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## Retention of mineral constituents in frozen brassicas depending on the method of preliminary processing of the raw material and preparation of frozen products for consumption

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**Abstract** The content of ash, P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, Cr and Ni was determined in four species of brassicas: Brussels sprouts, broccoli, and green and white cauliflowers. The investigation covered the raw material, the material blanched or cooked before freezing and frozen products after 12 months of refrigerated storage and prepared for consumption. Frozen products were obtained by the traditional method of freezing the blanched material or by the modified method of freezing the cooked material. The processing of vegetables before freezing (washing, grinding, blanching or cooking) caused statistically significant decreases in most constituents analysed. Blanching did not basically change the content of sodium and calcium; or that of chromium in both types of cauliflower; copper and nickel in white cauliflower; and nickel and phosphorus in Brussels sprouts. Cooking in brine, however, caused increases in the content of ash, sodium and calcium in white cauliflower, decreases in the content of potassium and iron and, in some species, of the remaining constituents. In comparison with the traditional method, a greater content of most analysed elements was found in frozen products obtained by the modified technology and prepared for consumption. However, no significant differences were noted in the level of chromium in all the samples; in the level of calcium in broccoli and green cauliflower; of nickel in broccoli; of nickel, copper and zinc in white cauliflower; and of copper in green cauliflower.

**Keywords** Brassicas · Minerals · Blanching · Cooking · Freezing · Preparing for consumption

### Introduction

The harvest of vegetables is seasonal and hence processing is necessary to ensure their constant availability to consumers. The best processing method is freezing, and the nutritive value of frozen products depends on factors connected with species, cultivar, conditions of harvest [1], preliminary processing before freezing, and the conditions of freezing and refrigerated storage [2, 3]. The quality of frozen products also depends on their preparation for consumption, particularly in the case of microwave heating [4]. Brassicas are popular in European countries where the range of their growing and hence their supply and consumption is constantly increasing [5] owing to their taste, nutritional values, the high content of biologically active constituents [2] and also, in comparison with other groups of vegetables, the high level of mineral constituents [6, 7].

The aim of the work was to evaluate the retention of ash and of 10 mineral constituents in frozen products prepared for consumption after 12 months of refrigerated storage. The investigation included frozen Brussels sprouts, broccoli, and white and green cauliflower obtained by the traditional method of freezing blanched material or by the modified method of freezing the material cooked in brine before freezing to obtain a ready-to-eat food, which only requires defrosting and heating to consumption temperature in a microwave oven.

### Material and methods

#### Material

The investigated material consisted of four species of brassica: Brussels sprouts—*Brassica oleracea* L. *convar. oleracea* var. *gemmifera* DC. (Luna F<sub>1</sub> cv.), broccoli—*Brassica oleracea* L. *convar. botrytis* (L.) Alef. var. *cymosa* Duch. (Lord F<sub>1</sub> cv.), white cauliflower—*Brassica oleracea* L. *convar. botrytis* (L.) Alef. var. *botrytis* L. (Planita F<sub>1</sub> cv.) and green cauliflower—*Brassica oleracea* L. *convar. botrytis*

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**Table 1** Pretreatment time (in min and s) of vegetables before freezing (blanching, sample B; cooking, sample C) and preparing frozen vegetables for consumption (cooking, sample D; defrosting and heating in a microwave oven, sample E)

Vegetable	Vegetable before freezing		Frozen vegetable	
	Sample B	Sample C	Sample D	Sample E
Brussels sprouts	5 min	15 min	9 min	8 min and 15 s
Broccoli	3 min	5 min	4 min and 30 s	8 min and 15 s
White cauliflower	3 min	6 min	5 min	8 min and 15 s
Green cauliflower	3 min and 15 s	6 min	5 min	8 min and 15 s

(L.) *Alef. var. botrytis* L. (Trevi F<sub>1</sub> cv.). The content of ash, P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, Cr and Ni was measured in fresh (samples A), blanched (samples B) and cooked vegetables in 2% brine to consumption consistency (samples C); frozen products prepared from blanched vegetables after 12 months of refrigerated storage at  $T = -30^{\circ}\text{C}$  and frozen products prepared from the cooked material. Frozen products obtained from the blanched material were cooked in brine (samples D), while those obtained from cooked vegetables were heated in a microwave oven (samples E) to consumption temperature [8].

