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Iodine biofortification with additional application of salicylic acid affects yield and selected parameters of chemical composition of tomato fruits (*Solanum lycopersicum* L.)

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ABSTRACT

Vegetables with increased content of iodine can become an alternative source of this element in the diet. Iodine is not a plant nutrient. Salicylic acid (SA) is involved in plant adaptation to stress conditions. The aim of the study was to evaluate the influence of iodine and SA on yield and selected parameters of chemical composition of tomato fruits. A three-year study with tomato cultivation in hydroponic system was conducted with the introduction of iodine and SA into nutrient solution: (1) Control, (2) KI, (3) KIO_3, (4) KI + SA, (5) KIO_3 + SA. Both iodine and SA were applied in a dose of 1 mg dm^{-3}, *i.e.* 7.88 μM I and 7.24 μM SA, respectively. Fruits of plants treated with KI contained significantly more iodine. SA contributed to a 157% and 37% increase in iodine accumulation in fruits – for KIO_3 + SA and KI + SA, respectively. Treatment with KIO_3 was the best for nutritional value of tomato fruits.

1. Introduction

Iodine is one of micronutrients crucial for the proper functioning of human and animal organisms. Its basic role includes the participation in the biosynthesis of thyroid hormones – thyroxin (T4) and triiodothyronine (T3) which regulate numerous physiological and biochemical processes. Additionally, iodine is essential for the development of nervous tissue and brain in fetus and during the first years of a baby's life. Irrespective of age, this micronutrient is involved in the immune response to ionizing radiation (Melse-Boonstra and Jaiswal, 2010).

It is estimated that 30–38% of world human population has inadequate iodine intake. The whole spectrum of organism dysfunctions related to insufficient iodine uptake is described as iodine deficiency disorders (IDD – Winger et al., 2008; White and Broadley, 2009). Current programs of iodine prophylaxis implemented in numerous countries are mainly based on salt iodization. However, the stability of iodine in that food product is low with its loss during storage, transport and processing reaching up to 90% (Winger et al., 2008). This may be explain the fact that despite the high level of salt consumption a substantial percentage of European population has insufficient iodine supply – 59.9% and 56.9%, respectively for children and adults (Andersson et al., 2007).

Vegetables with increased level of iodine can be proposed the alternative source of this microelement in the diet. The idea of biofortification of crops concerns the introduction not only of iodine but also other elements such as Se, Fe, Zn, Mg and Ca into the edible parts of plants (Hirschi, 2009). It has been demonstrated that the consumption of vegetables biofortified with iodine (potatoes, cherry tomatoes, carrots and green salad) contributed to the significant increase in the level of urinary iodine excretion (UIE) which is one of the major indictor of iodine status of the population (Tonacchera et al., 2013).

Iodine does not fulfill the criteria of plant micronutrient which is the major problem encountered during the studies on plant biofortification with this element. Prior to implementing agrotechnical rules for iodine biofortification it is necessary to determine the

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Abbreviations: SA, salicylic acid; NFT, nutrient film technique; UI, urinary iodine; NR, nitrate reductase; NiR, nitrite reductase.

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range of optimal iodine doses that allow to obtain the enrichment effect. It should be high enough to significantly improve daily intake of iodine by human but nor exceeding the toxicity level for plants (Mackowiak and Grossl, 1999). Another factor limiting the process of plant enrichment with iodine is its methylation followed by CH_3I volatilization (Saini et al., 1995; Rhew et al., 2003). Trials have been undertaken to minimize this process using biotechnological methods (Landini et al., 2012).

For vegetables with fruits as edible parts, iodine biofortification is particularly hampered as the transfer of this element into generative organs is strongly limited – its accumulation occurs more likely in roots and leaves (Mackowiak and Grossl, 1999) with only a small amount being found in fruits and seeds (Ujowundu et al., 2011).

Plant fertilization with iodine (particularly with its high doses) substantially affects physiological and biochemical processes in plants consequently changing its chemical composition. Due to iodine toxicity modification of the content of compounds responsible for organoleptic and nutritional qualities (sugars, acidity) as well as nutraceuticals in the yield may be noted (Dai et al., 2006; Blasco et al., 2008, 2011; Hong et al., 2008; Voogt et al., 2010).

Little attention has been put on iodine fertilization of tomato plants (Caffagni et al., 2011; Landini et al., 2011) particularly with respect to chemical composition of fruits. Kiferle et al. (2013) described the influence of iodine application only with respect to the content of sugars and antioxidant capacity in tomato fruits. It seems substantiated to state that there is a lack of results documenting the influence of iodine on chemical composition of tomato fruits.

It seems particularly relevant to determine iodine influence on chemical composition of plants (including tomato fruits) grown in soilless and hydroponic systems. In such types of plant cultivation iodine is taken up much more easily than from soil (Voogt et al., 2010; Dai et al., 2006) mostly due to strong sorption (and slow desorption) of this element in soil. In soilless and hydroponic systems, due to easier iodine uptake, much stronger interaction of this element with biochemical and physiological processes in plants, and therefore its chemical composition, occurs. A consequence of improved iodine uptake (even in non-toxic doses) may be the intensification of its volatilization in the form of CH_3I (Saini et al., 1995; Rhew et al., 2003). This process requires excessive metabolic energy what may negatively affect the level of carbohydrates in plants as well as the synthesis of secondary metabolites such as vitamins, pigments or phenolic compounds.

