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EFFECT OF DIFFERENTIATED FERTILIZATION AND FOLIAR APPLICATION OF IODINE ON YIELDING AND ANTIOXIDANT PROPERTIES IN RADISH (*Raphanus sativus* L.) PLANTS

WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA I DOKARMIANIA DOLISTNEGO JODEM NA PLONOWANIE I WŁAŚCIWOŚCI ANTYOKSYDACYJNE RZODKIEWKI (*Raphanus sativus* L.)

Abstract: The aim of this research was an attempt to obtain radish plants enriched with iodine by means of foliar application and soil fertilization with two forms of iodine – KI and KIO_3. The effect of iodine on radish yielding and its antioxidant characteristic was determined.

It was demonstrated that the form of applied iodine and the way of its application had a meaningful effect on the quantity of biological yield and leaf mass. Although all plants accumulated greater amounts of iodine in comparison with the control, it was best manifested in case of foliar application, as well as combined foliar application and soil fertilization of radish with KI form as 34.17 and 29.30 mg I · kg^{-1} f.m., respectively. Although, the effect of the form of applied iodine as well as the way of its application on antioxidant characteristics of radish was not revealed, the content of phenolic compounds turned out to be significantly higher than in case of foliar application combined with soil fertilization with both forms of iodine.

Keywords: iodine, radish, phenolic compounds, antioxidant properties

The environmental iodine deficiency can cause a number of health problems known as iodine deficiency disorders (IDD) [1]. To develop properly, human being needs 100–150 μg of iodine per day, half of which can be of vegetable origin. [2]. Nowadays, over a billion people live in the areas with a significant deficiency of this element in the environment [3]. The most effective and most popular method of preventing iodine deficiency disorders is iodization of domestic salt. However, its excessive intake causes

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constant increase in the frequency of circulatory system disorders and hypertension occurrences. Hence, in accordance with the directive of WHO, one shall aim at decreasing the content of salt in human diet [4]. This resulted in the search for alternative sources of provisioning people with iodine, among others by attempts of enriching vegetables with this element. Despite the fact that iodine is an indispensable element for plants, they take in this element easily from the environment in both iodate and iodide forms. However, after its introduction into soil iodine rapidly undergoes the sorption process as well as volatization into the atmosphere and only its trace amounts are available for plants [5–7]. Iodine introduction into plants can happen by soil or foliar application [3, 8]. The research carried out by Strzetelski et al [9] on spinach plants revealed that foliar application is more effective than soil fertilization. Also Altmok et al [10] research on lucerne cultivation demonstrated higher content of this element in plants cultivated under field conditions with KI foliar application form in comparison with soil fertilization.

The aim of this work is to determine which of the applied forms of iodine (I^- or IO_3^-) and the way of application (soil fertilization or foliar application) in pot cultivation of radish have effect on yielding, antioxidant activity and the content of this element in radish roots.

Material and methods

Small radish (*Raphanus sativus* L. var. *radicula* Pers.), 'Opolanka' cv., was cultivated in the years 2006–2007 in open-work containers sized 60 × 40 × 20 cm, placed in the open field under a shade providing fabric. The containers were filled with silt loam (35 % sand, 28 % silt and 37 % clay) with mean content of organic matter 2.52 % and the following contents of available (extracted with 0.03 mol · dm^{-3} CH_3COOH) nutrients forms: 14.9 mg N (NO_3-N+ NH_4-N), 73.8 mg P, 92.4 mg K, 159.8 mg Mg and 1299.0 mg Ca in 1 dm^3 soil. Soil $pH_{(H_2O)}$ was 6.88 and $pH_{(KCl)}$ 6.20, while total concentration of salt in soil measured as EC was 0.15 mS · cm^{-1}.

The following treatments with soil and foliar application of iodine in experiments were applied: 1 – control (without iodine application), 2 – foliar application in KI form (FA-KI), 3 – foliar application in KIO_3 form (FA-KIO_3), 4 – soil fertilization in KI form (SF-KI), 5 – soil fertilization in KIO_3 form (SF-KIO_3), 6 – soil fertilization in KI form + foliar application in KI form (SF-KI+FA-KI), 7 – soil fertilization in KIO_3 form + foliar application in KIO_3 form (SF-KIO_3+FA-KIO_3). Soil fertilization in KI and KIO_3 was carried out before sowing radish seeds to the level of 15 mg I · dm^{-3} soil. Foliar application in KI and KIO_3 performed twice using a liquid with iodine concentration per pure element 0.2 %, in rate 0.4 dm^3 · m^{-2}. The first foliar application with iodine was performed at two-leaf stage ie on 24 May 2006 and 15 May 2007, while the second application on 1 June 2006 and 18 May 2007, respectively.

Seeds sowing was performed on 4 May 2006 and 11 April 2007 in 5 rows with 25 seeds in one containers. After germination the plants were singled out leaving 12 seedlings in one row. The content of available nitrogen and potassium forms in soil before cultivation outset was supplemented to the level 100 mg · dm^{-3} of soil with the use of solid fertilizers of ammonium nitrate and potassium sulphate. The level of other macroelements (K, Mg, Ca) in soil did not need supplementation. Harvesting combined with gathering leaf, root and soil samples was performed on 8 June 2006 and 22 May 2007, respectively. For analyses we used radish roots which were suitable for consumption. Their mass was 3.0–7.6 g.

