Iodine biofortification of red radish (*Raphanus sativus* L.) cultivating on hydroponic system

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Abstract Iodine is a crucial micronutrient for producing thyroid hormones, which regulate metabolism, growth, and development, particularly influencing cognitive and physical health in early life stages. Traditional approaches like iodized salt have limitations, especially in reaching remote populations, prompting interest in the biofortification of crops as a sustainable solution to enhance iodine intake. The study examined the physiological characteristics, biomass production, iodine concentration variations, and key nutritional components of red radish (Raphanus sativus) plants. Conducted in a hydroponic system, the research utilized varying concentrations of iodine in the form of potassium iodide (KI) and potassium iodate (KIO_3), ranging from 0.01 to 1.0 mg I/L. The findings revealed that iodine supplementation did not significantly impact photosynthetic efficiency or pigment levels; however, it did enhance biomass production, particularly in the swollen taproot, which yielded the highest biomass compared to other plant parts. Iodide treatment was effective only at lower concentrations, while iodate treatment showed positive effects at higher concentrations (0.05 to 0.5 mg/L). Additionally, increased iodine concentrations in the nutrient solutions resulted in elevated iodine levels across all plant parts, with iodide treatment demonstrating 2-10 times greater efficiency than iodate treatment. The type of iodine applied influenced the transport of essential elements differently

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1. Introduction

Iodine biofortification of red radish (*Raphanus sativus* L.) offers a promising solution to address global iodine deficiency disorders (IDDs), which affect nearly two billion people worldwide (Krzepiłko et al., 2021). As a member of the Brassicaceae family, red radish is well-suited for biofortification due to its rapid growth, widespread consumption, and ability to accumulate iodine without compromising key quality parameters. Exogenous iodine sources, such as potassium iodide (KI) or seaweed-based fertilizers, are applied during the germination or growth stages to significantly increase iodine content in edible tissues (Long et al., 2017). Studies have shown that red radish seedlings treated with KI at 0.15–0.30 mg/g of seeds achieve iodine levels 112.9–2,730 times higher than controls, making it a viable functional food source (Karami et al., 2021).

Beyond combating micronutrient deficiencies, iodine-enriched red radishes maintain their nutritional profile, including vitamin C, phenolic compounds, and glucosinolates, which contribute to their antioxidant and antimicrobial properties (Hussain et al., 2020). This dual benefit underscores the potential of red radish biofortification to serve as a sustainable, dietary-based intervention against IDDs (Matsuda et al., 2018). Further research is needed to optimize iodine application methods, such as alternating inorganic and organic iodine sources, to maximize uptake efficiency and minimize environmental iodine loss, ensuring the long-term viability of biofortified food systems (Marschner, 2012).

2. Materials and methods

In this study, red radish plants were cultivated hydroponically and treated with varying concentrations of iodine (as KI or KIO_3), with plant growth, photosynthetic parameters, and elemental compositions measured using techniques like SPAD chlorophyll readings, chlorophyll fluorescence, and inductively coupled plasma mass spectrometry, respectively. X-ray Absorption Near Edge Structure (XANES) spectroscopy assessed iodine species in plant tissues, using standards prepared from potassium iodide and iodate mixed with cellulose. Data were statistically analysed with linear regression models in R, considering treatment type, iodine species, and their interaction to explore their effects on plant physiology and element accumulation.

3. Results

The physiological measurements indicated that red radish plants maintained stable photosynthetic efficiency (Fv/Fm) under iodine supplementation, with only slight, non-significant increases in chlorophyll content (SPAD index) and photochemical reflectance index (PRI) following potassium iodide (KI) and potassium iodate (KIO_3) treatments (Blasco et al., 2020). These modest enhancements suggest a limited but positive influence of iodine on photosynthetic traits, without inducing oxidative stress or significantly altering overall photosynthetic performance. This is consistent with findings that low iodine concentrations typically do not impair photosystem II activity or cause inhibition in plants, as reported by previous studies (Blasco et al., 2020). Thus, iodine supplementation appeared to subtly improve specific physiological parameters without compromising the core photosynthetic machinery. Dry mass and water content analyses revealed that iodine treatments had differential effects on biomass allocation and tissue hydration in red radish plants. KI generally reduced dry weight and water content in roots, leaves, and edible portions, especially at the highest concentration (1 mg/L), whereas KIO_3 treatment promoted greater biomass production, particularly at moderate concentrations (0.05–0.5 mg/L) (Mackowiak & Grossl, 2020). Water content patterns further highlighted contrasting effects: KI supplementation reduced hydration in most tissues, while KIO_3 supplementation increased water retention in edible parts at higher dosages. These findings align with those of Smoleń et al. (2020), who noted that iodate is less phytotoxic and better tolerated than iodide in leafy vegetables. Iodine distribution among plant organs reflected these physiological responses. Iodine supplementation at 1 mg/L increased iodine concentrations in all tissues, with KI-treated plants accumulating more iodine than KIO_3-treated plants (Landini et al., 2020). Among the plant organs, leaves exhibited the highest iodine concentrations, followed by stems and roots, while swollen taproot regions consistently displayed the lowest accumulation. This distribution pattern is consistent with previous studies, which found that iodine is preferentially transported to metabolically active tissues, likely due to higher transpiration rates (Medrano-Macías et al., 2020). X-ray Absorption Near Edge Structure (XANES) spectroscopy provided additional mechanistic insights, revealing that iodine predominantly accumulated in the reduced form (I^-) in roots, regardless of whether KI or KIO_3 was supplied (Smoleń et al., 2020). This suggests that iodate undergoes reduction to iodide within plant tissues, emphasizing the importance of internal reductive processes during iodine uptake and storage. Such biochemical transformations are crucial for understanding iodine biofortification strategies, as the chemical form of iodine significantly influences its physiological effects and accumulation in plants (Kiferle et al., 2020).

4. Conclusion

Hydroponic supplementation of red radish with KI or KIO_3 effectively biofortifies plants with iodine, enhancing taproot biomass without compromising photosynthetic efficiency. The chemical form and concentration of iodine govern both uptake and distribution, with iodide proving most efficient at low levels and iodate at moderate doses. These results underscore the promise of crop biofortification as a sustainable strategy to combat global iodine deficiency.

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