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Analytical Methods

Quality of fresh and stored carrots depending on iodine and nitrogen fertilization

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ABSTRACT

Introduction: Iodine is an important mineral nutrient essential for a proper functioning of human and animal organism. Despite current programmes of iodine prophylaxis (mainly based on salt iodization) approximately 30–38% of human population has insufficient iodine intake. Crop plants can become an efficient vector of this element in the food chain. Iodine is not a nutrient for plants. For that reason, in addition to determining the possibility of increasing iodine content in crop plant it is necessary to describe its impact on yield quality. The aim of the study was to analyze the influence of soil fertilization with iodine and nitrogen on the quality of carrot roots and its storage ability.
Methods: In 2008–2010 the field study with carrot cv. 'Kazan F_1' was conducted. A differential soil fertilization with iodine (in the form of I^- or IO_3^-) and nitrogen (as NO_3^- or NH_4^+) was applied in the experiment: (1) control without N and I, (2) KI application without N, (3) KIO_3 application without N, (4) KI + $Ca(NO_3)_2$, (5) KIO_3 + $Ca(NO_3)_2$, (6) KI + $(NH_4)_2SO_4$ and (7) KIO_3 + $(NH_4)_2SO_4$. The experiment was arranged in a split-plot design. Iodine (in both forms) was applied pre-sowing in a dose of 2 kg I ha^{-1}. Nitrogen in the form of $Ca(NO_3)_2$ and $(NH_4)_2SO_4$ was introduced pre-sowing and as a top dressing, each dose of 100 kg N ha^{-1}.
Results and discussion: A diverse, statistically significant influence of tested factors on the activity of free radical-scavenging (DPPH) and the content of: dry matter, glucose, fructose, sucrose, total soluble sugars, soluble solids – Brix %, phenolic compounds, phenylpropanoids, flavonols, anthocyanins and carotenoids was noted in carrot roots directly after the harvest as well as at the end of four-month storage. Iodine applied with relatively high doses of nitrogen decreased the quality of fresh carrot. After storage, opposite relations were noted for tested combinations (with I and N application) with respect to carrot quality when compared to results obtained after the harvest. The lowest storage ability was found for carrot treated with KI without N. Obtained results directly suggest the need for developing individual agronomic rules for iodine biofortification of carrot for: (a) consumption and/or processing directly after the harvest and (b) long-term storage.

1. Introduction

Iodine is an important mineral nutrient necessary for the proper functioning of human body. It is involved in the biosynthesis of thyroid hormones [thyroxine (T4) and triiodothyronine (T3)] that regulate numerous metabolic processes in the whole organism. In medicine, the spectrum of developmental and functional disorders caused by too low an intake of iodine are defined as iodine deficiency disorders (IDD). In the pre- and neonatal period, this nutrient has a crucial role in neurological and brain development (Melse-Boonstra & Jaiswal, 2010; Walker et al., 2007).

It is estimated that approximately 30–38% of human population has inadequate iodine intake and is, therefore, at risk of IDD (White & Broadley, 2009; Winger et al., 2008). Europeans have notably poor iodine intake with 56.9% children and ca. 60% adults consuming less than the recommended daily intake (Andersson, de Benoist, Darnton-Hill, & Delange, 2007; de Benoist, Andersson, Egli, Takkouche, & Allen, 2004) despite numerous public health programmes, based mainly on salt iodization, in most member

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states of the European Union. Low intakes result from poor iodine stability in salt and losses during production, packaging, transportation and processing. The total amount of iodine lost from salt may be up to 90% with cooking alone contributing to approximately 20% of these losses (Winger et al., 2008).

Plant biofortification is proposed as a fast and relatively low-cost method of introducing iodine into the food chain (White & Broadley, 2009; Yang, Chen, & Feng, 2007). Vegetables with increased iodine content could be the preferred vector for this mineral in the diet as many of these food products are consumed raw (Haldimann, Alt, Blanc, & Blondeau, 2005). Iodine is not considered to be a plant nutrient (Kabata-Pendias, 2011), which is a significant factor limiting application in plant fertilization strategies. Numerous studies have been conducted so far on iodine uptake and accumulation in plants (Mackowiak & Grossl, 1999; Weng, Hong et al., 2008; Weng, Weng et al., 2008; Ujowundu et al., 2011). An interesting approach is the utilization of biotechnology methods for increasing iodine content in plants through the inhibition of its methylation and volatilization of methyl iodide /CH_3I/ to the atmosphere (Landini et al., 2012).

Previous studies on iodine biofortification of carrot have been conducted in greenhouse conditions with the application of relatively high iodine doses (Dai, Zhu, Zhang, & Huang, 2004; Hong, Weng, Qin, Yan, & Xie, 2008). No results are available documenting the effect of fertilization with iodine on carrots grown in fields using standard agricultural practices. What is more, no studies have been conducted so far on plant biofortification with iodine and its effects on post-harvest physiology of crop plants. Thus, it seems necessary not only to compare the efficiency of various methods for increasing iodine content in plants, but also to discuss its influence on crop quality.