Phenolic compounds contents were determined with the use of Folin reagent [11] in radish roots. The division of phenolic compounds into phenylpropanoids, flavonols and anthocyanins were conducted spectrophotometrically on the basis of absorption spectrum as per Fakumoto and Mazza method [12]. The content of ascorbic acid was assessed according to Dulinski et al method [13]. The activity of free radicals scavenging was evaluated on the basis of plant tissue reaction with diphenylpicrylhydrazyl (DPPH) being colour stable free radical according to Pekkarinen et al method [14].

In soil samples as well as radish roots the content of iodine was assessed with ICP-OES method with the use of Prodigy Teledyne Leeman Labs USA spectrometer. In soil samples iodine was evaluated after prior extraction with 0.03 mol · dm^{-3} CH_3COOH [15], while in radish roots after TMAH trials incubation according to standard project prEN 15111-R2-P5-F01 [16].

The obtained results were verified statistically with the ANOVA module of 'Statistica 8.0 PL' for $p < 0.05$. The significance of differences was estimated with Duncan test.

Results

It was demonstrated that both the way and the form of applied iodine for plant fertilization had a significant effect on the quantity of biological yield of radish plants (Table 1). It was noted definitely lowest biological yield after foliar application treatment with KI form when compared with other sites of the experiment. The highest and comparable yield (roots plus leaves) was observed in plants with soil fertilization with both iodide (KI) and iodate form (KIO_3). Interestingly, the yield of radish roots (usable parts) was independent of both form and way of iodine application.

Table 1

The effect of fertilization and foliar application with iodine on radish yielding – means from 2006–2007

Treatments	Yield (roots+leaves)	Roots yield	Leaves yield
	[g · m^{-2}]		
Control	2138.0 bc	1055.6 a	1082.4 ab
FA-KI	1622.5 a	784.7 a	837.7 c
FA-KIO_3	1979.2 abc	934.0 a	1045.2 abc
SF-KI	2274.7 c	1135.4 a	1139.2 a
SF-KIO_3	2219.7 c	1041.7 a	1178.0 a
SF-KI+FA-KI	1731.1 ab	819.4 a	911.7 bc
SF-KIO_3+FA-KIO_3	1937.6 abc	854.2 a	1083.4 ab

Means followed by the same letters are not significantly different for $p < 0.05$.

Demonstrated differences proved insignificant after statistical verification. It results from the evaluation of plant yielding that the revealed diversity in the quantity of biological yield was associated with considerable differences in leaf mass (Table 1). These differences most probably resulted from leaf impairment caused by foliar application with iodine. As in case of biological yield, the lowest leaf mass was noted in plants treated with foliar application with potassium iodide (KI), while the highest mass was observed after soil fertilization with both forms of iodine.

The analysis of iodine content in radish roots (Table 2) demonstrated a wide diversity among individual sites of the experiment. The highest content of this element was noted after foliar application with iodide form (I^-) and after combined foliar application and soil fertilization with potassium iodide (KI). The smallest amount of iodine was accumulated by the roots after soil fertilization with both forms of iodine. It is worth noting that foliar application with KI caused threefold increase in the content of iodine in radish, when compared with other sites with foliar application, with KIO_3 form. The analysis of residues in the soil conducted after the experiment demonstrated that the highest amounts of this element were assessed after the application of iodate form (IO_3^-) in plant fertilization, independently of the way of application (Table 2).

Table 2

The effect of fertilization and foliar application with iodine on the content of this element in soil after harvest, and on the content of iodine and ascorbic acid in radish – means from 2006–2007

Treatments	Content of iodine in soil [mg I · dm^{-3} soil]	Content of iodine in radish roots		Ascorbic acid [mg · 100g^{-1} f.m.]
		[mg I · kg^{-1} d.m.]	[mg I · kg^{-1} f.m.]	
Control	0.25 a	14.8 a	0.68 a	25.2 a
FA-KI	1.25 a	739.5 c	34.17 c	29.6 c
FA-KIO_3	5.18 b	263.1 b	11.41 b	27.1 b
SF-KI	1.21 a	27.0 a	1.20 a	24.3 a
SF-KIO_3	13.77 c	60.8 a	2.78 a	24.1 a
SF-KI+FA-KI	1.32 a	631.5 c	29.30 c	23.9 a
SF-KIO_3+FA-KIO_3	23.06 d	292.3 b	13.31 b	24.6 a

Means followed by the same letters are not significantly different for $p < 0.05$.

The highest level of ascorbic acid was observed in radish roots after foliar application of plants both with KI and KIO_3 forms (Table 2). We did not note any significant effect of iodine form and the way of its application on the capacity of free radicals scavenging (DPPH) or on the content of phenylpropanoids, flavonols and anthocyanins in radish (Table 3).

