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ORIGINAL ARTICLE

Morphological and Qualitative Response of Carrot (*Daucus carota)* to Foliar Application of Iodine in southern Guinea Savannah Zone of Nigeria

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Abstract

Carrot is an important vegetable in Nigeria which is cultivated mainly in the Savannah zone. The region suffers from iodine-deficient soils due to its mountainous terrains, valleys, and distance from the ocean. This, coupled with the lack of access to seafood, exacerbates iodine deficiency, leading to conditions such as goitre, impaired cognitive function, and lower fertility in humans and plants. The objectives of this study were to evaluate the effects of foliar-applied iodine levels on growth performances and yield of carrot. Field experiments were conducted at the Teaching and Research Farm, University of Ilorin, Ilorin - Nigeria during 2023 and 2024 cropping seasons using randomized complete block design (RCBD) with four replicates. Treatments were foliar applied potassium iodate (KIO_3) at rates of 0, 3.5, 7.0, 10.5, 14.0 kgha^{-1}. Data on plant growth and yield were collected. Analysis of variance was carried out and means were separated by least significant difference ($p \leq 0.05$). The application of 14 kg ha^{-1} iodine resulted in the highest iodine and β-carotene contents in carrot tubers in both cropping seasons. The same application rate also produced the highest tuber yield during the first cropping season and the highest plant height during the second cropping season. Application of 10.5 kgha^{-1} demonstrated the highest shoot dry matter content in both seasons and the highest tuber yield during the second season. However, increased iodine levels reduced the chlorophyll content in both seasons. The study suggests that foliar application of iodine can improve carrot growth, yield, and nutritional quality. Further research across multiple cropping seasons is recommended to determine the optimum iodine dosage for carrot cultivation.

Keywords*: Cropping season, plant height, β-carotene, dry matter content, yield*

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1. Introduction

Carrot (*Daucus carota* L.) is one of the most widely cultivated root vegetables globally, which is valued not only for its vibrant colour and sweet flavour, but also for its substantial nutritional composition and economic value (Motegaonkar et al. 2024). Carrot is an excellent source of essential nutrients, such as minerals, vitamins, and dietary fibre, making it a vital component of a balanced diet (Ismail et al. 2023). The crop is well known for its high content of β-carotene, a precursor of vitamin A, which is crucial for maintaining healthy vision, skin, and immune functions. In addition, carrot provides significant amounts of vitamins C, K, and several B vitamins while remaining low in calories (Simon 2000; Dias 2014; Ahmad 2019). This combination of low calories and high nutritional value makes it a staple food in many weight-loss diets. Furthermore, carrots contain antioxidants, which help to mitigate oxidative stress and reduce the risk of chronic diseases, such as heart disease and cancer (Baida and Shetty 2020).

Iodine is a crucial micronutrient that plays a significant role in plant growth and development. It is involved in various physiological processes that enhance antioxidant activity, improve stress tolerance, and increase the overall biomass and yield of plants. One of the primary benefits of iodine application in agriculture is its influence in the synthesis of certain plant hormones such as auxins and cytokinins, crucial for plant development and growth regulation (Medrano-Macías et al. 2016). Incorporating iodine into plant nutrition programs can lead to crops that are more robust and resilient, ultimately promoting sustainability and food security (Shalaby 2025).

Micronutrient deficiencies, often referred to as "hidden hunger," are a global health issue affecting more than two billion people worldwide (FAO 2013). In sub-Saharan Africa, the prevalence of micronutrient deficiencies is particularly high, due to poor dietary diversity, low agricultural productivity, and socio-economic challenges (Zimmermann and Andersson 2021). Traditional cultivation methods have not adequately addressed micronutrient deficiencies in carrot cultivation, posing significant challenges to food security and public health. In the Southern Guinea Savannah zone of Nigeria, these deficiencies are particularly acute, exacerbated by its distance from the sea, mountainous terrain, valleys, and socio-economic constraints, such as excessive consumption of goitrogenic rich food such as cassava (*Manihot esculenta* Crantz L.) (Pearce 2013), which is the staple food in the area. Iodine deficiency in soils leads to low iodine content in crops, which may have profound implications on human health by reducing dietary iodine intake, and contributing to disorders such as goitre, impaired cognitive function, and reduced fertility (Zimmermann and Andersson 2021).

