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COMPARISON OF THE NUTRITIONAL VALUE AND STORAGE LIFE OF CARROT ROOTS FROM ORGANIC AND CONVENTIONAL CULTIVATION

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Summary

In the years 2008-2011, research was conducted whose objective was to assess the nutritional value and storage life of the roots of the carrot cultivars Perfekcja and Regulska grown in conventional and organic systems. The carrot roots came from a certified experimental field with a stable ecosystem adapted to conducting research on the organic cultivation of vegetables. In parallel, in the same climatic conditions, carrots were grown in the conventional system. The carrot roots were stored at a temperature of 0-1°C and relative humidity of 95-98%. Immediately after harvest and after several months of storage, the carrot roots were analyzed for dry matter content, total sugars, β-carotene, and nitrates. The results of the qualitative chemical assessment of the carrots showed no significant differences in the levels of dry matter and total sugars depending on the cultivar and the cultivation and storage methods (on average for three years). The carrots grown by the conventional method contained significantly more β-carotene than the carrots grown by the organic method, both before and after storage. It was found that the roots of the carrot cultivar Regulska had a higher β-carotene content than the roots of the cultivar Perfekcja grown in both the organic and conventional systems. The nitrate content in carrot roots immediately after harvesting both cultivars grown in the conventional system was significantly higher than in the roots from organic cultivation and ranged from 349.9 to 554.4 $mg \cdot kg^{-1}$. There were marked differences in storage life depending on the cultivar, cultivation method and storage period. A higher percentage of marketable roots after storing the cultivars Regulska and Perfekcja was achieved from conventional cultivation compared with organic cultivation. Losses (diseased roots and weight losses) were higher for the organic carrots than for those grown conventionally. There was a markedly higher percentage of marketable roots among the carrots of the cultivar Regulska compared with Perfekcja. For the cultivar Perfekcja, more diseased roots were found among the organically grown carrots. For the cultivar Regulska, the highest

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weight losses were recorded following the storage of the roots from organic cultivation.

key words: carrot roots, organic cultivation, biological value, storage life

INTRODUCTION

Recently, Poland has seen a steady rise in the popularity of organic agriculture as an alternative to the conventional method of food production. For the consumer, organic farming methods are a guarantee of obtaining safe food with high quality parameters (Meier-Ploeger 2005). This is because this kind of food contains considerably less of the compounds harmful to health, such as residues of pesticides and mineral fertilizers, especially nitrates, i.e. compounds widely used in conventional agriculture (Woese *et al.* 1997). This results from the basic principles of organic production, in which no synthetic pesticides or fertilizers are employed (Woese *et al.* 1997). Many studies conducted in Europe, including Poland, indicate that organically grown vegetables contain many bioactive compounds valuable to human health. Many authors claim that the differences in the chemical composition of plants grown in the two systems: organic and conventional, can be explained by different metabolic processes of these plants. Higher levels of bioactive compounds in vegetables from organic production can be explained by the ratio of carbon to nitrogen (C/N). In environments that are poor in readily available nitrogen, i.e. in organic systems, plants first synthesize carbon compounds (simple and complex sugars, organic acids, vitamins, pigments, phenolic compounds). By contrast, in environments rich in readily available nitrogen, the first compounds to be synthesized in plants are those represented by amino acids, peptides, proteins and alkaloids (Coley *et al.* 1985, Herms & Mattson 1992).

The carrot has a particularly important place in human nutrition. Its consumption has increased over the past few years mainly because of its high nutritional value and low energy value. The carrot root is known for its healthy properties, which it owes to high levels of antioxidant compounds such as β-carotene, α-carotene and lutein (Grajek 2007). β-carotene gives the carrot root its typical orange-red colour. The β-carotene content in the root is affected by: the stage of maturity, the cultivar, climate and soil conditions, harvest date and storage conditions. The largest amounts of β-carotene are accumulated by carrots at moderate temperatures, i.e. 15-21°C (Elkner 2003). The taste of the carrot is influenced by a variety of compounds, mainly sugars, which give the roots their sweet taste, and terpenes, which give them the characteristic bitterness. Sugars accumulate in the roots just before the end of the growing season and give them a nice sweet taste (Grajek 2007).

