Available online at www.sciencedirect.com

SCIENCE DIRECT®

Food Chemistry 91 (2005) 737–743

Food Chemistry

www.elsevier.com/locate/foodchem

Contents of macro and microelements in fresh and frozen dill (*Anethum graveolens* L.)

Jacek Słupski, Zofia Lisiewska *, Waldemar Kmiecik

Department of Raw Materials and Processing of Fruit and Vegetables, Agricultural University of Krakow, 122 Balicka Street, 30-149 Krakow, Poland

Received 22 March 2004; received in revised form 30 June 2004; accepted 30 June 2004

Abstract

The level of ash and its alkalinity and the contents of potassium, sodium, magnesium, iron, phosphorus, zinc, copper, cadmium, and lead, were determined in green dill (leaves and whole plants, about 20 cm in height, harvest time). The two usable parts were frozen using variable pretreatments (blanching or no blanching) and different storage temperatures (−20 and −30 °C). Analyses were conducted after 0, 3, 6, 9, and 12 months of refrigerated storage. Fresh leaves contained more ash, magnesium, iron, phosphorus, zinc, cadmium and lead but less sodium and copper than whole plants, while the contents of potassium and calcium were similar. Blanching significantly reduced the level of ash and its alkalinity and of potassium, calcium, magnesium, phosphorus, zinc, copper, cadmium, and lead, both in the usable parts of the plant, and of sodium in whole plants and of iron in leaves. During the storage period, changes in the contents of the analysed constituents did not depend on the usable part or storage temperature, being statistically significant only for the contents of iron and copper in the two usable parts of frozen non-blanched dill.

Keywords: *Anethum graveolens*; Dill; Freezing; Storage; Ash; Minerals

1. Introduction

Apart from their rich contents of vitamin C and beta-carotene, leafy vegetables are an excellent source of mineral constituents whose importance in the human diet is undisputable. Some of them, such as potassium, sodium, phosphorus, calcium, magnesium, or iron, are indispensable in the sustainment of human health. Others, such as copper or zinc, are equally indispensable, but in this case the interval between the acceptable and toxic levels is limited (Kimura & Itokawa, 1990).

The consumption of green dill plants is not great, owing to their seasonal supply. However, in some European countries, green dill leaves are used as a basic component of soups and sauces and as an addition to cottage cheese, in which case the consumption significantly increases. The increasing demand for ready-to-eat food products also increases the demand for all spices. The supply of fresh dill is limited to the vegetation season; hence its preservation, in a form for easy use and for ensuring its supply throughout the year, is important. Simple methods for preserving leafy vegetables are drying and freezing, though drying is regarded as hardly acceptable in the case of vegetables of intense aroma such as dill (Lisiewska & Kmiecik, 1998; Kmiecik & Lisiewska, 1999).

The aim of the work was to determine the level of ash, its alkalinity, and the contents of some macro and microelements in fresh leaves and whole dill plants and in frozen usable parts, depending on the pretreatment, temperature, and time of refrigerated storage.

* Corresponding author. Tel.: +48 12 662 47 57; fax: +48 12 662 47 57.

E-mail address: rrlisiew@cyf-kr.edu.pl (Z. Lisiewska).

0308-8146/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2004.06.046

2. Materials and methods

2.1. Raw material

The raw material, dill cv. Amat, was harvested in the experimental field of the Department for carrying out the present investigation. The dill was grown on brown soil developed from lees formations of the mechanical composition of silt loam. The production was carried out in the second year, after stable manure fertilisation with pod plant as the forecrop. The soil in a good horticultural culture showed a reaction approximating neutral (pH in H_2O was 6.5), an average content of humus (1.55%), and high contents of phosphorus (83 mg/dm^3), potassium (160 mg/dm^3) and calcium (1320 mg/dm^3). In mineral fertilisation applied before sowing, the contents of different macrocomponents and the requirements of the species were taken into consideration. The following fertilizers were used: nitrogen – 30 kg N ha^{-1} in the form of ammonium nitrate, phosphorus – 15 kg P_2O_5 ha^{-1} in the form of triple superphosphate, and potassium – 30 kg K_2O ha^{-1} in the form of 60% potassium chloride.

