

Effect of processing and cooking on total and soluble oxalate content in frozen root vegetables prepared for consumption

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The oxalate content of beetroot, carrot, celeriac and parsnip after freezing by traditional and modified methods (the latter resulting in a convenience food product), and after the preparation of frozen products for consumption was evaluated. The highest content of total and soluble oxalates (105 and 82 mg 100 g⁻¹ fresh matter) was found in beetroot. The lowest proportion (55%) of soluble oxalates was noted in celeriac; this proportion was higher in the remaining vegetables, being broadly similar for each of them. Blanching brought about a significant decrease in total and soluble oxalates in fresh vegetables. Cooking resulted in a higher loss of oxalates. The level of oxalates in products prepared for consumption directly after freezing approximated that before freezing. Compared with the content before freezing, vegetables prepared for consumption by cooking after frozen storage contained less oxalates, except for total oxalates in parsnip and soluble oxalates in beetroot and celeriac. The highest ratio of oxalates to calcium was found in raw beetroot; it was two times lower in raw carrot; five times lower in raw celeriac; and eight times lower in raw parsnip. These ratios were lower after technological and culinary processing. The percentage of oxalate bound calcium depended on the species; this parameter was not significantly affected by the procedures applied. The true retention of oxalates according to Judprasong et al. (2006) was lower than retention calculated taking its content in 100 g fresh matter into account.

Key words: root vegetables, oxalates, pretreatment before freezing, freezing; preparation for consumption

Introduction

Numerous studies have shown that vegetables contribute to cancer prevention by supplying various biologically active compounds to the diet (Noonan and Savage 1999). Hence, the consumption of these products is promoted by dieticians. However, vegetables also contain potentially harmful compounds. Included among these are oxalates, which in the digestive tract can limit the nutritional availability of calcium and, to a lesser extent, iron and magnesium (Noonan and Savage 1999, Weaver et al. 1997).

The occurrence of oxalates in plants is common; they appear in soluble form producing salts with potassium, sodium and NH_4 ions, and also in insoluble form producing insoluble salts chiefly with calcium, but also with iron and magnesium (Savage et al. 2000). Numerous publications discuss the effect of genetic, agro-technical and morphological factors on the level of oxalates; however, only a few works deal with factors associated with the processing of vegetables or preparing them for consumption (Catherwood et al. 2007, Kmiecik et al. 2004, Oscarsson and Savage 2007). Many vegetables, including those with a particularly high oxalate content, are generally consumed after culinary or technological processing. Since this is carried out with the use of water, the content of soluble oxalates in the vegetable is reduced as they are washed out into the medium; however, this decrease is negated if the water containing the leached oxalates forms part of the cooked product. The investigations usually concern vegetable species with high accumulations of these compounds. With the current tendency to reduce meat consumption, the increased proportion of vegetables in the diet may result in higher oxalate intake.

The aim of the work was to evaluate changes in the oxalate content of root vegetables after freezing by traditional and modified methods, the latter resulting in a convenience food product. A further aim was to evaluate oxalate content in vegetables prepared for consumption from frozen products directly after freezing and after 12-month storage at -20°C .

Materials and methods

Materials

The investigated material consisted of four root species: beetroot – *Beta vulgaris* L. (Czerwona Kula cv.); carrot – *Daucus carota* L. (Koral cv.); celeriac – *Apium graveolens* L. (Dukat cv.) and parsnip – *Pastinaca sativa* L. (Fagot cv.).

The content of components was determined in fresh vegetables (A), after blanching (B), after cooking in 2% brine to consumption consistency (C), and in frozen products after storage at -20°C and then prepared for consumption. Frozen products from sample B were cooked in brine, this yielding sample D (after 0 months of storage) and sample F (after 12 months of storage). Frozen products from sample C were defrosted and heated in a microwave oven, yielding sample E (after 0 months of storage) and sample G (after 12 months of storage).

Production of the raw material

The vegetables were grown in the experimental field of the Department carrying out the investigation. The field was in good horticultural condition; it lies on the western outskirts of Krakow in southern Poland. The cultivation was conducted on brown soil with the mechanical composition of silt loam in the third year after manure fertilization. The pH of the soil in H_2O was 7.08, with a humus content of 1.66%, nitrogen NO_3 24 mg dm^{-3} , phosphorus 53 mg dm^{-3} , potassium 101 mg dm^{-3} , and calcium 1020 mg dm^{-3} .