Studies show that 50-80% of the nitrates in foods comes from the vegetables we consume (Wojciechowska 2005). The presence in plants of certain quantities of nitrates(III) (i.e. nitrites) and nitrates(V) is normal because it is a consequence of the

natural nitrogen cycle in nature. Nitrates(V) are classed as not very toxic compounds and do not constitute a direct threat to the consumer's health. They are quite quickly absorbed from the digestive tract and excreted unchanged in the urine (Niewczas *et al.* 2006). The negative effect of nitrates on the condition of the body results from the fact that under the influence of digestive enzymes they are transformed into nitrites, i.e. nitrates(III), and these in turn into carcinogenic N-nitro compounds. In the human body, about 5% of ingested nitrates(V) is reduced to nitrates(III) (Gułajski 2002, Wojciechowska 2005). Nitrates also have a destructive effect on vitamins A and B, and carotenoids, which lowers the nutritional value of vegetables (Smoczyński & Skibniewska 1996).

According to Mazza (1989), the most important attributes of the commercial value and quality of the carrot is the size, shape, colour, texture, and the sensory quality and biological value of the root. As reported by Holden *et al.* (1999), carrot roots contain about 12% dry matter, 4.5% sugars, 2% fibre, 5.7 $mg \cdot 100g^{-1}$ β-carotene and 5.9% vitamin C. The amounts of chemical compounds in carrot roots are dependent on many factors, including the cultivar, climate and soil conditions, harvest date and storage conditions (Warman & Havard 1997). Suojala (2000) reports that carrot roots stored at a low constant temperature are characterized by a low rate of respiration and therefore longer storage life.

Several research centers have conducted studies comparing the quality parameters of carrots from organic and conventional crops, but there are not many reports that would present a 3-year study on the same cultivars of carrot grown simultaneously in two different cultivation systems. For this reason, it was deemed appropriate to undertake the study presented here.

MATERIALS AND METHODS

Two cultivars of carrot were selected for the study - Perfekcja and Regulska (PNOS Ożarów), grown on ridges at a density of 900 thousand plants/ha. The carrots were from a certified experimental field with a stable ecosystem adapted to conducting research on the organic cultivation of vegetables. At the same time, in the same soil and climatic conditions, carrot plants were also grown in the conventional system. The type of soil in the experimental field was sandy loam of soil quality class IVa. The soil pH was 5.7-6.0, organic matter content 1.7%. In the organic field, carrots were grown on a plot previously under wheat (2009) or zucchini (2010), and fertilized the following spring (April 20) with compost at 30 and 20 $t \cdot ha^{-1}$, respectively. In the conventional field, the forecrop for carrot was a cereal-legume mixture. Soil fertilization was based on the results of soil analysis. The nutrient content in the soil was supplemented with mineral fertilizers to the level of N-80, P-60 and K-150 mg/dm^3. Nitrogen was applied in the form of urea (pre-season - 2/3 of dose), and ammonium nitrate (top-dressing - 1/3 of dose). In conventional cultivation, chemical protection against pests and diseases was carried out according to standard recommendations, while in organic cultivation, two preventive treatments

with a grapefruit extract (Grevit) were performed.

Data concerning the average monthly temperatures and total precipitation during the vegetation period are shown in Table 1. The highest average temperatures and the highest amounts of rainfall during the period April-September were recorded in 2010.

Table 1. Characteristics of weather conditions during the growing season: Skierniewice 2008-2010 meteorological data

Month	Average temperature (°C)			Total precipitation (mm)		
	2008	2009	2010	2008	2009	2010
April	8.86	8.86	9.58	36.6	36.6	19.4
May	13.05	12.7	13.16	58.2	50.4	129.0
June	18.03	15.0	17.66	18.0	127.8	38.0
July	18.87	19.3	21.65	81.2	80.6	68.2
August	18.03	18.4	19.63	69.6	41.8	82.8
September	11.98	14.7	12.39	45.8	27.4	88.2

Meteorological data were obtained from the Meteorological Station in Skierniewice, a facility of the Institute of Meteorology and Water Management

Immediately after harvest and after storage, the carrot roots were subjected to chemical analyses to determine the amounts of dry matter by the gravimetric method, total sugars by the Luff-Schoorl method, β-carotene by the colorimetric method (Umiel & Gabelman 1971), and nitrates by potentiometry.