Seeds were sown on August 10, in 2000. The sowing date was so adjusted as to ensure the harvest time on the turns of summer and autumn, thus permitting shortening of the storage period of frozen dill of the new harvest and reducing the costs of refrigerated storage. Prior to sowing, the seeds were treated with a mixture of Funaben I and Marshal 250 DS preparations. On the plantation, the cultivation measures included mechanical weeding and two sprayings with preparations controlling aphids and fungal diseases. The sprinkling irrigations (on September 8 with 15 mm of water) were used once the moisture in the soil decreased to an excessive degree. Favourable weather conditions prevailed throughout the growth of dill. The sum of temperature was 704 °C, the mean pentad temperature ranging from 13.7 to 25.1 °C, this with the fairly low precipitation beneficially affecting the sanitary condition of the plantation and the quality of the obtained yields.

The harvest carried out after 37 days, when the plants had reached about 25 cm in height, consisted of cutting plant tops about 5 cm above the soil. The harvested plants were therefore 20 cm in height. They were then surveyed for removal of individuals of discoloured or unhealthy appearance. It should be mentioned that the plants were healthy, traces of yellowing appearing only on single stunted leaves at the plant base. The dill plants were harvested in the morning and the time from cutting to the beginning of analyses and technological processing of the raw material did not exceed 2 h. The first measure was to separate the leaves from the remaining parts of the plants. It was determined that the leaves constituted 51% by weight of whole plants.

The investigation concerned: (1) two kinds of the raw material: leaves alone and whole dill plants, i.e., leaves with petioles and stems; (2) differentiated treatment before freezing, namely blanched and non-blanched samples; (3) differentiated temperatures of refrigerated storage, namely −20 and −30 °C; (4) time of refrigerated storage throughout the year, frozen products being analysed at 3 month intervals.

2.2. Preparation of the material for analyses and freezing

Non-blanched leaves were cut into 5–7 mm sections. A sample representative of whole non-blanched plants was prepared by mixing leaves (previously cut into 5–7 mm sections) with the stem and petioles strained through a sieve of 2 mm sieve mesh. The preparation of blanched samples consisted of blanching in water at 94–96 °C. The proportion of water to the blanched material was 5:1. The time of blanching was adjusted to that necessary for decreasing the activity of peroxidase to at least 95%. The planned decrease in activity was attained after 30 s in leaves and after 3 min in stems with petioles. After cooling in water and removing the remaining water by centrifugation to the weight equal to that before blanching, the leaves were cut into sections of 5–7 mm while petioles and stems were granulated, as in the case of the non-blanched dill. In blanched and non-blanched samples, the same proportion as in the raw material was maintained between the leaves and the stems with petioles.

2.3. Freezing and storage of frozen dill

Packing the dill in polythene bags 0.08 mm thick preceded its freezing. The content of a bag was 650 g of the raw material. The bags were pressed tightly to remove as much air as possible, then welded closely. Directly after closing, the product was frozen at −40 °C in a 3626-51 Feutron blast freezer with forced air circulation to a temperature of −20 °C and to a temperature of −30 °C. After freezing, the bags were placed in storage chambers at −20 and −30 °C, respectively, and kept there until the time of evaluation.

2.4. Measurements

In chemical analyses, all the samples cited in "Materials and methods" were taken into consideration. In each object investigated, the average evaluated sample contained 650 g of the material and the manner of sampling ensured its being representative of the entire lot of the dill. Analyses of the raw material were begun within 2 h of the harvest and of frozen products after the storage period appropriate to the method of the investigation. The samples for analysis were defrosted at 2–4 °C during 17–18 h. An average laboratory sample, representing a given combination of the experiment, was granulated in a laboratory food mixer in a weight ratio of 1 part dill to 1 part water.

The level of dry matter was determined by method given in AOAC (1984, 32.064). Content of ash was determined by incinerating in the Nabertherm model L 9/S 27 furnace oven at 460 °C. For the determination of individual mineral elements, the mineralization of dill material was carried out in a 3:1 mixture of nitric and perchloric acids. A 50 g portion of the material and 30 cm^3 of the acid mixture were placed in a 250 cm^3 test tube of the Tecator Kjeltec 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 water to a volume of 100 cm^3 and filtered into a dry flask. The content of the individual elements in the solutions was determined using the flame method in a Philips PU 9100X atomic absorption spectrophotometer. Phosphorus was determined using the method given in AOAC (1984, 3.098) and alkalinity of ash by the AOAC method (1984, 32.028).

2.5. Statistical analysis

Determination of the investigated components was carried out in four replications, average results being calculated per 100 g fresh matter. This form of presentation of results gives information concerning the level of a component in the product ready for consumption.

