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Potassium iodide influence on iodine-leaf concentration and growth of amaranth (*Amaranthus cruentus* L.)

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Abstract

Low iodine content in soils is a common feature in lowland and in mountainous regions far from oceans. The diets of the people living in these regions are often deficient in dietary iodine, resulting in chronic iodine deficiency syndrome, goiter, hearing loss and other debilitating diseases. A field experiment was conducted at the Teaching and Research Farm, University of Ilorin, Nigeria during the 2017 and 2018 cropping seasons, to evaluate the response of amaranths to iodine enrichment using an agronomic approach. The trial consisted of potassium iodide (KI) applied as foliar spray at 0, 3.5, 7, 10.5, 14 kg ha^{-1} and soil applied at the rates of 4, 8, 12 and 16 kg ha^{-1}. These treatments were in four replicates laid out in a randomized complete block design. Data were collected on plant height, number of leaves, leaf area, crop growth rate, yield and iodine-leaf concentration. The data were subjected to analysis of variance (ANOVA) followed by mean separation using Duncan's Multiple range test $p < 0.05$. The results indicated that the use of KI improved the growth of amaranthus at the low level of application, but foliar application at 10.5 and 14 kg ha^{-1} yielded the highest iodine leaf concentration. Although application of iodine in amaranthus improved iodine leaf concentration, there was a colour change at higher rates of application which may affect the acceptability of the vegetable by consumers.

Keywords: Bio-fortification, micronutrient malnutrition, performance, amaranths

1 Introduction

Iodine deficiency in soils is common in many parts of the world due to irregular distribution of the mineral in the earth crust (FAO, 2009). The phenomenon is more pronounced in lowlands and in mountainous regions, and in individuals who excessively consume food rich in goitrogenic substances such as cassava (*Manihot esculenta* Crantz) and cabbage (*Brassica oleracea* L.) (Abua *et al*., 2008; Pearce *et al*., 2013). Estimates show that over two billion of the world population is at the risk of iodine deficiency disorders (Mottiar, 2013; Lazarus, 2015). The sources of iodine supplementation are mainly sea foods, which are expensive, especially for inhabitants of developing countries, whose staple diets are cereals, roots and tuber crops. Iodized salt, an alternative source of iodine, is volatile and allergenic to some individuals especially to hypertensive patients. Although, iodine is naturally present in negligible amounts in eggs, meat, dairy products and to some extent in grains and vegetables (Kiferle *et al*., 2013), for most adults its contents in these food sources cannot supply the recommended daily intake of 150 μg day^{-1} (WHO, 2014). To bridge this gap, the use of nutrient enrichment in food items or bio-fortification using agronomic approaches is necessary.

Bio-fortification refers to an enrichment of food crops with nutrients. Many methods are used for bio-fortification, but the cheapest is the agronomic method using mineral fertiliser. Substantial progress has been made in the bio-fortification of leafy vegetables such as spinach (Basella alba), Chinese cabbage (*Brassica campestris* var. *chinensis*), lettuce (*Lactuca sativa*) and celery (*Apium graveolens*) (Dai *et al*., 2004; Hong *et al*., 2009; Voogt *et al*., 2010). These vegetables are exotic and do not form part of the daily diet of millions of people living in the savannah zone of Nigeria. Bio-fortification of edible crops for human consumption is

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an approach for controlling malnutrition especially among dietary vulnerable groups in poor countries who have no access to mineral supplements (Nestel *et al.*, 2006).

Amaranth (*Amaranthus cruentus* L.) which belongs to the Amaranthaceae is an important vegetable crop, whose leaves are cultivated for human consumption (Fasuyi *et al.*, 2008). Apart from its use as a vegetable, it has also been used as an effective alternative to drug therapy of hypertensive and cardiovascular diseases (Martirosyan *et al.*, 2007). The crop is consumed by all population classes irrespective of their social status together with cereals, roots and tuber crops, the staple food of millions of people living in the savannah zone of Nigeria. The objective of this study was to determine the effects of potassium iodide (KI) amended to the crop on the iodine-leaf concentration, growth and yield of amaranth.

2 Materials and methods

2.1 Site description and treatments

A field experiment was conducted at the Teaching and Research Farm, University of Ilorin, Ilorin, Nigeria (8°29′ N 04°35′ E, 307 m above sea level), during the 2017 and 2018 cropping seasons. The site is located in the southern Guinea savannah zone of Nigeria on an Alfisol belonging to the Bolodunro Series (Ogunwale *et al.*, 2002). The soil depth of the area ranges from shallow to deep with granite outcrops throughout the landscape. The surface soils are coarsely textured, low in organic matter content and in some locations, the soils are highly degraded and erosion of the top soil is common, leading to low soil fertility. The rainfall pattern of the location is bimodal, starting in late March to July with the first peak in late July followed by a break in August. The second part of the rainy season usually starts in late August with a peak in late September and ends in late October. The annual rainfall for the location was 1562 mm in 2017 and 991 mm in 2018. The mean annual temperature of the study area is 29 °C while the average annual relative humidity is about 85 %. The study was conducted under rain-fed conditions without supplemental irrigation.