The storage period in the 2008/2009 season was 7 months, in 2009/2010 - 6 months, and in 2010/2011 - 7 months. The storage experiment was carried out with carrot roots selected with respect to size and shape. According to Adamicki & Czerko (2002) and Gajewski (2005), selection of carrot roots for storage is important. By selecting roots that are healthy, well-formed, undamaged and not withered, the development of fungal diseases of the genus *Botrytis* and *Sclerotinia* can be restricted.

The experimental combinations consisted of four replications with 10 kg of carrots each. The carrot roots were stored at 0°C and relative humidity of 95-98%. These values are reported in the literature as optimal for long-term storage of carrot roots (Adamicki & Czerko 2000, Gajewski 2005).

The roots were stored in wooden '1/2' crates lined with polyethylene film to maintain a high relative humidity level inside them. After storage, the roots were sorted according to the established methodology of the experiments, and the percentage of the following fractions was calculated:

- roots that had not sprouted leaves,
- roots that had sprouted leaves,
- roots that had sprouted leaves and new lateral roots,
- roots that had sprouted roots,
- diseased roots.

Also determined was the percentage of natural weight losses and the quantity of marketable roots in each combination. Marketable carrot roots were those that had not sprouted leaves and with leaves and new lateral

roots. Losses consisted of diseased roots and weight losses.

The results were analyzed with analysis of variance in the univariate system. Mean values were compared using the Newman-Keuls test at the significance level of α=0.05.