The fertility of the soil and the nutritional requirements of the crops having been taken into account, and doses of mineral fertilizers for all vegetables were as follows: nitrogen 60 kg (80 kg for celeriac) as ammonium nitrate 34%N, phosphorus P_2O_5 60 kg as superphosphate 46% P_2O_5 , and potassium K_2O 150 kg ha^{-1} as potassium chloride 60% K_2O . Cultivation measures included sprinkler watering, mechanical weed control and, where nec-

essary, protective treatments against diseases and pests. Vegetables were harvested in September and October 2009.

Directly after harvest, mean samples representing the whole batch of the material, 25–30 kg out of about 100 kg, were taken for analysis and preparation of frozen products. All the vegetables were cleaned in water. The investigation covered the following vegetables: beetroot about 6 cm in diameter; carrot 3–4 cm; celeriac 13–25 cm and parsnip 4–5 cm in diameter. The carrot, celeriac and parsnip were peeled; the carrot and celeriac were cut into cubes 10×10×10 mm and the parsnip into matchsticks 30×10×10 mm. After the processing described above (washing and appropriate cutting), the vegetables were ready for blanching or cooking. Before freezing, the raw vegetables (samples A) were blanched (samples B) or boiled (samples C). Beetroot was blanched and also cooked whole in the skin to protect it from loosing juice and natural color; then the beetroots were peeled and coarse grated.

Preparation of frozen products

Two methods of processing the raw materials before freezing were used. In method I, the traditional technology of blanching the raw material was applied; after freezing and refrigerated storage, the frozen product was cooked to consumption consistency. In method II, the raw material was cooked to consumption consistency to obtain a ready-to-eat product which, after freezing and refrigerated storage, only required to be defrosted and heated in a microwave oven.

In method I, 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 95–98 °C. The blanching time for the different species is given in Table 1. The blanching parameters applied enabled 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 cold water and left to drip on sieves for 30 min.

Table 1. Pre-treatment times of vegetables before freezing (blanched – B, cooked – C) and preparing frozen vegetables for consumption (from B by cooking – D and F; from C by defrosting and heating in a microwave oven – E and G).

Species	Vegetables before freezing		Frozen vegetables	
	B	C	D and F	E and G
Beetroot	15 min	35 min	— ^a	8 min 15 sec
Carrot	2 min 45 sec	12 min	6 min	8 min 15 sec
Celeriac	2 min 30 sec	8 min	5 min	8 min 15 sec
Parsnip	2 min 30 sec	10 min	4 min 30 sec	8 min 15 sec

^a The blanched frozen red beetroot was not cooked since it was regarded as a semi-finished product to be used in preparing beetroot soup (borsch); in this case it would be cooked in a different proportion to water while, and the vegetable and the fluid fractions would be utilized.

In method II, the vegetables were cooked in a stainless steel vessel in brine containing 2% added salt (NaCl), the proportion by weight of the raw material to brine being 1:1. The vegetables were placed in boiling water, and 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.

The materials from blanched and cooked samples were placed on trays and frozen at $-40\text{ }^{\circ}\text{C}$ in a Feutron 3626-51 blast freezer (Ilka Feutron, Germany). The time required for the inside of the product to reach $-20\text{ }^{\circ}\text{C}$ was 90 min. The frozen vegetables were then packed in 500 g polyethylene bags and stored for 12 months.

Preparation of frozen products for evaluation

Samples of vegetables blanched before freezing (sample B) 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 cooking time, measured from the moment when the water came to the boil again, is given in Table 2. After cooking, the water was immediately drained; the product was cooled to $20\text{ }^{\circ}\text{C}$ (samples D and F), and analyzed. Samples of vegetables cooked before freezing (sample C) were defrosted and heated in a Panasonic NN-F621 microwave oven (samples E and G). For microwave heating, a 500 g portion was placed in a covered heatproof vessel. The time required to defrost and heat the material to consumption temperature is given in Table 2. The samples were then cooled to $20\text{ }^{\circ}\text{C}$ and analyzed. All cooking experiments were carried out in duplicate.

Chemical analyses

All chemical analyses as well as cooking experiment were carried out in duplicate. Samples of fresh

and processed vegetables were homogenized and frozen at $-30\text{ }^{\circ}\text{C}$ and freeze-dried. The freeze-dried vegetables were stored in hermetically sealed vials at $-80\text{ }^{\circ}\text{C}$ until analysis. The level of dry matter was determined by the method given in AOAC (1990) to allow the calculation of oxalate content per 100 g dry matter.