Data were statistically analysed by analysis of variance (ANOVA) to determine the effect of usable part of the plant and processing on mineral values. Treatment mean values were compared by the least significant differences method to determine which processing treatments caused a significant effect on mineral level compared to raw values.

3. Results and discussion

The content of dry matter per 100 g of dill most frequently quoted in the literature ranges from 7.9 to 14.9 g (Michalik & Dobrzański, 1987; Witkowska, Borawska, Omieljaniuk, & Markiewicz, 1996). However, the above authors did not describe the conditions or time of plant growing, the stage of growth, or the analysed dill parts. According to Kmiecik, Lisiewska, and Jaworska (2002), the content of dry matter was 11.7–17.9 g in 100 g of leaves and 9.0–16.2 g in leaves with petioles, depending on the growing period. The results of the present work are within the above limits, the dill leaves showing a significantly greater content of dry matter than that found in whole plants (Table 1). The leaves also contained significantly more ash than whole plants, but the difference was considerably smaller than in the case of dry matter. The content of ash determined by Tabekhia (1980) was lower than the present results, while that given by Kmiecik et al. (2002) was higher. In spite of the statistically different ash contents of leaves and whole plants, the alkalinities of these two usable parts were equal.

Srikumar (1993) gives a classification of the elements contained in vegetables. Potassium, sodium, calcium, magnesium and iron are classed as macroelements, zinc, copper, manganese and selenium as trace elements, and cadmium, lead and mercury as toxic. According to Kleszczewska and Kaczorowski (2001), the elements classified in the last group have no biological functions. Potassium dominated in ash, leaves and whole plants, showing similar contents of this element. In the literature (Varo, Lahelma, Nuurtamo, Saari, & Koivistoinen, 1980; Udagawa, 1995) the content of potassium in dill exceeded those found in the present work (Table 2). The leaves were characterised by greater contents of magnesium, iron and phosphorus 56%, 16% and 42%, respectively, than whole plants, the differences being significant in all these cases. The content of the discussed elements in dill given in the literature varies over very wide ranges: magnesium 14–110 mg in 100 mg fresh matter; iron 2.3–4.8 mg, and phosphorus 60–110 mg (Varo et al., 1980; Kunachowicz et al., 1999). Contrary to the elements discussed above, the content of sodium was found to be different, being significantly greater in whole plants than in leaves. In the investigated dill, the content of sodium was twice that given by Kunachowicz, Nadolna, Iwanow, and Przygoda (1999). The data on calcium content in dill given in the literature differ to a great degree. The content of calcium given by Kunachowicz et al. (1999) was 64 mg in 100 g fresh matter while according to Varo et al. (1980) it varied from 190–320 mg in 100 g fresh matter. The level of calcium in 100 g fresh dill, given in Table 2, was 129 mg for leaves and 139 mg for whole plants, differences between these values being statistically non-significant.

The leaves of different leafy vegetables were characterised by a greater content of mineral constituents than whole plants, petioles, or stems. In leafy beet the leaf blades contained 43% more ash than the petioles (Gębczyński, 1998, 1999) while the leaves of batata had 38–90% more ash than the stems, depending on the cultivar (Ishida et al., 2000). The results given by Ishida et al. (2000) show that batata leaves contained 35–89% more potassium, and two- to four-times more phosphorus, magnesium and iron. Spinach leaves contained more calcium and magnesium and three times more iron than the petioles (Oguchi, Weerakkody, Tanaka, Nakazawa, & Ando, 1996). Frossard, Bucher, Mächler, Mozafar, and Hurrell (2000) claim that in comparison with any other part of the plant, the higher content of elements in leaves is due to their high metabolic activity.