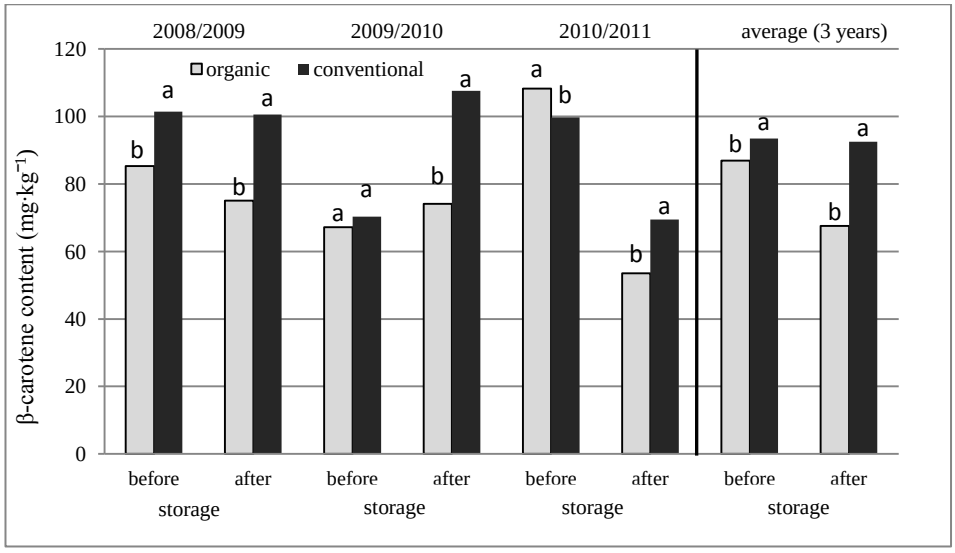
RESULTS AND DISCUSSION

The amounts of dry matter and total sugars in carrot roots immediately after harvest and after storage are presented in Table 2. In the 3-year study, the dry matter content immediately after harvest was slightly higher in the carrots from organic cultivation compared with the conventional crop, but the differences were not statistically significant. After storage, more dry matter was found in the roots of carrots grown in the conventional system, but these differences were also statistically insignificant. The dry matter content of vegetables depends on the properties of the soil, the cultivated variety, weather conditions, the vegetation period, and the type and dose of fertilizer (Rembiałkowska 2000a). It has been found that nitrogen fertilization in conventional cultivation increases the water content in vegetables, resulting in a lower dry matter content (Prędka & Gronowska-Senger 2009). In most comparative studies, it has been shown that the dry matter content in various vegetables, such as potatoes, carrots, white cabbage, were higher in organic vegetables, but the differences were not always statistically significant (Hagel *et al.* 2000, Rembiałkowska 2000, Velimirov 2005, Camin *et al.* 2007). In terms of the total sugar content it also turned out that the method of cultivation and the cultivar had no significant effect on this characteristic in carrot roots immediately after harvest, although the organic carrots contained slightly more total sugars compared with the conventionally grown carrots. Higher amounts of them were also found after storage in the carrot roots grown in the organic system. Similar results were obtained by Abele (1987), who found that organic carrots were characterized by higher levels of dry matter and total sugars. In both cultivation systems, the cultivar Regulska was characterized by slightly higher amounts of dry matter and total sugars in relation to the cultivar Perfekcja.

The 3-year study showed that the average β-carotene content in carrot roots depended on the cultivar and the cultivation method. The carrots grown by the conventional method contained significantly more β-carotene than the carrots grown by the organic method, both immediately after harvest and after storage (Fig. 1 & 2). After storage, an increase in β-carotene content was observed in the two cultivars irrespective of the method of cultivation. It was found that the roots of the carrot cultivar Regulska had a higher β-carotene content than the roots of the cultivar Perfekcja cultivated both in the ecological system and the conventional one. The reports by many authors contain discussions on the differences in the levels of β-carotene in organic and conventional carrots. Abele (1987) and Warman and Havard (1997) found no significant differences in β-carotene content between organically and conventionally grown carrots. On the other hand, Rembiałkowska (2000b) showed that

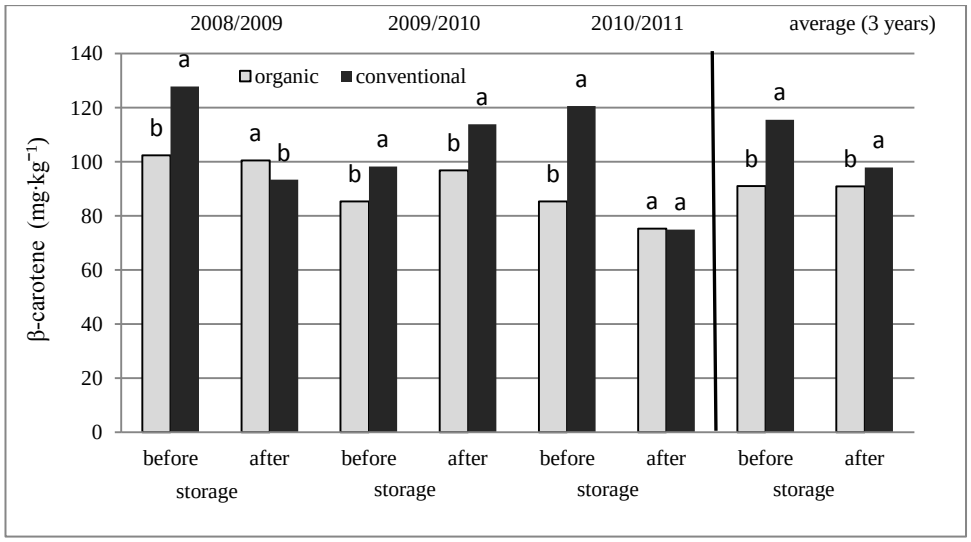
two cultivars, Regulska and Montana, contained significantly more β-carotene when they were grown in the conventional system. Opposing this are reports by Evers (1989) and Rembiałkowska and Hallmann (2007), who found that the opposite was true, i.e. that organic carrots were richer in β-carotene.