Bio-fortification, the process of enhancing the nutritional quality of food crops, offers a sustainable solution to these micronutrient deficiencies (Bhardwaj et al*.* 2022). Agronomic bio-fortification, which involves the application of micronutrient-rich fertilizers, could increase the micronutrient concentration of food crops (Cakmak and Kutman 2018; Nissar et al. 2019; Bhardwaj *et al.* 2022). However, there is limited research on the effectiveness of iodine application in the Southern Guinea Savannah zone of Nigeria. Farmers in this region could enhance the uptake and retention of this trace element by applying iodine containing salts or iodine-rich organic materials, such as seaweed, to their soils. However, seaweeds are not readily available in the Southern Guinea Savannah zone of Nigeria, as its far away from the ocean. Therefore, this study was carried out to evaluate the effects of foliar applied iodine on the growth and yield of carrot, and to assess its impact on the qualitative traits (iodine, β-carotene and leaf chlorophyll contents) of carrot.

2. Materials and Methods

2.1 Site description

A field experiment was conducted at the Teaching and Research Farm, University of Ilorin, Ilorin, Nigeria (8°29^{1}N 04°35^{1}E and 307 m above mean sea level) during the 2023 and 2024 cropping seasons. The site is located in the Southern Guinea Savannah zone of Nigeria with an Alfisol soil belonging to the Bolodunro Series (Ogunwale et al. 2002). The soil depth of the area ranges from shallow to deep, with granite outcrops dotting the landscape. The topsoil is coarse textured and low in organic matter content. In some locations, the soils are highly degraded, and erosion is common, resulting in low soil fertility. The rainfall pattern of the location is bimodal, starting in late March and continuing until July, with the first peak occurring in late July, followed by a break in August. The second part of the rainy season usually starts in late August, reaches its peak in late September, and ends in late October (Akan et al. 2022). The mean annual temperature of the study area is 29°C, while the average annual relative humidity is approximately 85% (FAO 2021). The study was conducted during the rainy season without supplementary irrigation.

2.2 Soil Analysis

Soil samples from all experimental plots were collected at a depth of 0 – 30 cm using a 2.5 × 2.5 m^2 grid and bulked before a composite sample was taken for soil physical and chemical analyses. The collected soil samples were air-dried, ground, and passed through a 2 mm sieve. The sieved soil samples were taken into the laboratory for chemical analysis as described by Carter & Gregorich (2007). Soil organic carbon (C) was determined according to Walkley & Black method using the dichromate wet oxidation procedure (Nelson & Sommers 1996). Organic matter content was estimated by multiplying C by 1.724. Total nitrogen (N) was determined by micro-Kjeldahl digestion and distillation techniques (Bremner 1996), while available phosphorus (Bray-P) was determined in a 1 N NH_4F + 0.5 N HCl extract using the vanadomolybdophosphoric acid method (Kuo, 1996). Soil pH was measured in a soil: water ratio of 1:2 using a glass electrode pH meter. Particle size analysis was done using the hydrometer method (Gee & Or 2002), and the textural class was determined using a textural triangle (Hunt & Gilkes 1992). Exchangeable bases were extracted using 1 N ammonium acetate. Exchangeable potassium (K) and sodium (Na) were determined by flame photometry, while calcium (Ca) and magnesium (Mg) were analysed by atomic absorption spectrophotometry. The iodine content of the soil before and after cropping was determined by iodometry titration with sodium thiosulfate (Kolthoff et al. 1969), while the total iodine concentration in the leaf and tuber samples was determined with the alkaline ash technique (Fisher et al. 1986).