2.2 Germination test of the seeds

Before the commencement of the study amaranth seeds were tested for their viability using a standard germination test whereby seed viability was >96 %.

2.3 Experimental layout and sowing

The land was ploughed and harrowed before marking out the plots and making raised seed beds. Plot size was 3×3 m with 0.50 m between plots as suggested by Asher *et al.* (2002) for densely populated vegetable crops. Amaranthus cruentus seeds were obtained from the National Horticultural Research Institute of Nigeria (NIHORT), Ibadan Oyo State, Nigeria and drilled into the soil on 15 July 2017 and again on 15 July 2018. Subsequently, seeds were covered lightly with soil to prevent desiccation by sunlight and later thinned to one seedling 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}); sixty plants constituted the net plot while the 40 remaining plants constituted the border rows.

2.4 Experimental design

The experiment was laid out as a randomized complete block design (RCBD) with four replications. The treatments imposed were potassium iodide (KI) applied as a foliar spray at the rates of 0, 3.5, 7, 10.5 and 14 kg ha^{-1} and as fertiliser to the soil at 4, 8, 12, and 16 kg ha^{-1} . These treatments were combined with a basal NPK 15:15:15 fertiliser application (300 kg ha^{-1}) three weeks after sowing. Potassium iodide was soil-applied 5 cm away from the plant using a side-band placement method while the foliar treatments were applied mid-morning using a knapsack sprayer following Shaw *et al.* (2007) and Tschiersh *et al.* (2009). Both iodine treatments were repeated in the second season given low iodine accumulation in the soil (Lawson *et al.*, 2015).

2.5 Soil and leaf analyses

Soil samples from all experimental plots were collected at a depth of 0–30 cm using a 2.5×2.5 m grid and bulked before a composite was taken for physical and chemical analyses. The soil samples collected were air-dried, ground, and passed through a 2 mm sieve. The sieved soil samples were taken to the laboratory for chemical analysis as described by Carter & Gregorich (2007). Soil organic carbon (C) was determined according to Walkley& Black using the dichromate wet oxidation method (Nelson & Sommers, 1996). Organic matter was estimated by multiplying carbon by 1.724. Total N was determined by micro-Kjeldahl digestion and distillation techniques (Bremner, 1996), and available phosphorus (Bray-P) was determined in a 1N NH4F + 0.5N HCl extractant by the vanadomolybdophosphoric acid method (Kuo, 1996). Soil pH was measured in a soil: water ratio of 1:2 using a glass electrode. Particle-size analysis was done using the hydrometer method (Gee & Or, 2002) and the textural class was determined with a textural triangle (Hunt & Gilkes, 1992; Brady & Weil, 1999). Extraction of exchangeable bases was done by 1N 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 samples was determined with the alkaline ash technique (Fisher *et al.*, 1986).

2.6 Vegetative traits

At 4, 6, 8 and 10 weeks after sowing (WAS) plant height was assessed as the distance from the soil level to the terminal point of the stem in fifteen randomly selected tagged plants using a measuring tape. At the same time, the number of leaves was determined and leaf area following the procedure of Law-Ogbomo & Ajayi (2009) which is length × breadth × 0.64. Two plants from the gross plots were harvested at each sampling period, oven dried at a temperature of 60 °C until a constant weight was attained to determine the Relative Growth Rate (RGR) according to Williams (1946):

$$RGR = \frac{log_e W_2 - log_e W_1}{t_2 = t_1}$$

Where, W_1 and W_2 are whole plant dry weight at t_1 and t_2, respectively, and t_1 and t_2 are time interval in days.

2.7 Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the Genstat statistical package 17^{th} Edition (Genstat, 2015). Means were separated using the Duncan‘s multiple range test at $p < 0.05$.

3 Results

3.1 Soil Properties

Soil pH was slightly acidic and organic carbon was very low, N, P, Ca and Mg concentrations were low, whereas soil K concentration was moderate (Table 1).

3.2 Plant height

Mean plant height of amaranth differed significantly at 4 WAS in the two seasons (Annex 1); however, at the following observation points only statistical differences have been found for the second season. These differences did not show a clear pattern between foliar and soil KI applications. At 7 WAS, foliar amended KI plots produced plants which were about 19 % and -2 % taller than the control in the first and second season, respectively, and soil amended KI plots showed 13 % and -15 % taller plants, respectively.