The nitrate content in the carrot roots immediately after harvesting both cultivars grown in the conventional system was significantly higher than in the roots from organic cultivation and ranged from 349.9 to 554.4 mg·kg^{-1}. In the carrot roots grown in the organic system, the nitrate content immediately after harvest ranged from 259.1 to 374.7 mg·kg^{-1} (Fig. 3 & 4). Moćko & Wacławek (2005) also found higher levels of nitrates in carrot roots grown in the conventional system than the organic one. After storage, a significant decrease in nitrate content was observed in carrots from both cultivation systems. The cultivar Regulska contained higher amounts of nitrates than the cultivar Perfekcja. It has been proven that the carrot, as opposed to other vegetables, accumulates the largest amounts of nitrates(V) in the autumn and winter (Gajewska *et al.* 2009).



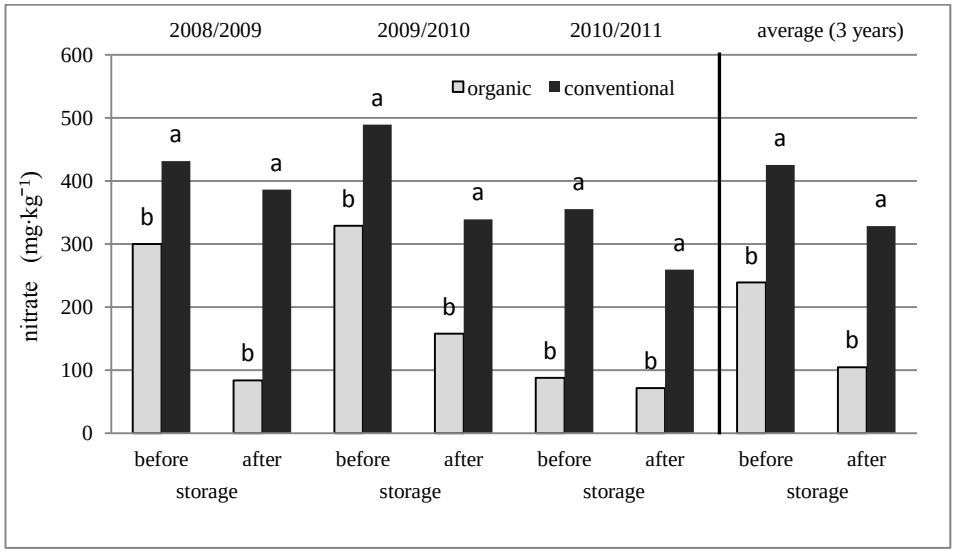
Note: The Newman-Keuls test
* Mean values marked with the same letters are not significantly different at α=0.05

Fig. 1. β-carotene content (mg·kg^{-1}) in the roots of carrot cultivar Perfekcja from organic and conventional cultivation, before and after storage in the years 2008-2011



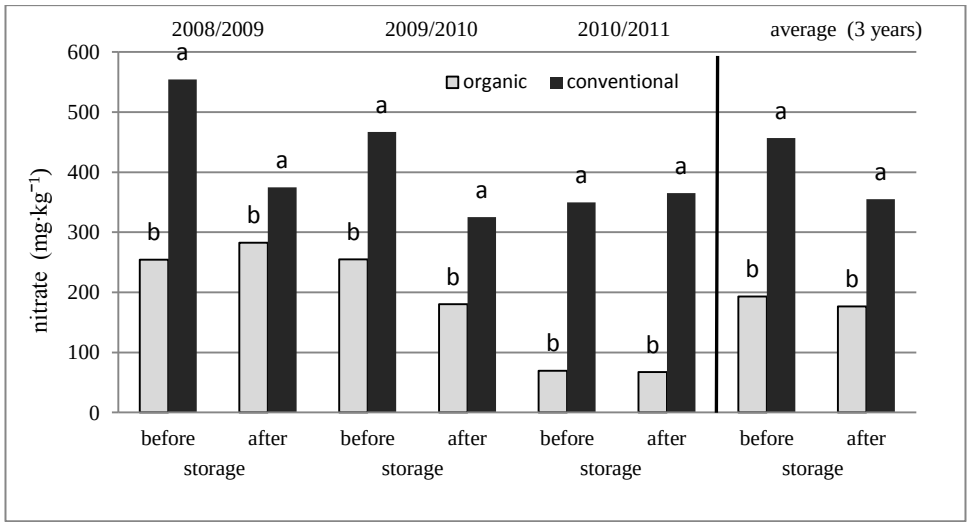
Note: see Fig. 1.