Salicylic acid (SA) is considered a phytohormone-like compound as it is involved in the regulation of plant growth, development and other physiological processes (Fariduddin et al., 2003; Hayat et al., 2010). In horticulture practice, tomato cultivation is widely conducted under cover using hydroponics with or without circulating system. However, there are some disadvantages of recirculating hydroponics, such as an increase in medium salinity and the risk of pathogen contamination. Pathogenic organisms easily multiplicate in the medium, especially when disinfecting systems are lacking, and can spread on the crops. The addition of exogenous SA increased tolerance of tomato plants to salinity (in concentration 0.1 μM; Tari et al., 2002), and induced plant resistance to *Fusarium oxysporum* f. sp. *lycopersici* (in concentration 200 μM applied for 7 days in hydroponics; Mandal et al., 2009), as well as to *Alternaria solani* (in concentration 200 μM SA for 24 h and 48 h; Spletzer and Enyedi, 1999). On the other hand, elevated levels of SA may be harmful to plants, as reported by Jung et al. (2004). They observed toxic effects of 50, 100, 150, 200 and 400 μM SA on tomato plants during 14-day long cultivation. Significantly, SA participation in inducing plant resistance to diseases is related with SA conversion and volatilization from plants in the form of ester-methyl salicylate (MeSA). This volatile compound plays a signaling role inducing plant resistance to pathogens (Taiz and Zeiger, 2010). What is more, volatilization or formation of sugar conjugates with SA is considered a natural process of endo- and exogenous SA degradation. The above-mentioned conversions of SA require substantial amount of metabolic energy what, as a consequence, may additionally limit the content of sugars as well as modify chemical composition of plants (Zhang et al., 2013).

Basically, no studies are however available presenting the influence of SA application on the effectiveness of iodine uptake by plants along with its impact on nutritional value and content of health promoting compounds in yield. In seawater SA causes the reduction of I_2 to HOI, the latter one undergoing further reactions into monovalent anions of iodine (Truesdale and Luther, 1995). Thus, it seems interesting to determine whether and to what extent the presence of SA in the nutrient solution affect iodine uptake by plants in hydroponics. It is worth to mention that in this type of plant cultivation water/medium disinfection can be obtained by using molecular iodine (I_2 – Ogai et al., 2007). The side-effect of that method is the increase of iodide (I^-) concentration in the water/medium. After 120 min from the introduction of I_2 concentration of I^- can be doubled – from 2 mg I^- dm^3 to approximately 4.5 mg I^- dm^3 (Ogai et al., 2007). Therefore, studies with plant cultivation on nutrient solution enriched with iodine may cover two aspects – the first one being closely related to the biofortification effect and the other one assessing the plant reaction to the elevated level of iodides in the root zone.

Agrotechnical methods of iodine biofortification of plants should be developer as to efficiently increase the accumulation of this element in yield within the range safe for the consumers. This process should not negatively affect the chemical composition of plants including the content of compounds responsible for organoleptic and nutritional values as well as of health promoting compounds (nutraceuticals). In case of tomato fruits the content of soluble solids (% Brix), sugars, ascorbic acid, free amino acids, lycopene, β-carotene, chlorophylls (a and b) and phenolic compounds should be taken into consideration as well as free radical scavenging activity (Wysocka-Owczarek, 2001; Gravel et al., 2010).

The aim of the study was to evaluate the influence of iodide (I^-) and iodate ($IO_3{}^-$) as well as SA applied with iodine on yield and selected parameters of chemical composition of tomato fruits growing in NFT (nutrient film technique) hydroponic system.

2. Materials and methods

2.1. Plant material and treatments

A three-year study (2010–2012) with tomato (*Solanum lycopersicum* L. cv. Rambozo F_1) cultivation in NFT recirculating system without medium disinfection was conducted in the experimental greenhouse of Faculty of Horticulture, University of Agriculture in Kraków. Greenhouse box was equipped with five individual NFT sets with 1300 dm^3 medium containers, facilitating tomato cultivation in recirculating hydroponics.

Each year in the beginning of February tomato seeds were sown into rockwool plugs. Seedlings at the first-leaf-stage were transferred into rockwool blocks sized 10 cm × 10 cm × 6.5 cm. In the third week of March plants with 5–6 true leaves were transferred into hydroponic beds of NFT system at the bottom of which capillary mats were placed and its surface was covered with black-and-white sheeting. No additional substrate was used. Plants were cultivated until the bud of the inflorescence in the sixth cluster was formed and then were trimmed above the second leaf above this cluster. Trimming was conducted in order to determine several physiological and chemical parameters, including iodine distribution in plant (in leaf petioles and pinnate leaves) and mineral status of the plants