The raw material was harvested in the experimental field of the Department where the investigations were conducted. The field lies in southern Poland, in the western outskirts of Krakow. The soil was of good horticultural quality with neutral pH and a high content of potassium, phosphorus and calcium. The fertility of the soil and the nutritional requirements of the crops having been taken into account, the following doses of mineral fertilizers in kg/ha were applied: for Brussels sprouts N, 120; P<sub>2</sub>O<sub>5</sub>, 80; K<sub>2</sub>O, 150; for the remaining vegetables 150; 100 and 150, respectively. Cultivation measures included, sprinkler watering, mechanical weed control, and where necessary, protective treatments against diseases and pests. Depending on the species, the harvest was conducted in the first (broccoli and cauliflowers) or second (Brussels sprouts) 10-day period of October.

Mean samples representing the whole batch of the material were taken for analysis and preparation of the frozen products. Brussels sprouts heads, 25–30 mm in diameter, were cleaned of stipules and the stems were cut. Florets of broccoli and cauliflowers (white and green) were cleaned of leaves and divided into pieces about 5 cm in diameter, the stems being cut 2 cm below the lowest ramification.

#### Preparation of frozen products

Two variants of processing the raw material before freezing were used. In variant 1, the traditional technology was to blanch the raw material; after freezing and refrigerated storage the frozen product was cooked in water to consumption consistency. In variant 2, the raw material was cooked to consumption consistency to obtain a ready-to-eat product, which after freezing and refrigerated storage only had to be defrosted and heated in a microwave oven to consumption temperature.

In variant 1, the fresh material was blanched in a stainless steel vessel in water, the proportion of water to the raw material being 1:5 and the blanching temperature  $T = 95\text{--}98^{\circ}\text{C}$ . The time of blanching of the different species is given in Table 1. The applied parameters of blanching allowed a decrease in the activity of catalase and peroxidase to a level not exceeding 5% of the initial activity. After blanching, the material was immediately cooled in a stream of water at about  $10^{\circ}\text{C}$  and left to drip on sieves for 30 min.

In variant 2, the vegetables were cooked in a stainless steel vessel in water with 2% added salt (NaCl), the proportion of the weight of the raw material to water being 1:1. The vegetables were placed in boiling water. The cooking time measured from the moment when the water came to the boil again is given in Table 1. After cooking to consumption consistency, the material was left on sieves and cooled in a stream of cold air at about  $10^{\circ}\text{C}$ . The materials from blanched and cooked samples were placed on trays and frozen at  $T = -40^{\circ}\text{C}$  in a Feutron 3626-51 blast chamber. The time required for the inside of the product to reach the storage temperature of  $T = -30^{\circ}\text{C}$  was 120 min. The frozen vegetables were then packed in 500 g polyethylene bags and stored for 12 months.

**Table 2** Content of dry matter in raw, blanched, cooked and frozen, then prepared for consumption, cabbage vegetables, in fresh matter

Samples	Brussels sprouts		Broccoli		White cauliflower		Green cauliflower	
	g/100 g	%	g/100 g	%	g/100 g	%	g/100 g	%
A	18.11	100	10.34	100	7.28	100	9.30	100
B	16.14	89	8.37	81	6.61	91	8.08	87
C	17.15	95	10.74	104	8.59	118	10.46	113
D	16.78	93	9.02	87	7.40	102	9.20	99
E	18.66	103	11.21	108	9.56	131	11.23	121

*Note.* A, raw material; B, blanched material before freezing; C, cooked material before freezing; D, product cooked after 12 months frozen storage from material blanched before freezing; E, product defrosted and heated in a microwave oven after 12 months frozen storage from material cooked before freezing

**Table 3** Content of selected minerals in raw, blanched, cooked and frozen, then prepared for consumption Brussels sprouts, in fresh matter