Fig. 2. β-carotene content (mg·kg^{-1}) in the roots of carrot cultivar Regulska from organic and conventional cultivation, before and after storage in the years 2008-2011



Note: see Fig. 1.

Fig. 3. Nitrate content (mg·kg^{-1}) in the roots of carrot cultivar Perfekcja from organic and conventional cultivation, before and after storage in the years 2008-2011



Note: see Fig 1.

Fig. 4. Nitrate content (mg·kg^{-1}) in the roots of carrot cultivar Regulska from organic and conventional cultivation, before and after storage in the years 2008-2011

Table 2. Dry matter content (%) and total sugars (%) in the roots of carrot cultivars Perfekcja and Regulska grown in organic and conventional systems in the years 2008-2011

Cultivation method	Cultivar	Years	Dry matter (%)		Total sugars (%)	
			before storage	after storage	before storage	after storage
organic	Perfekcja	2008/2009	12.11	12.65	6.49	7.06
		2009/2010	11.15	10.53	6.31	5.50
		2010/2011	13.73	12.28	7.56	7.40
		mean	12.33	11.82	6.79	6.65
	Regulska	2008/2009	13.76	12.56	7.81	6.98
		2009/2010	12.49	11.71	6.65	6.33
		2010/2011	13.99	12.32	8.29	6.94
		mean	13.41	12.20	7.58	6.75
Mean for organic			12.87a	12.01a	7.18a	6.7a
conventional	Perfekcja	2008/2009	12.33	12.06	6.84	6.61
		2009/2010	11.52	12.33	6.29	6.65
		2010/2011	12.68	12.34	7.14	6.70
		mean	12.18	12.24	6.76	6.65
	Regulska	2008/2009	13.86	12.49	6.91	5.75
		2009/2010	12.84	11.42	7.12	5.50
		2010/2011	13.45	11.98	6.75	5.72
		mean	13.38	11.96	6.93	5.66
Mean for conventional			12.78a	12.1a	6.84a	6.15a