In comparison with whole plants, the leaves of dill accumulated significantly more zinc but less copper. With respect to zinc, the difference was 54% but to

Table 1
Contents of dry matter, ash and level of its alkalinity in raw and frozen dill, in fresh matter

Item	Usable part	Pre-treatment	Before freezing	After 12 months frozen storage at temperature		A
				−20 °C	−30 °C	
Dry matter g 100 g^{-1}	Leaves	Non-blanched	12.89 ± 0.17	13.08 ± 0.17	13.01 ± 0.17	0 ÷ +2
		Blanched	10.51 ± 0.23	10.77 ± 0.10	10.65 ± 0.10	−1 ÷ +3
	Whole plants	Non-blanched	9.49 ± 0.19	9.73 ± 0.14	9.65 ± 0.15	−1 ÷ +3
		Blanched	8.56 ± 0.15	8.74 ± 0.12	8.64 ± 0.12	−2 ÷ +2
				LSD = 0.299		
Ash g 100 g^{-1}	Leaves	Non-blanched	1.96 ± 0.10	1.99 ± 0.10	2.01 ± 0.10	−1 ÷ +3
		Blanched	1.37 ± 0.06	1.40 ± 0.06	1.37 ± 0.05	−1 ÷ +3
	Whole plants	Non-blanched	1.81 ± 0.06	1.89 ± 0.07	1.87 ± 0.04	−2 ÷ +4
		Blanched	1.30 ± 0.04	1.30 ± 0.06	1.29 ± 0.06	−3 ÷ +2
				LSD = 0.134		
Alkalinity of ash cm^3 0,1 M HCl 100 g^{-1}	Leaves	Non-blanched	17.5 ± 0.7	17.8 ± 0,5	18.0 ± 0.6	−3 ÷ +3
		Blanched	12.9 ± 0.5	13.0 ± 0.7	12.8 ± 0.6	−1 ÷ +4
	Whole plants	Non-blanched	17.2 ± 0.6	17.4 ± 0.6	17.2 ± 0.4	−2 ÷ +1
		Blanched	12.9 ± 0.4	13.0 ± 0.5	12.9 ± 0.5	−3 ÷ +2
				LSD = 1.16		

A, extreme percentage deviations from the content prior to freezing, determined during the refrigeration storage (analyses carried out after 0, 3, 6, 9, and 12 months).
x ± mean values and standard deviations of four replications LSD, $P = 0.01$.

copper only 17% (Table 3). However, Ishida et al. (2000) found that the leaves of batata accumulated more copper than the stems of this plant. The investigation carried out by Golcz and Dłubak (1998), on numerous dill samples from various regions of Poland and different growing periods, showed seven-times differentiation in the content of zinc and five-times that in the content of copper. The results of the present work are below the medium level of the values obtained by Golcz and Dłubak (1998). Szymczak, Ilow, and Regulska-Ilow (1993) classified dill among the vegetables accumulating zinc and copper, but greater contents of these elements were found in parsley and lettuce leaves (Golcz & Dłubak, 1998).

The leaves of dill also contained 22% more cadmium and 18% more lead than whole plants. The amounts determined in 1 kg fresh matter of dill were 0.023–0.028 mg cadmium and 0.124–0.146 mg lead. Extreme values given in the literature range from trace amounts to 0.067 mg cadmium and from 0.052 to 0.567 mg lead in 1 kg fresh matter of dill (Kowalska-Pyłka et al., 1995; Varo et al., 1980). Maximum contents of elements acknowledged as noxious in Poland are given in Government Regulations and Laws Gazette of the Polish Republic (2001). In accordance with the above regulation concerning fresh and frozen leafy vegetables, hence also dill, the admissible content of lead is 0.30 mg in 1 kg of the product, of cadmium 0.05 mg, and of zinc 10.0 mg. The respective amounts of these elements determined in the present work were: lead 41–48%, cadmium 46–56%, and zinc 57–87% of the admissible content, depending on analyses of either leaves or whole dill plants.

As shown by the results of the authors' so far unpublished works, the blanching of dill in water before freezing permitted the preservation of good quality frozen dill products during 12 months of storage at −20 °C; a decrease in the storage temperature to the level of −30 °C was unnecessary. As reported by Lyimo, Mugula, and Elias (1992) Kmiecik, Lisiewska, and Jaworska (2000), in the course of vegetable pretreatment with water, the leaching of mineral constituents depends, among other factors, upon their content in the treated material and on the water used for treatments, on the time taken by the treatment and the surface to weight ratio in the material. The following level of constituents, expressed in mg/dm^3, characterized the water used for blanching: $CaCO_3$ – 440 (water hardness), potassium – 48, sodium 34.5, calcium – 134, magnesium – 20.6, iron – 0.12, zinc – 1.11, copper – 0.71, cadmium – 0.003 and lead – 0.01. The above values were lower than those given in Government Regulations and Laws Gazette of the Polish Republic (2001). In the discussed experiment, the only variable was the material (leaves or whole plants) and hence, the surface: weight ratio.