There were, however, considerable variations in the content of phenolic compounds. Their highest level was assessed in radish roots after foliar application with potassium iodide (KI) and combined foliar application and soil fertilization with I^- as well as IO_3^- form.

Table 3

The effect of fertilization and foliar application with iodine on the content of phenolic compounds in roots and leaves of radish, and free radical scavenging activity (DPPH) – means from 2006–2007

Treatments	Phenolic compounds	Phenyl propanoids compounds	Flavonoids	Anthocyanins compounds	DPPH [%]
	[mg · 100 g^{-1} f.m.]				
Control	42.1 ab	40.5 a	15.9 a	52.5 a	11.00 a
FA-KI	45.1 abc	40.3 a	16.0 a	48.2 a	11.53 a
FA-KIO_3	42.0 ab	38.1 a	15.7 a	46.7 a	10.54 a
SF-KI	41.0 a	35.7 a	14.7 a	45.6 a	10.96 a
SF-KIO_3	42.8 ab	36.9 a	15.4 a	48.1 a	10.83 a
SF-KI+FA-KI	46.1 bc	39.7 a	16.8 a	49.0 a	11.69 a
SF-KIO_3+FA-KIO_3	47.3 c	39.4 a	17.1 a	51.1 a	11.94 a

Means followed by the same letters are not significantly different for $p < 0.05$.

Discussion

The results obtained after assessment of iodine content in radish roots indicate that foliar application with this element is an undoubtedly better way of enriching plants with iodine in comparison with soil fertilization. Similar results in the search for efficient ways of plant bio-fortification with iodine were revealed by other authors [3, 9, 10]. Presented research allows to conclude that bioaccumulation of iodine in radish was threefold higher when the plants were treated with foliar application with iodide form (I^-) when compared with iodate form (IO_3^-). More rapid accumulation of iodine applied in the form of KI was also observed by Smith et al [17]. However, there is an opinion in contemporary literature that it is IO_3^- form which is taken by plants more efficiently, which was already confirmed by the research on spinach, carrot, celery and onion [18, 19] and lettuce [20]. Solving this problem would require further studies on the subject.

Demonstrated differences in the content of iodine in radish influenced the shape of biological yield and leaf mass of this vegetable (Table 1). High iodine level after foliar application with KI resulted in a significant decline in biomass of harvested plants, leaf mass and root yield (insignificant effect). A similar tendency was revealed when the plants were concurrently treated with foliar application and soil fertilization with iodide form (I^-). This is a very interesting interrelation, which was confirmed by Hong et al [21] in their research into iodine accumulation in celery, pepper and radish. It turned out that increasing content of iodine in soil and plants up to 150 mg I · kg^{-1}, decreased biomass of the examined plants by 40 % in pepper, 25 % in celery and by 10–15 % in radish.

Conducted assessment of ascorbic acid content demonstrated that foliar application of plants with iodine resulted in a significantly elevated level of this vitamin in radish, with iodide (KI) being the more efficient form. Similarly higher content of ascorbic acid in lettuce leaves after soil fertilization with potassium iodide was presented by

Ledwozyw et al [22]. Other authors also revealed a positive correlation between the content of iodine in plant and the content of ascorbic acid [23]. However, this problem needs further detailed studies.

Conclusions

1. Foliar application of radish plants with potassium iodide significantly decreased biological yield and leaf mass. The biggest biological yield was gathered after soil fertilization with both forms of iodine.
2. Foliar application and foliar application combined with soil fertilization with iodine, particularly in I^- form, caused the highest accumulation of this element in radish.
3. It was found an insignificant effect of the factors applied in the experiment on the content of ascorbic acid and phenols total in radish yield.

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Abstrakt: Celem podjętych badań była próba uzyskania roślin rzodkiewki wzbogaconych w jod poprzez zastosowanie dokarmiania dolistnego oraz nawożenia doglebowego dwoma formami jodu – KI oraz KIO_3. Określono również wpływ jodu na plonowanie rzodkiewki oraz jej właściwości antyoksydacyjne.

Wykazano, że forma użytego jodu oraz sposób jego aplikacji miały statystycznie istotny wpływ na ilość plonu biologicznego i masę liści. Chociaż wszystkie rośliny akumulowały większe ilości jodu w porównaniu z kontrolą to jednak najbardziej uwidoczniło się to przy dolistnym dokarmianiu, jak również przy łącznym dokarmianiu dolistnym i nawożeniu doglebowym rzodkiewki formą KI odpowiednio 34,17 oraz 29,30 mg I $\cdot$ kg^{-1} ś.m. Pomimo, iż nie wykazano statystycznie istotnego wpływu zarówno formy użytego jodu oraz sposobu aplikacji tego pierwiastka na właściwości antyoksydacyjne rzodkiewki, to zawartość sumy związków fenolowych okazała się istotnie większa w przypadku łącznego dokarmiania dolistnego jak i nawożenia doglebowego roślin rzodkiewki obiema formami jodu.

Słowa kluczowe: jod, rzodkiewka, związki fenolowe, właściwości antyoksydacyjne