Samples	Ash (g/100 g)	P (mg/100 g)	K (mg/100 g)	Ca (mg/100 g)	Mg (mg/100 g)	Na (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	Mn (mg/100 g)	Cu (mg/100 g)	Cr (mg/100 g)	Ni (mg/100 g)
A	1.27 ± 0.07	59 ± 4	425 ± 25	35.6 ± 1.3	20.7 ± 1.2	10.7 ± 0.7	0.76 ± 0.02	0.58 ± 0.04	0.231 ± 0.013	0.099 ± 0.009	0.014 ± 0.002	0.015 ± 0.002
B	1.07 ± 0.05	57 ± 4	364 ± 14	35.0 ± 2.2	18.2 ± 1.1	10.1 ± 0.7	0.66 ± 0.04	0.47 ± 0.04	0.187 ± 0.016	0.076 ± 0.004	0.007 ± 0.001	0.016 ± 0.001
C	1.30 ± 0.06	60 ± 6	259 ± 13	30.6 ± 2.5	18.5 ± 1.1	73.4 ± 8.1	0.59 ± 0.04	0.50 ± 0.03	0.202 ± 0.015	0.071 ± 0.005	0.008 ± 0.002	0.011 ± 0.002
D	1.24 ± 0.08	37 ± 4	189 ± 16	26.1 ± 3.5	11.9 ± 1.9	61.8 ± 7.2	0.39 ± 0.03	0.35 ± 0.02	0.103 ± 0.014	0.046 ± 0.004	0.006 ± 0.001	0.007 ± 0.002
E	1.40 ± 0.01	62 ± 6	276 ± 27	31.8 ± 2.6	18.8 ± 1.5	81.0 ± 8.4	0.63 ± 0.04	0.54 ± 0.05	0.209 ± 0.013	0.079 ± 0.002	0.008 ± 0.001	0.011 ± 0.002
LSD												
$\alpha = 0.01$	0.123	9.7	41.5	5.21	2.91	12.82	0.070	0.082	0.0301	0.0109	0.0027	0.0035
$\alpha = 0.05$	0.089	7.0	30.0	3.77	2.11	9.27	0.051	0.059	0.0218	0.0079	0.0020	0.0026

Note. A, raw material; B, blanched material before freezing; C, cooked material before freezing; D, product cooked after 12 months frozen storage from material blanched before freezing; E, product defrosted and heated in a microwave oven after 12 months frozen storage from material cooked before freezing

## Preparation of frozen product to evaluation

Samples (D) were cooked in 2% brine, the proportion by weight of the brine to the raw material being 1:1. As was the case when cooking fresh vegetables, the frozen product was placed in boiling water. The time of cooking measured from the moment when the water came to the boil again is given in Table 1. After cooking, the water was immediately drained; the product was cooled to  $T = 20$  °C and analysed. Samples of vegetables cooked before freezing were defrosted and heated in a Panasonic NN-F621 microwave oven (samples E). In this case, a 500 g portion was placed in a covered heatproof vessel. The time of defrosting and heating to  $T = 75$  °C is given in Table 1.

Water samples used in the technological and culinary processing of all the vegetables species did not significantly differ ( $\alpha = 0.01$ ) in the content of the investigated elements; the highest content of the analysed elements did not exceed 50% of the legally admissible amounts [9].

## Chemical analysis

The level of dry matter was determined by gravimetric method by drying at 105 °C AOAC [10]. Content of ash was determined by incinerating in the Nabertherm model L 9/S 27 furnace oven at  $T = 460$  °C. For the determination of individual mineral elements, the mineralization of material was carried out in a 3:1 mixture of nitric and perchloric acids. A 50 g portion of the material and 30 mL of the acid mixture were placed into 250 mL test tubes of the Tecator Kjeltac Auto Plus II mineralization set. The treated samples were left until the next day when complete mineralization was carried out. The mineralized samples were diluted with ultra-pure water to a volume of 100 mL and filtered into dry flask. Contents of the elements in solutions were determined with the use of an atomic emission spectrophotometer with inductively coupled argon plasma (ICP-AES) Jobin Yvon 238 Ultrace. Flasks were soaked 24 h in 10% nitric acid and then rinsed with ultra-pure water before use. Phosphorus was analysed spectrophotometrically with molybdenum blue [10].

The content of mineral constituents in the raw material, semi-cooked product and the product prepared for consumption was converted to 100 g fresh matter. To allow for conversion of the results in dry matter, however, the content of dry matter in the investigated material at each stage of evaluation is given in Table 2.