Soluble and total oxalate contents of each sample of vegetable were extracted using the procedure described by Savage et al. (2000). For soluble oxalic acid extraction, 1–2 g samples of finely ground freeze-dried plant material were weighed into 250 ml beakers and 50 ml distilled water was added. The beakers were placed in a shaking water bath at $80\text{ }^{\circ}\text{C}$ for 15 min. The extract was allowed to cool and then transferred quantitatively to a 100 ml volumetric flask and made up to volume with distilled water. For total oxalic acid, 1–2 g samples of the freeze-dried material were weighed into a 250 ml beaker and 50 ml 2M HCl was added. The beakers were placed in a shaking water bath at $80\text{ }^{\circ}\text{C}$ for 15 min. The extract was allowed to cool and then transferred quantitatively to a 100 ml volumetric flask and made up to volume with 2M HCl.

An enzymatic method (Trinity Biotech 2008) proposed for the determination of oxalate content in urine was used to determine the soluble oxalate in raw and processed root vegetables. The same method was used in plant studies for example by Ilarslane et al. (1997) and Quinteros et al. (2003). This method is based on the oxidation of oxalate by oxalate oxidase action producing hydrogen peroxide. The H_2O_2 then reacted with 3-methyl-2-benzothiazolinone hydrazone (MBTH) and 3-(dimethylamino) benzoic acid (DMAB) in the presence of peroxidase to yield an indamine dye which has an absorbance maximum at 590 nm. An oxalate kit for the quantitative, enzymatic determination of oxalate in vegetables was used according to procedure No. 591 (Trinity Biotech 2008). Deionized water from a Millipore-MilliQ apparatus was used in the study.

The content of calcium was determined in mineralized, diluted and filtered samples by inductively coupled argon plasma emission spectrometry using JY 238 Ultrace apparatus (Jobin Yvon, France). The content of calcium was used

to calculate the oxalate:calcium ratio and calcium bound as calcium oxalate. On the assumption that all the insoluble oxalate is in the calcium oxalate, it was calculated as follows: the content of insoluble oxalates was converted into the quantity of oxalate acid moles, this corresponding to the quantity of calcium moles bound in the form of calcium oxalate. The quantity of grams of calcium bound in the form of oxalates was then calculated and converted into the percentage of bound calcium in relation to the calcium content in a sample. The percent true retention (%TR) was also calculated. This value was determined as the amount of oxalates remaining in the vegetables after technological and culinary treatments were applied. The calculation was carried out according to the formula given by Judprasong et al. (2006). For each sample, the raw material weight of the fresh vegetable and the weight after technological and culinary processing were determined.

Statistical analysis

All experiments were carried out in two independent experimental replications, and all chemical analyses were carried out in two parallel replications. The statistical analysis, which enabled a comparison of the oxalate content in the fresh raw material – in blanched and cooked material and in frozen material after preparation for consumption – was carried out using single-factor analysis of variance (ANOVA) on the basis of the Duncan test calculated at the probability level $p < 0.05$. The Statistica 6.1 (Stat-Soft Inc., Tulsa, OK, USA) programme was used.

Results and discussion

Content of total and soluble oxalates

According to Franceschi and Nakata (2005), the formation of oxalates is genetically controlled and hence different vegetable species contain different

amounts of these compounds. In the investigated root crops, the highest content of total and soluble oxalates was found in fresh and dry matter of beetroot (Table 2). Noonan and Savage (1999) and Santamaria et al. (1999) classified this species as an oxalate-accumulating vegetable. However, the values quoted in the literature vary considerably. Santamaria et al. (1999) report that the total content of oxalates in beetroot varied from 540–1088 mg 100 g⁻¹ fresh matter, while according to Savage et al. (2000), the content in beetroot was only 46 mg oxalates in 100 g fresh matter. Lower amounts of oxalates in carrot and celeriac than those found in the present investigation were reported by Hönow and Hesse (2002) and higher amounts by Santamaria et al. (1999).

The accumulation of oxalates in plants is associated with the activity of photosynthesis and, as the observations show, different tendencies in this process depend on the species and age of the plant as well as on the phase of growth (Franceschi and Nakata 2005, Poeydomenge and Savage 2007). Moreover, the oxalate content within a particular species depends on the conditions and year of growth (Bakr and Gawish 1997, Jaworska 2005a), as well as on the usable part of the plant (Kmieciak et al. 2004). The accumulation of oxalates is also influenced by the form of nitrogen fertilization: if the nitrogen is supplied in nitrate form, it has to undergo reduction through nitrate reductase before it is utilized by the plant. This process results in the production and accumulation of organic acids, including oxalic acid (Libert and Franceschi 1987). Investigations into different forms of fertilization revealed that a higher content of calcium in the substrate results in a reduced level of soluble oxalates in plants (Bakr and Gawish 1997).