2.3 Sowing

Carrot seeds of variety 'Carotte Touchon' were obtained from an Agro-shop in Ilorin metropolis and sown on a bed measuring 3 x 3 m^2 at a depth of 2 cm, covered lightly with soil to prevent desiccation by sunlight, on the 15^{th} of July 2023 and repeated on 15^{th} July 2024 using the drilling method. The beds were watered regularly. Three weeks after sowing, the plants were thinned out to two plants per stand at a spacing of 30 × 30 cm between and within the rows resulting in 100 plants per plot (111,111 plants ha^{-1}) and 60 plants constituted the net plot, while the remaining 40 plants served as the border rows.

2.4 Experimental Design and Treatment Application

The experiment had five levels (0, 3.5, 7.0, 10.5, 14.0 $kgha^{-1}$) of potassium iodate (KIO_3) laid out in a Randomised Complete Block Design (RCBD) with four replicates. To prepare the treatment solutions, 0, 3.9, 7.8, 11.66, and 15.55 g of potassium iodate were each dissolved in one litre of water to represent the respective application rates of 0, 3.5, 7.0, 10.5, and 14.0 kg ha^{-1}. Potassium iodate was applied as a foliar spray three weeks after sowing.

2.5 Vegetative Traits

At 4, 6, 8, and 10 weeks after sowing (WAS), the height of the stands in the ten tagged plants in the net plot was determined by measuring the distance from the soil level to the tip of the uppermost leaf when stretched upright using a measuring tape and the mean was calculated. The average total number of green leaves per plant was visually assessed and recorded. The fresh weight of harvested carrot tubers from each plot was taken at harvest. At 60 days after sowing, shoot dry matter was recorded by sampling three plants per plot. Sampled shoots were oven-dried at $70^{o}C$ for 48 hours until constant weight and then removed from the oven to cool and weighed.

2.6 β-Carotene Content

The β-carotene was determined by soaking 1 g of the sample (paste of fresh carrot tubers) in 5 ml of methanol for 2 h at room temperature under dark conditions in order to get a complete extraction. The β-carotene layer was separated using hexane through a separating funnel. The volume was made up to 10 ml with hexane, and then this layer was again passed through sodium sulphonate using a funnel in order to remove any moisture from the layer. The absorbance of the layer was measured at 436 nm using hexane as a blank (Ranganna 1999). The β-carotene was calculated using the formula:

β-carotene (μg/g) = Absorbance (436 nm) x V x D x 100 x 100/W x Y, where: V = total volume of extract; D = dilution factor; W = sample weight; Y = percentage dry matter content of the sample.

2.7 Chlorophyll Content

The leaf chlorophyll content was determined using the procedure of Coombs *et al.* (1985).

2.8 Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat statistical package 17*th* edition (Genstat, 2015). Means were separated using the least significant difference at $p \leq 0.05$.

3. Results and Discussion

3.1 Effect of Iodine Bio-fortification on Plant Height (cm)

At 4, 6, 8, and 10 WAS, iodine biofortification had no significant effect on plant height compared to the control in the first cropping season (Table 1). However, 14 kgha^{-1} iodine gave the highest plant height in the second cropping season ($p \leq 0.05$). Iodine might have promoted cell division and expansion, which may have increased the plant height. Iodine plays a role in plant hormone regulation, particularly in the synthesis of auxin, which is involved in cell elongation and division (Pasternak and Steinmacher 2024). Higher iodine concentration (14 kgha^{-1}) might have promoted auxin production, leading to increased plant height. The soils of the savannah are low in iodine, but an increase in iodine application will give a positive result (Eifediyi et al. 2021). This is in contrast to the findings of Singh et al. (2012), who observed that higher concentration of potassium iodide (KI) significantly reduced the plant height of rice genotypes compared to the control. Too much iodine may cause toxicity as was exemplified by the reduction in number of leaves and production of curly endive plants (Sabatino et al. 2019).