The contents of all elements were reduced after blanching. Greater decreases by about 5–6% in the contents of magnesium, zinc, and lead, were noted in leaves rather than in whole plants. As far as the remaining elements are concerned, the decreases were very similar, though greater losses could have been expected in leaves, since the surface weight of the material exposed

Table 2
Contents of macroelements in raw and frozen dill, in fresh matter

Item	Usable part	Pre-treatment	Before freezing	After 12 months frozen storage at temperature		A
				−20 °C	−30 °C	
Potassium mg 100 g^{-1}	Leaves	Non-blanched	570 ± 16	556 ± 28	565 ± 20	−2 ÷ +2
		Blanched	385 ± 13	380 ± 13	376 ± 12	−2 ÷ +3
	whole plants	Non-blanched	552 ± 7	564 ± 12	569 ± 11	+1 ÷ +3
		Blanched	386 ± 6	376 ± 13	374 ± 14	−3 ÷ +1
				LSD = 28.3		
Sodium mg 100 g^{-1}	Leaves	Non-blanched	17.3 ± 1.1	16.7 ± 0.4	16.9 ± 0.4	−3 ÷ +1
		Blanched	16.0 ± 0.5	15.6 ± 0.5	15.5 ± 0.4	−3 ÷ +2
	whole plants	Non-blanched	24.4 ± 0.7	24.0 ± 0.7	23.8 ± 1.1	−2 ÷ +2
		Blanched	21.9 ± 1.1	20.9 ± 1.0	20.9 ± 0.9	−5 ÷ +0
				LSD = 1.51		
Calcium mg 100 g^{-1}	Leaves	Non-blanched	129 ± 10	126 ± 5	131 ± 5	−2 ÷ +4
		Blanched	114 ± 5	112 ± 3	110 ± 3	−4 ÷ +1
	whole plants	Non-blanched	139 ± 7	135 ± 5	133 ± 8	−5 ÷ +1
		Blanched	116 ± 5	115 ± 4	109 ± 3	−6 ÷ +2
				LSD = –12.2		
Magnesium g 100 g^{-1}	Leaves	Non-blanched	40.2 ± 1.2	40.9 ± 1.5	41.0 ± 1.7	−1 ÷ +4
		Blanched	32.8 ± 1.5	32.2 ± 0.7	32.7 ± 0.9	−2 ÷ +1
	whole plants	Non-blanched	25.7 ± 1.1	26.7 ± 1.4	26.3 ± 0.6	+1 ÷ +4
		Blanched	22.7 ± 0.7	22.7 ± 0.7	22.4 ± 0.4	−2 ÷ +1
				LSD = 2.36		
Iron mg 100 g^{-1}	Leaves	Non-blanched	4.29 ± 0.20	3.84 ± 0.11	4.00 ± 0.15	−10 ÷ +2
		Blanched	3.90 ± 0.15	3.72 ± 0.15	3.83 ± 0.11	−5 ÷ +2
	whole plants	Non-blanched	3.70 ± 0.13	3.29 ± 0.07	3.41 ± 0.15	−11 ÷ +0
		Blanched	3.48 ± 0.16	3.28 ± 0.07	3.33 ± 0.16	−5 ÷ +1
				LSD = 0.283		
Phosphorus mg 100 g^{-1}	Leaves	Non-blanched	63.6 ± 3.3	61.0 ± 3.6	63.3 ± 3.2	−5 ÷ +3
		Blanched	58.5 ± 2.4	60.0 ± 3.4	62.1 ± 2.4	0 ÷ +7
	whole plants	Non-blanched	44.7 ± 2.6	44.2 ± 1.6	41.6 ± 3.2	−7 ÷ +4
		Blanched	40.5 ± 2.1	42.1 ± 1.8	41.5 ± 2.4	+2 ÷ +4
				LSD = 4.43		

A, extreme percentage deviations from the content prior to freezing, determined during the refrigeration storage (analyses carried out after 0, 3, 6, 9, and 12 months).
x ± mean values and standard deviations of four replications LSD, $P = 0.01$.

to leaching is greater in the case of leaves than of whole plants. In both usable parts of plants, blanching caused greater losses in the level of ash and its alkalinity, and in potassium, zinc and copper by 29%, 27%, 33%, 27%, and 20%, respectively. Average and also similar losses were determined in calcium and magnesium, 14% and 15%, respectively, and in cadmium and lead, 13% each. The smallest but significant losses of 8–12% were noted in the contents of sodium, iron, and phosphorus. The determined amounts of heavy metals in raw material were considerably below their admissible level (Government Regulations & Laws Gazette of the Polish Republic, 2001) although, contrary to the remaining elements, their reduction caused by blanching can be regarded as beneficial.