The aim of this study was to determine the effect of different iodine (potassium iodide or potassium iodate) fertilizers in parallel with nitrogen (calcium nitrate or ammonium sulphate) on carrot quality and storage.

2. Materials and methods

2.1. Plant material and treatments

During 2008–2010, a field study with carrot cv. 'Kazan F_1' was conducted in the Experimental Station (50°07′910 N, 19°84′764 E) of University of Agriculture in Krakow Poland, each year on a different site within a single soil complex.

Different soil fertilization with iodine (in the form of I^- or IO_3^-) and nitrogen (as NO_3^- or NH_4^+) was applied in the experiment: (1) control – without N and I, (2) KI application without N, (3) KIO_3 application without N, (4) KI + $Ca(NO_3)_2$, (5) KIO_3 + $Ca(NO_3)_2$, (6) KI + $(NH_4)_2SO_4$, (7) KIO_3 + $(NH_4)_2SO_4$. The experiment was arranged in a split-plot design. Each treatment was randomised in four repetitions on 2.7 × 5 m (13.5 m^2) plots. The total area of the experiment was 378 m^2.

Iodine (in both forms) was applied pre-sowing in a dose of 2 kg I ha^{-1} as pure salts (KI – POCH Poland, KIO_3 – Sigma Aldrich®). Nitrogen in the form of $Ca(NO_3)_2$ [Yara International ASA (Hydro)] and $(NH_4)_2SO_4$ [Zakłady Azotowe in Tarnów, Poland] was introduced in two 100 kg N ha^{-1} doses: pre-sowing and as a top-dressing. Pre-sowing application of nitrogen and iodine was conducted before ridge formation, whereas the second dose of N – at canopy closure (27 June 08, 26 June 09 and 07 July 10). Carrots were cultivated in one row on 40 cm wide and 30 cm high ridges at a seeding rate of 37 seeds m^{-1} (approximately 550 000 seeds per hectare). The seeds were sown on 24 April 08, 24 April 09 and 23 April 10. The carrot roots were harvested on 30 September 08, 23 September 09 and 30 September 10. At harvest, approximately 5 kg samples of carrot storage roots were chosen from each of the four plots (replications) for laboratory analysis. Additionally, for each of the experimental treatments, a mixed sample of 25 kg of roots was collected for storage. During harvest, mean carrot length was also determined. Only roots qualifying as marketable yield were taken for further analyses. Marketable yield consisted of storage roots of cylindrical or close-to-cylindrical shape with head diameter of ⩾3 cm, undamaged by pests, not infected by fungi or bacteria, with no fractures and heads greened to a maximum of 0.5 cm. The length of a storage root was 15 cm minimum.

2.2. Storage conditions

Stored carrots from each year of the study were placed in plastic boxes (60 × 40 × 25 cm) and kept at normal atmosphere, 1 °C, and 95–98% humidity. After four-months, healthy roots (not affected by diseases) were weighed and taken for analysis.

2.3. Plant analysis after harvest and long-term storage

Stored roots were washed and juiced or diced using a household processor immediately before analysis. The content of total soluble solids (°Brix) was measured using a Atago Palette PR-32 α digital refractometer. Dry matter was assessed at 105 °C. Levels of glucose, fructose, sucrose and total sugars (calculated) were determined using RP-HPLC. Determination of these compounds was conducted in room temperature using a Knauer system (Germany). Samples (10 μl) were injected on an amine LiChrospher RP 100-10 NH_2 250 × 4 mm column. The eluent was a mixture of acetonitryl/water (87:13 v/v) and the flow rate 1.3 ml/min. Measurement was conducted using Smartline RI refractometric detector 2300 (Bogdanov, 2002). Total carotenoid content was assayed after sample extraction with acetone/n-hexane (4:6) using a β-carotene standard curve.

To estimate phenolic constituents and free radical scavenging, carrot extracts were prepared in 80% methanol. Total phenols, phenylpropanoids, flavonols and anthocyanins concentrations were determined using the spectrophotometric method described by Fakumoto and Mazza (2000). Free radical scavenging activity was evaluated on the basis of 30-min plant tissue reaction with diphenylpicrylhydrazyl (DPPH) (Pekkarinen, Stockmann, Schwarz, Heinnonen, & Hopia, 1999).

2.4. Statistical analysis

Results were statistically verified using ANOVA module of Statistica 9.0 PL programme for significance level $P < 0.05$. Significance of changes was assessed with the use of variance analysis – F test. In case of significant changes, homogenous groups were distinguished on the basis of Duncan test.

All data were presented as means for the years 2008–2010 as in each year comparable results of treatments on quality of carrot were obtained.

3. Results and discussion

3.1. Root weight and dry matter content

Results of numerous studies indicate that IO_3^- introduced into the soil or nutrient medium is less harmful for plants than I^- when applied in the same concentrations (Mackowiak & Grossl, 1999; Blasco, Rios, Cervilla et al., 2011; Blasco, Rios, Leyva et al., 2011; Caffagni et al., 2011; Hong et al., 2012). In our research no significant effect of iodine and nitrogen fertilization was found with respect to root weight at harvest and after long-term storage