## Statistical analysis

Analysis of variance (ANOVA) was carried out on the basis of the Snedecor  $F$ -test and the Student  $t$ -test; the least significant difference (LSD) for the probability level  $\alpha = 0.05$  and 0.01 was calculated to show the variation in the content of ash and the analysed elements between the compared samples from the different vegetable species. All analy-

**Table 4** Content of selected minerals in raw, blanched, cooked and frozen, then prepared for consumption broccoli, in fresh matter

Samples	Ash (g/100 g)	P (mg/100 g)	K (mg/100 g)	Ca (mg/100 g)	Mg (mg/100 g)	Na (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	Mn (mg/100 g)	Cu (mg/100 g)	Cr (mg/100 g)	Ni (mg/100 g)
A	0.89 ± 0.05	80 ± 5	289 ± 7	27.2 ± 2.0	18.1 ± 0.8	18.0 ± 0.6	0.87 ± 0.05	0.95 ± 0.03	0.192 ± 0.009	0.094 ± 0.007	0.012 ± 0.002	0.010 ± 0.002
B	0.51 ± 0.03	64 ± 5	161 ± 9	30.1 ± 3.5	12.8 ± 0.6	10.0 ± 0.6	0.59 ± 0.04	0.63 ± 0.03	0.135 ± 0.008	0.061 ± 0.006	0.007 ± 0.001	0.006 ± 0.002
C	1.34 ± 0.10	68 ± 3	200 ± 12	25.0 ± 2.4	13.1 ± 0.8	269.1 ± 12.3	0.66 ± 0.04	0.62 ± 0.05	0.165 ± 0.007	0.063 ± 0.005	0.006 ± 0.001	0.006 ± 0.001
D	0.93 ± 0.05	56 ± 4	94 ± 5	29.7 ± 0.9	8.8 ± 0.6	188.8 ± 8.3	0.54 ± 0.06	0.45 ± 0.02	0.122 ± 0.004	0.052 ± 0.007	0.006 ± 0.001	0.004 ± 0.001
E	1.50 ± 0.11	72 ± 6	214 ± 10	27.0 ± 1.1	14.1 ± 0.7	295.8 ± 7.9	0.67 ± 0.04	0.61 ± 0.06	0.186 ± 0.010	0.070 ± 0.006	0.007 ± 0.002	0.005 ± 0.001
LSD												
$\alpha = 0.01$	0.157	9.5	18.7	ns	1.47	15.68	0.100	0.082	0.0163	0.0133	0.0029	0.0030
$\alpha = 0.05$	0.113	6.9	13.5	3.31	1.06	11.34	0.072	0.059	0.0118	0.0096	0.0021	0.0022

Note. A, raw material; B, blanched material before freezing; C, cooked material before freezing; D, product cooked after 12 months frozen storage from material blanched before freezing; E, product defrosted and heated in a microwave oven after 12 months frozen storage from material cooked before freezing; ns, not significant

ses were carried out in four replications. The Statistica 6.1 program was used.

## Discussion of results

The content of mineral compounds found in fresh vegetables was similar to or did not significantly differ from that given in tables showing the composition of nutritive compounds in food products [6, 7]. The greatest content of ash in 100 g fresh matter was found in Brussels sprouts (Table 3); in broccoli it was 30% less (Table 4); and in white and green cauliflowers 51 and 39% less, respectively (Tables 5 and 6). Since they contained the greatest amount of ash, Brussels sprouts also had the highest levels of potassium, sodium, calcium, magnesium, manganese, copper and chromium. The greatest content of zinc and phosphorus was found in broccoli, and that of sodium, iron and nickel in green cauliflower.

During preliminary processing, changes in the level of mineral constituents are due to numerous factors, but particularly the species, and more specifically the kind of surface of the vegetable; the compactness, density and size of particles; and on the surface of cut in dividing the material into smaller parts [11–14]. It is therefore difficult to compare the effects of specific procedures in preliminary processing in the different experiments reported in the literature. In the investigations conducted by Kmiecik et al. [11] on broad beans, the decreases in the analysed elements varied from 7 to 19%. Słupski et al. [12] observed a much greater loss in green parts of dill, and Amaro et al. [15] in asparagus: 28–30 and 22–57%, respectively. However, in studies concerning broccoli [14] and peas [16], the effect of blanching on the level of elements was not so significant.

