximum shear force values of garlic cut with Warner–Bratzler type knife

Environment	Method	Max shear force (N)
Water	forced circulation	23
	natural convection	24.3
Air	impingement	17.39
	natural convection	31.8
Raw material		17.37

The general organoleptic assessment of the vegetables after their thawing showed that the vegetables thawed according to the impingement method and in air at natural convection were characterized by the best palatability (Tab. 4)

Table 4. Quality evaluation of the studied products after thawing

Method	Atribute	French fries	Carrot cube	Radish
Impingement	texture	1	1	1
	colour	2	1	1
	taste	–	1	1
Water	texture	1	1	1
	colour	1	1	1
	taste	–	2	2
Air	texture	4	3	3
	colour	4	2	2
	taste	–	3	3

Analysing the results of colour investigations, it was found out that the shorter the freezing time, the closer to fresh product colour is possible. Both radish and garlic thawed after the reverse fluidization method exhibited better consistency and flavour.

CONCLUSIONS

1. Studying the freezing kinetics of carrot and potato French fries it was established that reverse fluidization method makes the process time significantly shorter.
2. Weight measurement prior to and after freezing treatment showed higher weight loss of vegetables frozen by the impingement method, which probably resulted from more intensive air flow around the frozen material.
3. The freezing time and environment characteristics where the process is realized affect the material weight loss values. As to thawing in air at natural convection, the vegetable weight decreases (garlic by 1.28%) in relation to the initial weight, while at reverse fluidization system this loss is lower (garlic by 0.74%).Thawing in water, however, brings material weight gain by 1.9% at average and may cause some component wash out of the studied material and contribute to its quality deterioration.
4. The results of shear tests performed on raw garlic and thawed after reverse fluidization method application are similar. In other thawing cases the values are considerably higher and maintain over 20 N. The choice of thawing conditions affected the garlic texture.
5. The impingement technique application in the reverse fluidization method for vegetable freezing and thawing allows to obtain a product of good quality in the experimental conditions, the quality being often higher compared to other treatment methods. This was confirmed clearly by the results of texture studies and organoleptic tests. Furthermore, this method is free of numerous drawbacks accompanying the process at water conditions.

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ZMIANY WŁAŚCIWOŚCI FIZYCZNYCH WARZYW PODCZAS ZAMRAŻANIA METODAMI KONWENCJONALNYMI I W SYSTEMIE IMPINGEMENT

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Streszczenie. Analizowano zmiany wybranych właściwości fizycznych obrabianych warzyw podczas chłodniczej obróbki metodami konwencjonalnymi i metodą impingement w systemie odwróconej fluidyzacji. Frytki ziemniaczane o przekroju 8 x 8 mm, kostkę sześcienna z marchwi o boku 8 mm poddano zamrażaniu metodą impingement i w warunkach konwekcji swobodnej. Natomiast czosnek, frytki ziemniaczane, marchew i rzodkiewkę rozmrażano w łaźni wodnej w warunkach konwekcji swobodnej i wymuszonej oraz w powietrzu w warunkach konwekcji swobodnej i metodą impingement. Stwierdzono, że zamrażanie przebiegało najszybciej w systemie impingement pomimo najwyższej temperatury środowiska oraz wykazano większy ubytek masy warzyw zamrażanych tą metodą. Czas rozmrażania i właściwości środowiska, w którym prowadzony jest proces wpływają na wielkość strat masy surowca oraz istotnie wpływają na wyniki testu cięcia. Wykorzystanie techniki impingement w systemie odwróconej fluidyzacji do zamrażania i rozmrażania warzyw prowadzi do uzyskania w warunkach badań produktu o jakości często lepszej niż surowca obrabianego innymi metodami.

Słowa kluczowe: warzywa, właściwości fizyczne, metody zamrażania, rozmrażanie