3.3 Number of leaves

In the first season at 4 WAS, the mean number of leaves produced did not show a clear pattern between treatments (Annex 2). However, in the second season, the foliar amended plots produced the highest number of leaves which was significantly different ($p < 0.05$) from the other treatments and the number of leaves produced were about 86.5 % higher than observed for the soil amended KI at 16 kg ha^{-1}. Treatment effects differed over the two seasons.

3.4 Leaf area

At 4 WAS, the soil amended KI treatments produced the highest leaf area which was about 50 % and 100 % more than

Table 1: *Physical and chemical properties of the experimental soil at Ilorin (Nigeria) before sowing in 2017.*

Parameter	*Before planting*
pH in H_20	6.37
Organic C (%)	0.09
N (%)	0.05
Bray1-P (mg kg^{-1})	6.12
Exchangeable Ca (cmol kg^{-1})	3.12
Exchangeable Mg (cmol kg^{-1})	0.17
xchangeable Na (cmol kg^{-1})	0.15
Exchangeable K (cmol kg^{-1})	0.41
Total I (mg kg^{-1})	1.20
Sand (%)	89.0
Silt (%)	6.96
Clay (%)	5.24
Textural class	sandy loam
Soil classification	Alfisol

Table 2: *Effect of different rates of foliar and soil applied potassium iodide (KI) on the relative crop growth rate (RGR) of amaranth in 2017 and 2018.*

Treatments	*KI Rate* ($kg\ ha^{-1}$)	*4–5 WAS*		*5–6 WAS*		*6–7 WAS*	
				Seasons			
		1	*2*	*1*	*2*	*1*	*2*
Control	0	0.31	0.38	0.53	0.30	0.84	0.77
Foliar	3.5	0.21	0.30	1.43	1.54	1.16	1.00
Foliar	7.0	0.15	0.31	1.36	1.09	1.14	0.72
Foliar	10.5	0.12	0.37	1.37	1.12	0.67	0.63
Foliar	14.0	0.30	0.31	1.95	1.14	1.31	0.90
Soil	2.0	0.34	0.47	2.22	0.85	0.91	0.92
Soil	4.0	0.22	0.32	2.23	1.09	1.46	0.82
Soil	8.0	0.36	0.57	1.17	1.61	0.70	1.10
Soil	16.0	0.17	0.37	0.75	1.14	0.66	0.71
s.e.d. ($p < 0.05$)		NS	NS	NS	NS	NS	NS

WAS: weeks after sowing; s.e.d.: Standard error of difference; NS.not significant

the control in the first and second season, respectively (Annex 3). At 5 WAS, the soil amended KI at 16 kg ha^{-1} produced the highest leaf area which was 44 % and 56 % more than the control in the first and second seasons, respectively. At 7 WAS, the soil amended KI treatments produced the highest leaf area which was 100 % and 125 % more than the foliar amended KI in the first and second seasons, respectively.

3.5 *Crop growth rate*

At 4–5 WAS, in the first and second season, no particular order in RGR was observed, but the soil amended KI at 8 kg ha^{-1} had the fastest growth rate (Table 2). This increase in growth rate was about 14 % and 33 % higher as the control in the first and second season, respectively. Also in the period 5–6 WAS, no treatment effect in RGR was observed; however, the overall soil amended KI treatments showed a 67 % and 74 % higher RGR as compared to the control in the first and second season. Between 6–7 WAS in the first season the foliar applied KI treatments showed higher RGR values than the other treatments; the same was the case for the soil applied KI treatments during the second season.

3.6 *Iodine - leaf concentration and consumable leaf yield per hectare*

Iodine-leaf concentration was highest for foliar applied KI at 10.5 kg ha^{-1} and 14 kg ha^{-1} with 0.14 mg kg^{-1} in both seasons (Table 3) which was significantly different from the control (0.09 in the first and 0.11 mg kg^{-1} in the second season). The overall seasonal and treatment mean showed a 21.6 % and 15.0 % higher Iodine - leaf concentration for foliar applied KI and soil applied KI, respectively, as compared to the control.

The effect of KI application on the amaranth yield per hectare indicated that soil applied KI at 4.0 kg ha^{-1} produced the highest yield of 6.10 t ha^{-1} followed by soil applied KI at 16.0 kg ha^{-1} (5.28 t ha^{-1}) and soil applied KI at 8.0 kg ha^{-1} (5.11 t ha^{-1}) in the first season while in the second season, the foliar amended KI plots produced the highest yield which was similar to the yield in the soil amended KI treatments at 4 kg ha^{-1} and 16 kg ha^{-1}. The overall fertiliser effect of KI application on leaf yield was negligible, -1.8 % for foliar applied and 4.8 % for soil applied KI over all treatments and seasons as compared to the control.