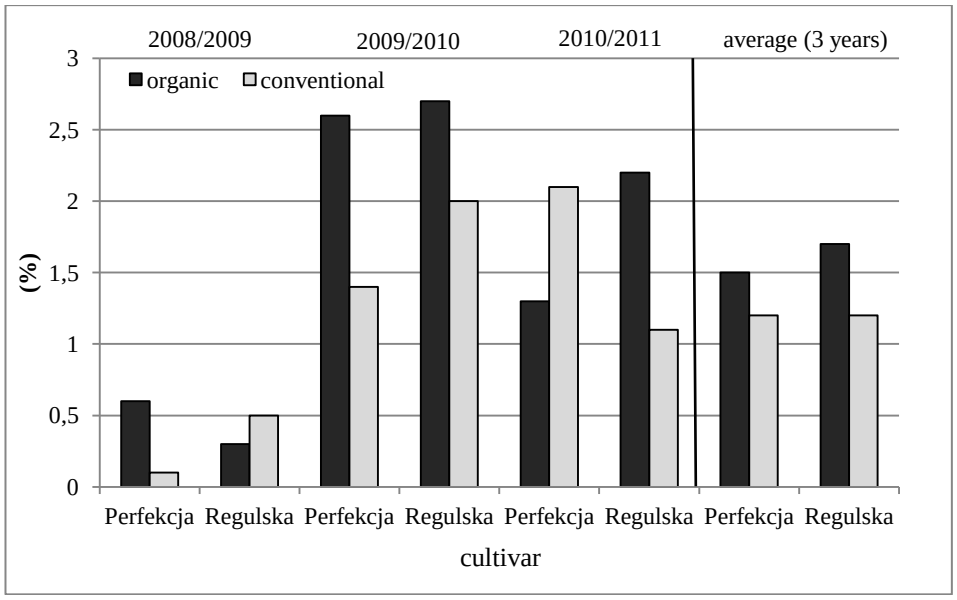
Note: see Fig. 1

There were marked differences in storage life influenced by the cultivar, cultivation methods and storage time (Table 3). A statistically significant, higher percentage of marketable roots of both cultivars in the two cultivation systems was obtained in the years 2009/2010, possibly because of the shorter storage period. Based on the average results for the three years, a higher percentage of marketable roots of the cultivar Regulska was obtained from conventional cultivation (84%). The lowest amount of marketable roots in total was recorded for the cultivar Perfekcja from organic cultivation (71.2% on average for three years). Generally, after storing the carrots from conventional cultivation, 65% of the roots were of the highest quality (healthy and not having sprouted new leaves or lateral roots), and 62.2% from organic cultivation. According to Suslov *et al.* (2009), storage of carrots for a prolonged period of time at temperatures above 2°C results in heavy sprouting of the tops and lateral roots. The author maintains that at a higher temperature carrot roots retain good quality for 3 to 5 months. Losses (diseased, rotting and rotten roots, and weight loss) were on average higher for the roots from organic cultivation compared with conventional cultivation. According to the authors of many publications, the primary factor adversely affecting the quality of carrot roots during storage are fungal and bacterial diseases. The most serious storage diseases of carrot include: grey mould (*Botrytis cinerea*), black dry root rot (*Alternaria radicina*), sclerotinia rot (*Sclerotinia sclerotiorum*) and wet root rot (*Erwinia carotovora* ssp *carotovora*) (Adamicki 2000, Davis & Raid 2002, Gajewski 2008). The highest losses due to rotting of the roots were recorded for the cultivar Perfekcja from conventional cultivation (6.8% on average for 3 years). The largest amount of diseased roots in the three storage seasons was noted for the cultivar Perfekcja from organic farming (23.9%). The smallest amount of diseased roots was noted for the cultivar Regulska from conventional cultivation (10.9%). The highest weight loss was found for the organically grown roots of the cultivar Regulska (1.7%), and the lowest for both cultivars grown in the conventional system (1.2%) (Fig. 5).

The study also revealed cultivar-dependent differences. In both cultivation systems, the cultivar Regulska was characterized by the highest percentage of marketable roots and the lowest losses due to diseases and rotting of the roots compared with the cultivar Perfekcja.

Table 3. The results of storing carrot roots cv. Perfekcja and Regulska at 0°C (% by weight of roots put in storage)

Cultivation method	Cultivar	Years	Carrot roots						
			marketable in total	not sprouted	sprouted leaves	sprouted leaves and lateral roots	sprouted lateral roots	diseased	rotting and rotten
organic	Perfekcja	2008/2009	81.2	55.4	15.4bc	5.2	5.2	16.8b	1.4b
		2009/2010	86.6b	86.6	-	-	-	8.0	2.8a
		2010/2011	45.9	37.9	-	0.4	7.6	46.9b	5.9
			71.2	59.9	5.1	1.8	4.3	23.9	3.4
	Regulska	2008/2009	82.6	53.6	22.6b	4.0	2.3	15.7b	1.4b
		2009/2010	86.0b	85.9	-	-	0.1	7.8	3.5ab
		2010/2011	71.4	54.3	10.8	0.2	6.1	21.9ab	4.5
			80	64.6	11.1	1.4	2.8	15.1	3.1
Mean for organic			75.6	62.2	8.1	1.6	3.5	19.5	3.2
conventional	Perfekcja	2008/2009	66.6	52.7	6.3c	2.6	5.0	28.1a	5.2a
		2009/2010	87.0b	87.0	-	-	-	5.9	5.7b
		2010/2011	76.5	58.6	9.7	0.8	7.4	12.0a	9.4
			76.7	66.1	5.3	1.1	4.1	15.3	6.8
	Regulska	2008/2009	89.7	41.2	40.3a	5.8	2.4	9.7b	0.1b
		2009/2010	94.2a	89.2	3.1b	0.4	1.5	2.3	1.5a
		2010/2011	68.1	61.7	2.9	-	3.5	20.9ab	9.9
			84	64	15.4	2.0	7.6	10.9	3.8
Mean for conventional			80.3	65	10.3	1.5	5.8	13.1	5.3
Mean for cultivar		Perfekcja	73.9	63	5.2	1.4	4.2	19.6	5.1
		Regulska	82	64.3	13.2	1.7	5.2	13	3.4



Note: note see Fig 1.