The least loss brought about by blanching in the levels of ash, sodium, potassium, magnesium, iron and phosphorus was found in Brussels sprouts, varying from 3 to 16% (Table 3). The least loss of the remaining constituents was found in white cauliflower, varying from 0 to 15% (Table 5). By far the greatest loss in the content of most constituents was found in both blanched and cooked broccoli, by 20–44 and 14–50%, respectively (Table 4). Of the cooked samples, the smallest decrease of 0–15% was reported in the levels of potassium, iron, copper and nickel in white cauliflower; and in the levels of potassium, magnesium, zinc, chromium and phosphorus in green cauliflower.

Calcium should be discussed separately since its content in the vegetables after preliminary processing approximated to that in the raw material, or was higher by 2–11% in the case blanched samples, and by 12–28% in the cooked ones. The present authors [11, 12, 17] and also other workers [16, 18] obtained similar results in earlier studies. The results reported by Bressani et al. [18], showing that prolonging the thermal processing increased the level of calcium in vegetables, have not been fully confirmed. In the present experiment, only white and green cauliflowers contained more calcium after cooking than after blanching; in the case of the remaining species the opposite was ob-

**Table 5** Content of selected minerals in raw, blanched, cooked and frozen, then prepared for consumption white cauliflower, in fresh matter

Samples	Ash (g/100 g)	P (mg/100 g)	K (mg/100 g)	Ca (mg/100 g)	Mg (mg/100 g)	Na (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	Mn (mg/100 g)	Cu (mg/100 g)	Cr (mg/100 g)	Ni (mg/100 g)
A	0.62 ± 0.03	47 ± 4	221 ± 14	17.5 ± 1.7	14.5 ± 2.2	19.2 ± 2.7	0.50 ± 0.03	0.64 ± 0.03	0.131 ± 0.007	0.056 ± 0.007	0.009 ± 0.002	0.009 ± 0.002
B	0.47 ± 0.02	39 ± 2	182 ± 10	17.8 ± 1.2	11.1 ± 0.9	12.5 ± 0.8	0.42 ± 0.02	0.55 ± 0.02	0.111 ± 0.007	0.048 ± 0.008	0.007 ± 0.001	0.009 ± 0.001
C	1.13 ± 0.08	46 ± 5	187 ± 7	22.4 ± 1.3	12.0 ± 0.5	236.6 ± 11.0	0.44 ± 0.05	0.48 ± 0.04	0.126 ± 0.008	0.051 ± 0.005	0.007 ± 0.001	0.009 ± 0.002
D	0.96 ± 0.06	38 ± 3	119 ± 8	17.3 ± 0.6	7.9 ± 0.4	172.6 ± 8.4	0.38 ± 0.03	0.45 ± 0.02	0.084 ± 0.007	0.045 ± 0.006	0.007 ± 0.002	0.006 ± 0.001
E	1.26 ± 0.10	50 ± 3	198 ± 8	22.3 ± 1.1	12.0 ± 1.2	247.9 ± 11.8	0.48 ± 0.00	0.46 ± 0.02	0.132 ± 0.009	0.055 ± 0.009	0.007 ± 0.001	0.008 ± 0.002
LSD												
$\alpha = 0.01$	0.138	7.5	20.1	2.57	2.55	17.15	0.064	0.055	0.0163	ns	ns	ns
$\alpha = 0.05$	0.100	5.5	14.5	1.86	1.84	12.40	0.046	0.040	0.0118	ns	ns	ns

Note. A, raw material; B, blanched material before freezing; C, cooked material before freezing; D, product cooked after 12 months frozen storage from material blanched before freezing; E, product defrosted and heated in a microwave oven after 12 months frozen storage from material cooked before freezing; ns, not significant

served, in spite of the same tap water being used in both kinds of preliminary processing.