The lowest proportion of soluble oxalates in total oxalates was found in celeriac (55%); this proportion was higher in the remaining vegetables, being broadly similar for each of them (68–78%). Savage et al. (2000) and Chai and Liebman (2005) reported that in many species the level of soluble oxalates exceeded that of insoluble oxalates. Soluble oxalates are potentially more harmful than insoluble since they reduce the nutritional availability of calcium in the organism and contribute

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Table 2. Dry matter content (DM, g 100g⁻¹), total oxalate and soluble oxalate content (mg 100 g⁻¹ of fresh matter – FM or dry matter – DM) and retention (%) in root vegetables (raw material – A; material before freezing: blanched – B, cooked – C; product prepared for consumption after freezing: from B by cooking – D, from C by defrosting and heating in microwave oven – E; product prepared for consumption after frozen storage: from B by cooking – F, from C by defrosting and heating in microwave oven – G).

Item	DM	Total oxalate				Soluble oxalate			
		FM ^a	%	DM ^a	%	FM ^a	%	DM ^a	%
Beetroot									
A	14.2	105 ± 10d	100	739 ± 69c	100	82 ± 10b	100	577 ± 69b	100
B	14.1	90 ± 6c	86	638 ± 43b	86	60 ± 7a	73	426 ± 49a	74
C	13.5	77 ± 6ab	73	570 ± 47ab	77	52 ± 7a	63	385 ± 55a	67
D	14.0	86 ± 9bc	82	614 ± 61b	83	55 ± 6a	67	393 ± 44a	68
E	14.2	74 ± 6a	70	521 ± 40a	71	49 ± 8a	60	345 ± 54a	60
F	14.0	73 ± 3a	70	521 ± 24a	71	48 ± 6a	59	343 ± 44a	59
G	14.1	76 ± 5ab	72	539 ± 37a	73	50 ± 7a	61	355 ± 51a	61
Carrot									
A	13.1	74 ± 6c	100	565 ± 43e	100	50 ± 5d	100	382 ± 41c	100
B	10.8	50 ± 5b	68	463 ± 42d	82	25 ± 4c	50	231 ± 32b	61
C	12.3	45 ± 6ab	61	366 ± 49b	65	19 ± 3ab	38	154 ± 27a	40
D	10.5	48 ± 5ab	65	457 ± 43cd	81	22 ± 3bc	44	210 ± 30b	55
E	12.9	46 ± 5ab	62	357 ± 35b	63	17 ± 3ab	34	132 ± 21a	34
F	10.4	42 ± 3a	57	404 ± 32bc	71	16 ± 3a	32	154 ± 25a	40
G	13.6	41 ± 3a	55	301 ± 24a	53	18 ± 2ab	36	132 ± 16a	35
Celeriac									
A	16.9	40 ± 4b	100	237 ± 23c	100	22 ± 4c	100	130 ± 22c	100
B	15.4	31 ± 4a	78	201 ± 29b	85	16 ± 3b	73	104 ± 17b	80
C	18.1	28 ± 3a	70	155 ± 18a	65	11 ± 2a	50	61 ± 10a	47
D	16.7	29 ± 3a	73	174 ± 15ab	73	16 ± 3b	73	96 ± 16b	74
E	18.8	30 ± 5a	75	160 ± 26a	67	13 ± 3ab	59	69 ± 14a	53
F	16.5	25 ± 3a	63	152 ± 18a	64	11 ± 2a	50	67 ± 10a	51
G	19.1	27 ± 3a	68	141 ± 16a	60	13 ± 2ab	59	68 ± 10a	52
Parsnip									
A	20.7	25 ± 2c	100	121 ± 8c	100	18 ± 2c	100	87 ± 8c	100
B	17.7	20 ± 2b	80	113 ± 10bc	93	12 ± 2b	67	68 ± 10ab	78
C	19.1	19 ± 2b	76	99 ± 12ab	82	10 ± 2ab	56	52 ± 11a	60
D	15.5	18 ± 2b	72	116 ± 14bc	96	12 ± 3b	67	77 ± 17bc	89
E	20.5	20 ± 2b	80	98 ± 9a	81	12 ± 3b	67	59 ± 13a	67
F	15.5	14 ± 2a	56	90 ± 15a	75	8 ± 2a	44	52 ± 10a	59
G	20.5	21 ± 3b	84	102 ± 13abc	85	11 ± 3b	61	54 ± 13a	62

^aMeans with different letters in the same column, within one species of vegetable, indicate significant differences ($p < 0.05$).

to the formation of renal calculi (Noonan and Savage 1999). Soluble salts are produced when oxalates bind with potassium, sodium or magnesium, magnesium salts being less soluble than potassium or sodium salts. Insoluble salts are formed when oxalates bind with calcium or iron (Noonan and Savage 1999).