The losses in ash content recorded in the work considerably exceeded the reduction caused by blanching in New Zealand spinach and leafy beet leaves and petioles, but they approximated to the results obtained for common spinach (Gębczyński, 1998, 1999; Jaworska & Kmiecik, 2000). As in the analysed dill, Lyimo et al. (1992) reported that iron was fairly resistant to leaching. Zurera and Moreno (1990) found less lead than in the raw material and a similar level of cadmium, while Amaro, Moreno, Zurera, and Sánchez (1999) found less iron and manganese but more copper and zinc. In the case of asparagus, blanching reduced the content of lead in heads by 37% and in shoots by 6% while it did not affect the content of cadmium, copper, or zinc (Amaro et al., 1999; Zurera & Moreno, 1990).

Table 3
Contents of microlements in raw and frozen dill, in fresh matter

Item	Usable part	Pre-treatment	Before freezing	After 12 months frozen storage at temperature		A
				−20 °C	−30 °C	
Zinc mg kg^{-1}	Leaves	Non-blanched	8.72 ± 0.36	8.39 ± 0.64	8.46 ± 0.38	−3 ÷ +1
		Blanched	6.10 ± 0.24	6.02 ± 0.20	5.89 ± 0.19	−3 ÷ +1
	whole plants	Non-blanched	5.67 ± 0.20	5.49 ± 0.10	5.36 ± 0.19	−5 ÷ +0
		Blanched	4.25 ± 0.17	4.18 ± 0.18	4.01 ± 0.15	−6 ÷ +2
				LSD = 0.589		
Copper mg kg^{-1}	Leaves	Non-blanched	2.16 ± 0.07	1.98 ± 0.08	1.96 ± 0.08	−9 ÷ +0
		Blanched	1.75 ± 0.05	1.69 ± 0.06	1.67 ± 0.11	−5 ÷ +2
	whole plants	Non-blanched	2.62 ± 0.09	2.46 ± 0.09	2.46 ± 0.07	−6 ÷ +1
		Blanched	2.08 ± 0.05	1.96 ± 0.07	1.95 ± 0.05	−6 ÷ −3
				LSD = 0.153		
Cadmium mg kg^{-1}	Leaves	Non-blanched	0.028 ± 0.002	0.027 ± 0.000	0.026 ± 0.001	−7 ÷ +0
		Blanched	0.024 ± 0.002	0.023 ± 0.001	0.023 ± 0.001	−4 ÷ +2
	whole plants	Non-blanched	0.023 ± 0.001	0.021 ± 0.001	0.022 ± 0.002	−9 ÷ +0
		Blanched	0.020 ± 0.001	0.018 ± 0.001	0.018 ± 0.001	−10 ÷ +0
				LSD = 0.0025		
Lead mg kg^{-1}	Leaves	Non-blanched	0.146 ± 0.005	0.151 ± 0.007	0.149 ± 0.007	−3 ÷ +3
		Blanched	0.122 ± 0.008	0.125 ± 0.004	0.126 ± 0.004	−1 ÷ +4
	whole plants	Non-blanched	0.124 ± 0.003	0.127 ± 0.003	0.129 ± 0.005	0 ÷ +4
		Blanched	0.110 ± 0.005	0.114 ± 0.003	0.112 ± 0.003	0 ÷ +4
				LSD = 0.0105		

A, extreme percentage deviations from the content prior to freezing, determined during the refrigeration storage (analyses carried out after 0, 3, 6, 9, and 12 months).
x ± mean values and standard deviations of four replications LSD, $P = 0.01$.

Changes in dry matter content, ash and its alkalinity, and in the analysed elements recorded during the refrigerated storage, were non-significant except for copper and iron in samples not blanched before freezing. Thus the Tables contain only the values observed during the entire storage period (Tables 1–3). Therefore, to check the pattern of variation in the level of the investigated elements, the extreme deviations from the level before freezing were given (A values in the Tables). The calculations took into consideration the level of a given elements after 3, 6, 9, and 12 months at the two storage temperatures. The greatest variations in the A values were noted for iron −11–+2%, copper −9–+2%, and cadmium −10–+2%, much lower values being found for the remaining constituents. During the refrigerated storage of asparagus, Amaro, Moreno, and Zurera (1998) observed a significant decrease in the contents of iron and copper but also in the contents of potassium, manganese and zinc. A statistically non-significant increase in the contents of phosphorus and no changes in the levels of sodium and calcium were also recorded.