Decreases in the content of most analysed constituents due to blanching were statistically significant ( $\alpha = 0.01$ ). However, no significant changes in the content of sodium and calcium were reported in any of the investigated species or of chromium in both cauliflowers. Neither did the content of copper and nickel change in white cauliflower, nor of nickel and phosphorus in Brussels sprouts. After cooking in brine, the content of ash, sodium and calcium increased ( $\alpha = 0.01$ ) in white cauliflower, while that of potassium, iron, and in some species, the remaining constituents was reduced. No decrease in the content of phosphorus was noted, with the exception of broccoli; nor of chromium, nickel and manganese, with the exception of both types of cauliflower; magnesium and zinc in green cauliflower; and copper and nickel in white cauliflower. The greatest divergences between the investigated species with regard to differences ( $\alpha = 0.01$  or  $\alpha = 0.05$ ) between the content in the raw and cooked material concerned the amount of calcium in cooked samples, since in broccoli and green cauliflower cooking did not cause changes; in white cauliflower the calcium content increased, while in Brussels sprouts no changes occurred at  $\alpha = 0.01$ , although a decrease was noted at  $\alpha = 0.05$ .

A comparison of the level of analysed mineral constituents in vegetables before freezing but after preliminary processing showed that cooked samples contained more ash and sodium than the blanched ones. No significant differences were found in the content of copper and chromium; neither of magnesium, with the exception of green cauliflower (more at  $\alpha = 0.05$ ); nor of iron, with the exception of Brussels sprouts (less at  $\alpha = 0.05$ ). No regularity was established in the level of the remaining constituents, since the relative content of an element in cooked and blanched material varied.

The obtained results agree with earlier observations by Kimura and Itokawa [19]. These authors claim that the prolongation of thermal treatment did not always lead to a greater loss of mineral compounds. Amaro et al. [20] observed that the quality of water used during preliminary processing affects the content of mineral constituents. In the present experiment, the same water was used in both the treatments; hence the quality of the water could not have affected the retention of mineral constituents in the investigated vegetables. However, it should be stressed that blanching was conducted in water without any additives, while table salt added during cooking enhanced the retention of soluble compounds in water [21].

In comparison with the raw material, the products obtained by the traditional method and prepared for consumption by cooking in brine did not significantly differ in the content of the following constituents: calcium, with the exception of Brussels sprouts (less at  $\alpha = 0.01$ ); chromium, with the exception of broccoli and Brussels sprouts (less at  $\alpha = 0.01$ ); ash, with the exception of both the cauliflowers (more at  $\alpha = 0.01$ ); and copper and nickel, but only in white cauliflower. The level of the remaining constituents was significantly lower. In comparison with the raw material,

**Table 6** Content of selected minerals in raw, blanched, cooked and frozen, then prepared for consumption green cauliflower, in fresh matter

Samples	Ash (g/100 g)	P (mg/100 g)	K (mg/100 g)	Ca (mg/100 g)	Mg (mg/100 g)	Na (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	Mn (mg/100 g)	Cu (mg/100 g)	Cr (mg/100 g)	Ni (mg/100 g)
A	0.77 ± 0.03	62 ± 4	302 ± 14	25.3 ± 2.4	18.5 ± 1.1	21.3 ± 2.3	1.07 ± 0.03	0.85 ± 0.05	0.216 ± 0.011	0.075 ± 0.005	0.006 ± 0.001	0.010 ± 0.002
B	0.54 ± 0.02	55 ± 4	200 ± 10	27.0 ± 2.2	15.8 ± 1.3	17.7 ± 2.1	0.89 ± 0.05	0.70 ± 0.07	0.177 ± 0.011	0.058 ± 0.006	0.006 ± 0.001	0.006 ± 0.002
C	1.32 ± 0.09	66 ± 5	257 ± 18	28.3 ± 3.0	17.5 ± 0.7	250.8 ± 12.6	0.88 ± 0.07	0.84 ± 0.08	0.213 ± 0.019	0.056 ± 0.006	0.006 ± 0.001	0.009 ± 0.001
D	0.95 ± 0.03	52 ± 5	138 ± 11	27.3 ± 1.3	10.9 ± 0.6	204.1 ± 10.2	0.64 ± 0.03	0.53 ± 0.04	0.147 ± 0.008	0.048 ± 0.005	0.007 ± 0.001	0.003 ± 0.001
E	1.41 ± 0.07	68 ± 5	278 ± 17	30.0 ± 1.7	16.6 ± 1.1	281.5 ± 8.8	0.89 ± 0.07	0.90 ± 0.07	0.230 ± 0.013	0.058 ± 0.005	0.006 ± 0.001	0.008 ± 0.001
LSD												
$\alpha = 0.01$	0.118	9.5	30.2	ns	2.06	17.41	0.117	0.135	0.0272	0.0117	ns	0.0031
$\alpha = 0.05$	0.085	6.9	21.9	ns	1.49	12.59	0.085	0.098	0.0197	0.0084	ns	0.0023