Table 1: Effect of iodine biofortification on plant height (cm) of carrot at 4, 6, 8 and 10 weeks after sowing (WAS)

Treatments (kgha^{-1})	**4 WAS**		**6 WAS**		**8 WAS**		**10 WAS**	
	Seasons		Seasons		Seasons		Seasons	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
0	21.85	22.65	33.55	24.65	35.75	26.65	36.7	29.85
3.5	22.5	25.35	29.8	26.7	31.35	28.95	32.2	32.55
7.0	24.55	28.8	32.5	30.85	33.6	33.6	34.1	35.7
10.5	26.75	31.4	28.85	35.1	31.5	37.3	33.5	39.6
14.0	27.1	33.1	41.3	42.5	43.5	44.1	44.2	43.7
LSD (0.05)	NS	4.649*	NS	4.406*	NS	6.647*	NS	4.96*

3.2 Effect of Iodine Biofortification on Number of Leaves

Our outcomes revealed that iodine biofortification had no significant impact on the number of leaves across most sampling periods (Table 2), which is similar to the work of Gonnella et al. (2019), where iodine showed no significant effect on the number of leaves of Brassica vegetables (broccoli raab, curly kale, mizuna, red mustard). This observation suggests that moderate iodine supplementation may not strongly influence vegetative leaf initiation processes. This explanation aligns with reports from lettuce biofortification studies, where iodine treatments increased iodine accumulation but produced limited or inconsistent effects on morphological characteristics (Smoleń et al. 2019). Similarly, Ojok et al. (2019) reported that agronomic iodine biofortification in cabbage and cowpea effectively increased iodine concentration in edible tissues under field conditions, while growth parameters remained largely unaffected at appropriate iodine application rates.

Table 2: Effect of iodine biofortification on number of leaves of carrot at 4, 6, 8 and 10 weeks after sowing (WAS)

Treatments ($kgha^{-1}$)	**4 WAS**		**6 WAS**		**8 WAS**		**10 WAS**	
	Seasons		Seasons		Seasons		Seasons	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
0	13	18	16	18	16	15	18	20
3.5	14	18	17	19	16	16	16	18
7.0	16	21	18	20	19	18	19	21
10.5	15	19	18	20	17	17	18	20
14.0	14	23	19	21	21	16	22	24
LSD (0.05)	NS	3.18	NS	NS	3.28	NS	NS	NS

3.3 Effect of Iodine Biofortification on Chlorophyll, β-Carotene and Tuber-Iodine Contents

In the first and second cropping seasons, there was a reduction in the chlorophyll content in carrot leaves as iodine application increased (Fig. 1 c). Perhaps the reduction in the chlorophyll level was not at the critical growth stage hence the yield of carrot was not significantly affected. This step down in chlorophyll content with an increase in dose was similarly reported by Krzepitko et al. (2016). In addition, increase in iodine content could be toxic to plants, thus inhibit chlorophyll formation leading to reduced photosynthetic activity with resultant chlorosis (Kiferle et al. 2021).

In the first and second cropping seasons, iodine biofortification increased the tuber-iodine content and β-carotene content of carrot, with the application of 14 $kgha^{-1}$ producing the highest ($p \leq 0.05$). This indicates that the application of iodine had no negative impact on the β-carotene level and tuber iodine content (Fig. 1 a and 1 b). This is similar to the result of Signore *et al.* (2018), who reported that the highest iodine content in carrot roots was observed from the highest application dose of iodine applied as a foliar fertilizer.