Thermal processing with the use of water causes many changes due to the leaching of soluble constituents to the medium; the absorption or release of water; and the shrinking of the raw material, resulting in absolute or relative changes in the content of the constituents. In general, the above reactions are characterized by changes in the weight and content of dry matter. In the case of the investigated species, blanching in water brought about a significant decrease in the content of total and soluble oxalates both in fresh and dry matter, with the exception of total oxalate content in the dry matter of parsnip. The loss of total oxalates varied from 20–32% and that of soluble oxalates from 27–50% converted into fresh matter, and 7–18% and 20–39% respectively converted into dry matter. The results obtained by Bakr and Gawish (1997) showed that blanching in solutions of calcium citrate and sodium ascorbate instead of tap water brought about a higher loss of oxalates. The above authors claim that this was due to differences in the permeability of plant tissue in these solutions.

Cooking, a process which takes longer than blanching, increased the losses of total oxalates; however, these were only significant in the fresh matter of beetroot and the dry matter of carrot and celeriac. This may have been due to fact that in the latter two species cooking caused a much greater increase in the level of dry matter than blanching. Compared with blanching, cooking resulted in significant decreases in soluble oxalate content in the fresh and dry matter of carrot and celeriac. When Mosha et al. (1995) prolonged thermal processing, they observed increased losses in oxalates, as was also found in the present study; however, these were significant only in a few cases. It can be assumed that this was due to the low solubility of these compounds and their resistance to the effect of temperature (Baldwin et al. 1986). However, by prolonging the soaking time in water by

several dozen times, Savage and Dubois (2006) were able to show a progressive decrease in soluble oxalates from marginal quantities to 26% of their initial content. The blanching parameters applied in the present investigation were selected in order to minimize the activity of peroxidase and catalase. The cooking parameters were selected in order to obtain optimal consistency and to ensure that the frozen product after storage had all the traits of a convenience food; but also to retain the greatest possible quantities of antioxidative constituents (Gębczyński 2005, 2006a, 2006b).

Compared with the raw material before freezing, the level of the investigated compounds did not change significantly either in the traditional frozen product prepared for consumption by cooking in brine, or in the “convenience” frozen product after defrosting and heating to 70 °C in a microwave oven.

Frozen storage drastically curtails biochemical and chemical processes, and after 12 months of storage at –20 °C no regeneration of catalase and peroxidase was recorded. However, chemical reactions and changes in the permeability of cell membranes taking place during processing and storage may have increased the leaching of oxalates, the traditionally frozen product when prepared for consumption following frozen storage: after cooking it contained 12–22% less total oxalates and 13–43% less soluble oxalates compared with vegetables cooked directly after freezing. In the case of samples prepared for consumption in a microwave oven the changes varied from +5 to –11% and from +6 to –9% respectively. This variation could be evoked by increase in dry matter content and from the other side by the leaching with cell sap after heating. This change was not always significant. Compared with vegetables before freezing, oxalate content in the fresh matter of frozen products obtained using the traditional method was significantly reduced, except for total oxalate content in celeriac and soluble oxalate content in beetroot and parsnip. In products obtained using the modified method, a significant decrease in the content of oxalates was noted only in the dry matter of carrot. At the same time there were observed only small changes in calcium content (Table 3). The solubility of calcium could be

limited by such components of plants like phytic acid, some proteins or polyphenols (Hurrell 2003, Vitali et al. 2008).

Products obtained using the traditional method and prepared for consumption retained 57% and 32% (carrot) and 70% and 59% (beetroot) of total and soluble oxalates respectively compared with the content in the raw material. Products of the convenience food type usually contained slightly more oxalates, significant differences being found only in the case of total and soluble oxalates in the fresh matter of parsnip. Gębczyński (2005, 2006a, 2006b) reported that the retention of antioxidative compounds and the sensory evaluation were similar for the two types of product or slightly lower for frozen products of the convenience food type.