In the frozen dill product stored for 12 months, the preserved content of ash was 70–104%, of potassium 66–103%, sodium 83–98%, calcium 78–102%, magnesium 80–106%, iron 87–94%, phosphorus 91–98%, zinc 68–97%, copper 75–95%, cadmium 78–96%, and lead 86–104%, depending on the usable part analysed, the reference product being fresh non-blanched dill. In frozen beans, the preservation of the investigated elements ranged from 73–171% (Lopez & Williams, 1985), in frozen artichoke 81–112%, French beans 67–93%, and in peas 77–149% (Polo, Lagarda, & Farre, 1992). It appears that no regularity was found showing a better or worse preservation of any of the elements in frozen vegetable species.

Acknowledgements

This work was carried out within the project 3 P06T 01922 supported by the State Committee for Scientific Research.

References

Amaro, M. A., Moreno, R., & Zurera, G. (1998). Nutritional estimation of changes in mineral content during frozen storage of white asparagus. *Journal of Food Quality, 21*, 445–458.

Amaro, M. A., Moreno, R., Zurera, G., & Sánchez, P. J. (1999). Nutritional changes in the essential trace elements content of asparagus during industrial processing. *Food Research International, 32*, 479–486.

AOAC. (1984). *Official Methods of Analysis*. 14th ed. Arlington, VA, USA: Association of Official Analytical Chemists.

Frossard, E., Bucher, M., Mächler, F., Mozafar, A., & Hurrell, R. (2000). Potential for increasing the content and bioavailability of Fe, Zn, and Ca in plants for human nutrition. *Journal of the Science of Food and Agriculture, 80*, 861–879.

Gębczyński, P. (1998). Wpływ wybranych czynników technologicznych na jakośćmrożonych ogonków buraka liściowego (English summary). *Zeszyty Naukowe Akademii Rolniczej w Krakowie, seria Technologia Żywności, 10*, 41–48.

Gębczyński, P. (1999). Ocena przydatności blaszek liściowych buraka liściowego (*Beta vulgaris v. cicla*) do mrożenia (English summary). *Zeszyty Naukowe Akademii Rolniczej w Krakowie, seria Technologia Żywności, 11*, 139–147.

Golcz, A., & Dłubak, S. (1998). Zawartość metali ciężkich w wybranych gatunkach warzyw (English summary). *Roczniki Akademii Rolniczej w Poznaniu, seria Ogrodnictwo, 27*, 95–99.

Government Regulations and Laws Gazette of the Polish Republic. (2001) *Rozporządzenie Ministra Zdrowia z dnia 27 grudnia 2000 roku w sprawie wykazu dopuszczalnych ilości substancji dodatkowych i innych substancji obcych dodawanych do środków spożdown ywczych lub używek, a także zanieczyszczeń, które mogą znajdować się wśrodkach spożywczych lub używkach*. nr 9, poz. 72, Warszawa. (non-English).

Ishida, H., Suzuno, H., Sugiyama, N., Innami, S., Tadokoro, T., & Maekawa, A. (2000). Nutritive evaluation on chemical components of leaves, stalks and stems of sweet potatoes (*Ipomoea batatas* poir). *Food Chemistry, 68*, 359–367.

Jaworska, G., & Kmiecik, W. (2000). Comparison of the nutritive value of frozen spinach and New Zealand spinach. *Polish Journal of Food and Nutrition Sciences, 9/50*, 79–84.

Kimura, M., & Itokawa, Y. (1990). Cooking losses of minerals in foods and its nutritional significance. *Journal of Nutrition Science and Vitaminology, 36*, S25–S33.

Kleszczewska, E., & Kaczorowski, W. (2001). Korzystny i niekorzystny wpływ metali ciężkich na organizm ludzki. Nikiel i ołów (English summary). *Żywienie Człowieka i Metabolizm, 28*, 370–377.

Kmiecik, W., & Lisiewska, Z. (1999). Effect of pretreatment and conditions and period of storage on some quality indices of frozen chive (*Allium schoenoprasum* L.). *Food Chemistry, 67*, 61–66.