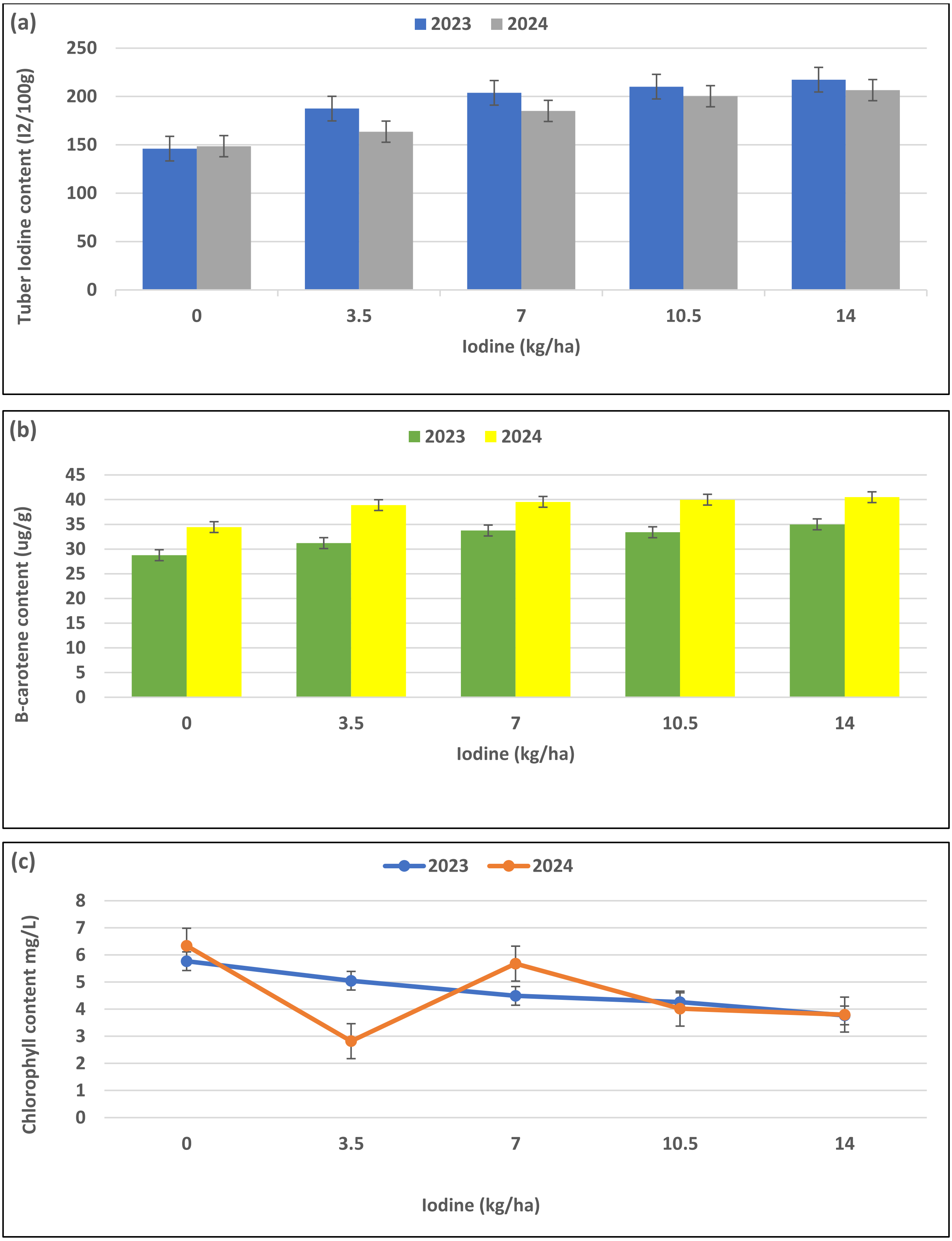

Figure 1. Effect of Iodine Biofortification on tuber Iodine Content, β-carotene Content, and Chlorophyll Content of Carrot in 2023 and 2024 cropping seasons