A much higher reduction in oxalates can be obtained if a high-calcium product, such as milk, is added during vegetable processing (Brogren and Savage 2003, Savage et al. 2009). Water with a high calcium content can play a similar role. The tap water used in the present experiment for processing and preparing vegetables for consumption contained 130–150 mg Ca dm⁻³, which, according to the data given by Belitz et al. (2004), can be classed as hard water containing 325–375 mg CaCO₃ dm⁻³.

Oxalate:calcium ratio, calcium bound as calcium oxalate and oxalate true retention

Fresh beetroots contained the highest amount of oxalates and the lowest amount of calcium, giving a high oxalate:calcium ratio (Table 3). In fresh carrot this ratio was almost halved, while in celeriac and parsnip it was five and eight times lower respectively. Nowadays, parsnip is not a popular species in spite of its attractive sensory traits and significant levels of antioxidative compounds (Gębczyński personal report). Parsnip's favorable oxalate:calcium ratio should recommend it for wider use.

The technological and culinary procedures applied had only an insignificant effect on the content of calcium (Table 3); however, as Table 2 shows,

they contributed to a decrease in oxalate content. Therefore, the oxalate:calcium ratio in the products prepared for consumption was always lower than in the raw material, the greatest decrease being noted in carrot.

There is no clear evidence that oxalates in food preferentially bind with calcium since some soluble fractions can be also bound with dietary fiber (Savage et al. 2000). On the assumption, however, that insoluble oxalates in vegetables are calcium oxalates, it is possible to calculate the content of calcium bound in that molecule (Oscarsson and Savage 2007). The results given in Table 3 show that the percentage of bound calcium depended on the species, but technological and culinary processing did not significantly affect this parameter. According to Brogren and Savage (2003), as much as 77% of calcium in spinach was bound in insoluble oxalates, while Oscarsson and Savage (2007) stated that differences in the amounts of bound calcium in taro leaves depended on their age.

As mentioned previously, the weight of vegetables was affected by technological and culinary treatments. Judprasong et al. (2006) suggest that changes in weight can be utilized to calculate the true retention (TR) of oxalates. The values in Table 3 calculated according to the formula given by Judprasong et al. (2006) show that in samples having undergone technological and culinary processing, the true retention of both total and soluble oxalates was lower than when calculated taking the content in 100 g fresh matter into account (Table 2), with the exception of blanched parsnip. Similar results were reported by Murphy et al. (1975) since in their opinion the apparent retention overestimated the TR. The results presented are among the few which reveal changes in the level of oxalates in the whole process of freezing vegetables and preparing them for consumption (Kmieciak et al. 2004, Jaworska 2005b).

Finally, hydrothermal processing, in this number blanching and cooking, decreased significantly oxalate level in studied vegetables. It is especially important for the beetroot which is one of the most important root vegetable for European consumers. Products of the convenience food type usually contained slightly more oxalates, compared to traditional products.

Table 3. Total calcium content, oxalate:calcium ratio, calcium bound as calcium oxalate and true retention of total and soluble oxalate in root vegetables (raw material – A; material before freezing: blanched – B, cooked – C; product prepared for consumption after frozen storage: from B by cooking – F, from C by defrosting and heating in microwave oven – G).

Item	Total calcium content (mg 100 g ⁻¹ fresh matter)	Oxalate:Calcium ratio	Calcium bound		True retention of	
			mg 100g ⁻¹ fresh matter	% of total calcium	total oxalates	soluble oxalates
Beetroot						
A	24.4	1.92	10.2	42	100	100
B	23.4	1.71	13.4	57	84	72
C	22.3	1.54	11.1	50	68	59
F	22.9	1.42	11.1	49	66	56
G	22.2	1.52	11.6	52	62	52
Carrot						
A	38.8	0.85	10.7	28	100	100
B	38.2	0.58	11.1	29	65	48
C	36.8	0.54	11.6	31	55	35
F	36.5	0.51	11.6	32	51	29
G	37.6	0.49	10.2	27	45	30
Celeriac						
A	46.1	0.39	8.0	17	100	100
B	45.9	0.30	6.7	15	77	72
C	41.3	0.30	7.6	18	66	47
F	38.2	0.29	6.2	16	59	47
G	42.3	0.28	6.2	15	58	51
Parsnip						
A	46.8	0.24	3.1	7	100	100
B	46.5	0.19	3.6	8	82	68
C	45.8	0.18	4.0	9	73	53
F	43.9	0.14	2.7	6	55	44
G	46.8	0.20	4.4	9	74	54

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