Fig. 5. Weight loss in carrot roots cv. Perfekcja and Regulska from organic and conventional cultivation after storage in the years 2008-2011

CONCLUSIONS

1. In the 3-year study, no significant differences were found in the dry matter content and total sugars in the roots of the carrot cultivars Perfekcja and Regulska between the two cultivation systems used.
2. Carrot roots of both cultivars from conventional cultivation contained significantly more β-carotene and nitrates compared with those grown organically.
3. A higher percentage of marketable roots after storage of the carrot cultivars Regulska and Perfekcja was achieved from conventional cultivation than from organic cultivation.
4. Regardless of the cultivation method, the carrot cultivar Regulska was characterized by a longer storage life than the cultivar Perfekcja.

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PORÓWNANIE WARTOŚCI ODŻYWCZEJ I TRWAŁOŚCI PRZECHOWALNICZEJ KORZENI MARCHWI Z UPRAWY EKOLOGICZNEJ I KONWENCJONALNEJ

Streszczenie

W latach 2008-2011, przeprowadzono badania, których celem była ocena wartości odżywczej i trwałości przechowalniczej korzeni marchwi odmiany Perfekcja i Regulska uprawianych w systemie konwencjonalnym i ekologicznym. Korzenie marchwi pochodziły z certyfikowanego pola doświadczalnego o ustabilizowanym ekosystemie, przystosowanym do prowadzenia badań nad ekologiczną uprawą warzyw. Równolegle w tych samych warunkach klimatycznych uprawiano marchew w systemie konwencjonalnym. Korzenie marchwi były składowane w temperaturze 0-1°C i wilgotności względnej powietrza na poziomie 95-98%. W korzeniach marchwi bezpośrednio po zbiorze i po kilkumiesięcznym przechowywaniu oznaczono zawartość suchej masy, cukrów ogółem, β-karotenu i azotanów. Wyniki chemicznej oceny jakościowej marchwi nie wykazały istotnych różnic w zawartości suchej masy i cukrów ogółem w zależności od odmiany, sposobu uprawy i przechowywania (średnie z trzech lat). Marchew uprawiana metodą konwencjonalną zawierała istotnie więcej β-karotenu niż marchew upra-

wiana metodą ekologiczną, zarówno przed jak i po przechowywaniu. Stwierdzono, że korzenie marchwi odmiany Regulska miały wyższą zawartość β-karotenu niż korzenie odmiany Perfekcja uprawiane zarówno w systemie ekologicznym jak i konwencjonalnym. Zawartość azotanów w korzeniach marchwi bezpośrednio po zbiorze obu odmian uprawianych w systemie konwencjonalnym była istotnie wyższa niż w korzeniach z uprawy ekologicznej i wahała się w granicach 349.9-554.4 ($mg \cdot kg^{-1}$). Zaznaczyły się znaczne różnice w trwałości przechowalniczej w zależności od odmiany, metody uprawy i okresu przechowywania. Wyższy procent korzeni handlowych po przechowywaniu marchwi odmiany Regulska i Perfekcja uzyskano z uprawy konwencjonalnej w porównaniu do uprawy ekologicznej. Straty (korzenie chore i ubytki masy) były wyższe dla korzeni z uprawy ekologicznej w porównaniu do uprawy konwencjonalnej. Zanotowano wyraźnie wyższy procent korzeni handlowych w korzeniach marchwi odmiany Regulska w porównaniu do marchwi Perfekcja. Dla odmiany Perfekcja więcej korzeni chorych stwierdzono w uprawie ekologicznej. Natomiast dla odmiany Regulska zanotowano najwyższe ubytki masy po przechowaniu korzeni z uprawy ekologicznej.