3.4 Effect of Iodine Biofortification on Tuber Yield of Carrot

Iodine biofortification showed a significant effect on yield of carrot in the first cropping season (Fig. 2 b). Application of 3.5 kg, 7 kg and 10.5 kg of iodine per hectare decreased carrot yield compared to the control by 51.72%, 28.74% and 57.47%, respectively, while 14 kg/ha iodine increased yield by 21.84% ($p \leq 0.05$). Similarly, in the second cropping season, iodine biofortification reduced yield except for 10.5 kg/ha application rate which enhanced yield; although, differences were not significant. The variation in carrot yields following iodine application at 3.5, 7, 10.5, and 14 kg ha^{-1} in 2023 and 2024 can be attributed to the dose-dependent and narrow beneficial range of iodine in crop biofortification. At lower application rates (3.5 and 7 kg ha^{-1}), the observed yield reduction in carrot may be due to insufficient iodine stimulation of beneficial metabolic processes, while still causing mild disruptions in nutrient balance and physiological functioning. According to Cakmak et al. (2017), the addition of iodine to soil in wheat cultivation, resulted in lower yields, even at the lowest dose applied, may be due to phytotoxic effect. Smoleń et al. (2016) further emphasized that carrot is particularly sensitive to iodine concentration, with improper dosing potentially affecting photosynthesis, nutrient uptake, and biomass allocation. This likely explains the inconsistent yield responses observed at intermediate rates.

In contrast, the significant yield increase recorded at 14 kg ha^{-1} suggests that this rate may have reached an optimal threshold for beneficial physiological activation. At appropriate concentrations, iodine has been reported to enhance antioxidant activity, improve metabolic efficiency, and support better nutrient use efficiency (Smoleń et al. 2016), ultimately promoting assimilate production and its translocation to storage roots, resulting in higher yield. Nath et al. (2018) similarly reported that yield of vegetables, including carrot, were improved by iodine application.

3.5 Effect of Iodine Biofortification on Shoot Dry Matter Content

Iodine biofortification showed no significant effect on shoot dry matter content of carrot (shoot dry matter refers to the petioles, leaves and the stems excluding the tubers) (Fig. 2 a). In the first and second cropping seasons, 10.5 kgha^{-1} of iodine increased the shoot dry matter content ($p \leq 0.05$), while other application levels of iodine (3.5 kgha^{-1}, 7 kgha^{-1}, and 14 kgha^{-1}) decreased the dry matter content of carrot. The variable response of carrot shoot dry matter to different iodine levels may also reflect the narrow threshold between beneficial and toxic iodine concentrations in plants. Although iodine is increasingly recognized as a beneficial element for higher plants, its effects are highly dose-dependent. . This result is in conformity with the findings of Eifediyi et al. (2021) who opined the use of potassium iodide at the rate 10.5 kgha^{-1} for amaranths, a leafy vegetable. The lower rates (3.5 and 7 kg ha^{-1}) may have been inadequate to stimulate beneficial metabolic activities associated with iodine nutrition, while the highest rate (14 kg ha^{-1}) may have induced mild phytotoxicity or physiological stress. Excessive iodine concentrations have been associated with oxidative stress, membrane damage, reduced chlorophyll synthesis, and impaired photosynthetic activity, ultimately reducing dry matter accumulation. Comparable findings were reported by Zhu et al. (2003), who noted that excessive iodine concentrations reduced biomass accumulation in spinach and rice because of inhibited photosynthetic efficiency and altered enzymatic activities. Similarly, Blasco et al. (2011) observed that iodine application at optimal concentrations improved biomass production in lettuce, whereas higher concentrations caused reductions in dry matter yield due to toxicity effects. The authors attributed this decline to disruptions in nutrient uptake and metabolic imbalance induced by excess iodine.