4 Discussion

4.1 *Soil properties*

The low nutrient status of the experimental soil can be attributed to the granitic base rock as a parent material followed by continuous cropping with little or no fallow periods reflecting increasing population pressure and infrastructural development in the area. The soil texture was a sandy loam at a pH of 6.4 which is within a range ideal for vegetable production (Olaniyi & Ojetayo, 2010). The low iodine content of the experimental soil may be attributed to the fact that iodine binds firmly to organic matter and also to aluminium oxides (Johanson, 2000).

Table 3: *Effect of different rates of foliar and soil applied potassium iodide (KI) on the iodine - leaf concentration and consumable leaf yield per hectare of amaranth in 2017 and 2018.*

		Iodine concentration ($mg\,kg^{-1}$) dry matter		*Consumable leaf Yield ($t\,ha^{-1}$)*	
		Seasons			
Treatments	*KI Rate ($kg\,ha^{-1}$)*	*1*	*2*	*1*	*2*
Control	0	0.09e	0.11b	4.20b	4.00a
Foliar	3.5	0.11c	0.11b	2.75c	3.94ab
Foliar	7.0	0.12b	0.12b	4.17b	4.95a
Foliar	10.5	0.14a	0.14a	4.14b	4.56a
Foliar	14.0	0.14a	0.14a	3.99b	4.00a
Soil	2.0	0.10d	0.11b	4.46b	2.50b
Soil	4.0	0.11c	0.12b	6.10a	4.95a
Soil	8.0	0.13a	0.12b	5.11ab	3.56b
Soil	16.0	0.12b	0.13a	5.28a	3.50b
s.e.d. ($p < 0.05$)		0.006	0.017	1.12	1.071

s.e.d.: Standard error of difference; NS: not significant; mean followed by the same letter(s) do not differ from each other

4.2 *Effects of potassium iodide on the vegetative growth of amaranth*

The KI application did not affect plant height of amaranths at early stages of the plant growth especially for soil applied KI. However, at later stages of growth, such positive growth effects started to become visible even when they were not statistically significant. The inconsistent response of amaranth to iodine application in the study could be attributed to the fact that iodine is not an essential plant nutrient (Johanson, 2000). There was no major effect of KI on the number of leaves especially at the first season and at early stages of plant establishment in both seasons. The decline in leaf number could be attributed to negative effects of foliar applied KI which resulted in a decolouration of leaves leading to lower assimilate production. This observation is in agreement with Mackowiak & Grossl (1999), Blasco *et al.* (2008), and Piatkowska *et al.* (2016). This effect was also in concordance with the results of Hong *et al.* (2008) and Weng *et al.*(2008) for different vegetable species as these authors observed deleterious effect of iodine doses ≤ 50 mg kg soil^{-1}. Our results were also consistent with those of Huang *et al.* (2003) stating that excessive iodine is poisonous to plants and different plants exhibit different sensitivities to iodine toxicity. However, there was no change in leaf colour after soil application of KI. Leaf number was reduced in foliar treated plants as the rate of application increased from 7 – 14 $kg\,ha^{-1}$, especially the older leaves changed to mottled colour which may have infringed on photosynthesis and led to lower production of assimilates resulting in low biomass production and also suggesting iodine toxicity. This agrees with the findings of Lehr *et al.* (1958) who reported that at higher concentrations, iodine can be toxic leading to leaf damage, stunted growth and death. The reduction in the leaf area at later stages of growth could be adduced to the reduction in the leaf size, chlorosis and senescence of older leaves, especially in foliar treated plants. This is consistent with the findings of Smolen *et al.* (2011) who reported no significant difference in biomass production in butter head lettuce and carrot with iodine bio-fortification. The lowest crop yield was noticed at the highest rates of application (both foliar and soil) which may be a result of detrimental effects on crop leaves while an application rate of 4 $kg\,ha^{-1}$ produced the highest yield. Also Dai *et al.* (2004) reported that iodine application rates $> 5\,mg\,kg^{-1}$ reduced the yields of many crops. Soil applied KI produced the highest amaranth yield which may have been due to a slower absorption of iodine by the crop compared to foliar sprays (Shaw *et al.*, 2007). In all cases the accumulated iodine in the leaves was below the recommended dietary allowance for adults which is between 150 - 200 µmg per day (Pearce *et al.*, 2004).

5 Conclusions

Foliar iodine application led to higher iodine leaf concentration compared to soil application, but soil application led to highest growth and yield. Higher rates of KI application resulted in severe discoloration of the leaves during the two cropping seasons. Leaf chlorosis and necrosis observed for foliar applied KI may hinder the acceptability of iodine sprayed leaves by amaranth producers and consumers. However, the use of KI foliar at 10.50 kg ha^{-1} is recommended for application by farmers for higher iodine-leaf content in amaranths.

Supplement

The supplement related to this article is available online on the same landing page at: https://doi.org/10.17170/kobra-202104133654 .

Conflict of interest

The authors declare that they have no conflict of interest.

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