Kmiecik, W., Lisiewska, Z., & Jaworska, G. (2000). Content of ash components in the fresh and preserved broad bean (*Vicia faba* v. major). *Journal of Food Composition and Analysis, 13*, 905–914.

Kmiecik, W., Lisiewska, Z., & Jaworska, G. (2002). Effect of biological and agrotechnical factors on the chemical composition of dill (*Anethum graveolens* L.). *Electronic Journal of Polish Agricultural Universities, series Food Science and Technology*, Available: http://www.ejpau.media.pl/series/volume5/issue1/food/art-06.html.

Kowalska-Pyłka, H., Kot, A., Wierciński, J., Kursa, K., Wałkuska, G., & Cybulski, W. (1995). Zawartość ołowiu, kadmu, miedzi i cynku w warzywach, owocach agrestu oraz glebie ogrodów działkowych Lublina (English summary). *Roczniki Państwowego Zakładu Higieny, 46*, 3–12.

Kunachowicz, H., Nadolna, I., Iwanow, K., & Przygoda, B. (1999). *Wartość odżywcza wybranych produktów spożywczych i typowych potraw*. Państwowy Zakład Wydawnictw Lekarskich, Warszawa. 288. (non-English).

Lisiewska, Z., & Kmiecik, W. (1998). Dependence of dried chive (*Allium schoenoprasum* L.) quality upon the drying method and storage period. *Electronic Journal of Polish Agricultural Universities, series Food Science and Technology*, Available: http://www.ejpau.media.pl/series/volume1/food/art-06.html.

Lopez, A., & Williams, H. L. (1985). Essential elements and cadmium and lead in fresh, canned, and frozen green beans (*Phaseolus vulgaris* L.). *Journal of Food Science, 50*, 1152–1157.

Lyimo, M., Mugula, J., & Elias, T. (1992). Nutritive composition of broth from selected bean varieties cooked for various periods. *Journal of the Science of Food and Agriculture, 58*, 535–539.

Michalik, H., & Dobrzański, W. (1987). Jakość liści warzyw suszonych metodą owiewową i sublimacyjną (non-English). *Przemysł Fermentacyjny i Owocowo-Warzywny, 6*, 30–32.

Oguchi, Y., Weerakkody, W. A. P., Tanaka, A., Nakazawa, S., & Ando, T. (1996). Varietal differences of quality related compounds in leaves and petiols of spinach grown at two locations. *Bulletin of the Hiroshima Prefectural Agriculture Research Center, 64*, 1–9.

Polo, M. V., Lagarda, M. J., & Farre, R. (1992). The effect of freezing on mineral element content of vegetables. *Journal of Food Composition and Analysis, 5*, 77–83.

Srikumar, T. S. (1993). The mineral and trace element composition of vegetables, pulses and cereals of southern India. *Food Chemistry, 46*, 163–167.

Szymczak, J., Ilow, R., & Regulska-Ilow, B. (1993). Zawartość miedzi i cynku w warzywach, zbożach i owocach pochodzących z terenu o zróżnicowanym zanieczyszczeniu przemysłowym oraz ze szklarni (English summary). *Roczniki Państwow ego Zakładu Higieny, 44*, 347–359.

Tabekhia, M. M. (1980). Total and free oxalates calcium, magnesium and iron contents of some fresh vegetables. *Deutsche Lebensmittel-Rundshau, 76*, 280–282.

Udagawa, Y. (1995). Some responses of dill (*Anethum graveolens*) and thyme (*Thymus vulgaris*), grown in hydroponic, to the concentration of nutrient solution. *Acta Horticulturae, 396*, 203–210.

Varo, P., Lahelma, O., Nuurtamo, M., Saari, E., & Koivistoinen, P. (1980). Mineral element composition of Finnish foods. VII. Potato, vegetables, fruits, berries, nuts and mushrooms. *Acta Agriculturae Scandinavica*(Supplement 22), 89–113.

Witkowska, A., Borawska, M., Omieljaniuk, N., & Markiewicz, R. (1996). Zawartość błonnika pokarmowego całkowitego w wybranych warzywach (English summary). *Bromatologia i Chemia Toksykologiczna, 29*, 135–138.

Zurera, G., & Moreno, R. (1990). Lead and cadmium content in fresh and canned asparagus. *Journal of Food Quality, 13*, 225–232.