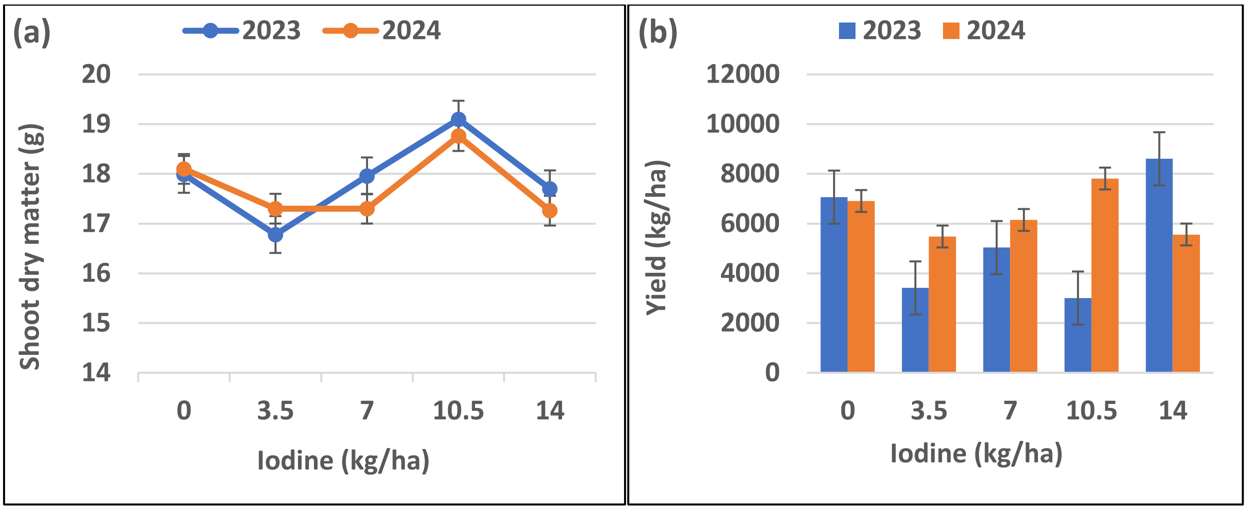

Figure 2. Effect of Iodine Biofortification on Total Shoot Dry Matter Content and Yield of Carrot in 2023 and 2024

4. Conclusions

In conclusion, the findings of this study highlight that the effectiveness of iodine biofortification in carrot production is strongly dependent on the application rate, with specific rates demonstrating superior performance in growth, yield, and nutritional quality across the two cropping seasons. Notably, the application of 14 $kgha^{-1}$ iodine consistently produced the most pronounced improvements in key parameters. This rate significantly enhanced plant height in the second cropping season and resulted in the highest tuber iodine and β-carotene contents in both seasons, indicating its strong potential for improving the nutritional quality of carrot.

In terms of yield, 14 $kgha^{-1}$ iodine also recorded a significant increase in the first cropping season, outperforming all other application rates and the control. However, its effect on yield was not sustained in the second season, suggesting possible seasonal influences or threshold effects associated with iodine application. Conversely, 10.5 $kgha^{-1}$ iodine demonstrated some advantage in improving shoot dry matter content across both seasons and showed relatively better yield performance in the second season, although not statistically significant.

Overall, while lower application rates (3.5 kgha^{-1} and 7 kgha^{-1}) were largely ineffective or even detrimental to yield and dry matter accumulation, and higher iodine levels posed potential risks of reduced chlorophyll content, the 14 kgha^{-1} rate emerged as the most effective for enhancing nutritional quality and, under favourable conditions, growth and yield. Therefore, 14 kgha^{-1} iodine is recommended as the most promising rate for iodine biofortification of carrot, though its application should be carefully managed to account for seasonal variability and to avoid potential phytotoxic effects. Further research is recommended to refine optimal application rates and understand seasonal variability to ensure sustainable and efficient use of iodine in crop production systems.

Nomenclature

Not applicable

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Conflicts of Interest

The authors declare no competing interests

Data Availability

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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