Note. A, raw material; B, blanched material before freezing; C, cooked material before freezing; D, product cooked after 12 months frozen storage from material blanched before freezing; E, product defrosted and heated in a microwave oven after 12 months frozen storage from material cooked before freezing; ns, not significant

vegetables prepared for consumption in a microwave oven from frozen products obtained by the modified method had significantly more ( $\alpha = 0.01$ ) ash, sodium and calcium in white cauliflower; no statistically different content of phosphorus, apart from broccoli (less at  $\alpha = 0.05$ ); neither of manganese, with the exception of Brussels sprouts (less at  $\alpha = 0.05$ ); nor of zinc, with the exception of broccoli and white cauliflower (less at  $\alpha = 0.01$ ); nor of chromium, with the exception of broccoli and Brussels sprouts (less at  $\alpha = 0.01$ ). In these samples, the level of potassium was significantly lower, with the exception of green cauliflower (no differences at  $\alpha = 0.01$ ), as was that of iron, copper and nickel, apart from white cauliflower (no difference at  $\alpha = 0.01$ ). The level of magnesium did not differ in Brussels sprouts or green cauliflower, in the last species at  $\alpha = 0.05$  only.

The total loss caused by technical and culinary processing varied according to species, the applied method and the analysed elements. It was found that the loss was always greater when the vegetable was subjected to processing in water twice, i.e. when the raw material was blanched and then the frozen product was cooked. The following are quoted as examples of losses—varying according to species—recorded in samples subjected to the traditional or modified technologies, respectively: 55–67 and 8–26% for potassium; 26–51 and 10–22% for magnesium; 24–49 and 5–23% for iron and 20–53 and 2–26% for copper. It is obvious that these were not actual losses since Lisiewska et al. [17] reported the weight of vegetables, including their dry matter, changes during technological and culinary processing (Table 2). However, the authors assumed that the level of mineral constituents would be presented in the product prepared for consumption, hence in fresh matter.

According to Lopez and Williams [21], compared to the raw material, the content of mineral constituents in frozen green beans was 73–171%. According to these authors, of the 18 elements analysed, the amounts of iron, phosphorus and potassium were smaller in the frozen product, while those of calcium, sodium and zinc were greater than in the raw material. It should be stressed here that only one vegetable species and one uncooked product were analysed. Polo et al. [22] compared the level of mineral constituents of three vegetable species in the raw material and in products frozen but not prepared for consumption, and found that fresh and frozen vegetables provided similar amounts of these compounds. The investigations carried out by Puupponen-Pimiä et al. [23] also concluded with an analysis of the level of mineral constituents in frozen vegetables.

A comparison of the level of analysed elements in products prepared for consumption using the traditional or modified method showed that the latter had a greater content of most elements analysed. However, the differences were statistically non-significant in the level of chromium in all the samples; in that of calcium in broccoli and green cauliflower; of nickel in broccoli; of nickel, copper and zinc in white cauliflower; and also of copper in green cauliflower, but only at  $\alpha = 0.01$ .

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## Conclusion

In comparison with the fresh raw material, blanching before freezing significantly decreased the level of most mineral constituents in brassicas. Subsequent treatment of cooking in a 2% NaCl solution before freezing caused similar or smaller losses of the analysed elements than blanching, while in the case of ash and sodium the level was higher in cooked vegetables. The comparison of products prepared for consumption showed that those obtained by the modified method contained significantly more ash, potassium, sodium, magnesium, iron, manganese and phosphorus than those obtained using the traditional method. Differences between the evaluated products in the content of the remaining elements were statistically non-significant or their content was greater in vegetables processed according to the modified method.

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