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Research Article

Effect of chitosan iodate complex biofortification on nutrient uptake in 'shivam' hybrid of tomato (*Solanum lycopersicum L.*)

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Abstract

Iodine deficiency occurs when iodine levels in the soil are inadequate, resulting in limited crop uptake and, as a result, a population with insufficient iodine intake. Iodine deficiency can be avoided by biofortifying commonly consumed crops with iodine. A field experiment was conducted to investigate the effect of iodine biofortification on the nutrient uptake of fruits and plants of 'shivam' hybrid tomato. Potassium iodate and chitosan were applied in the form of soil, foliar, and chitosan iodate complex with control comprising 16 treatments (T_1 to T_{16}) at different stages of plant growth. Iodine accumulation in tomato fruits and plants was achieved by combining foliar and iodine chitosan forms as electrostatic interaction between chitosan and iodate prevents volatilization and gradually increases the bioavailability of iodine from soil to fruits. Biofortification of iodine throughT_{14}- Chitosan -KIO_3Complex ($CsKIO_3$) - (SA)-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT the iodine content in tomato fruit at green (0.95ppm), pink (1.01ppm) and red ripen (0.99ppm) stages of tomato and introducing it in present-day daily diet may help to reduce iodine deficiency disorder. Iodine biofortification also influenced the uptake of nitrogen, phosphorous and potassium in plants and fruits of tomatoes.

Keywords: Biofortification, Chitosan, Iodine, Tomato, Volatilization

INTRODUCTION

Iodine is a trace element that may be found in some foods naturally. Baumann discovered iodine in the thyroid gland.Although iodine is not regarded as a micronutrient by higher plants, it is necessary for animals. Thyroid hormones play a role in a number of physiological activities, such as maintaining proper metabolism, preserving the central nervous system, and performing reproductive tasks (Alagawany *et al*., 2021). Thyrotropin (Thyroid Stimulating Hormone) is a hormone secreted by the pituitary gland that regulates thyroid hormone production and secretion. It also guards against hypothyroidism and hyperthyroidism. TSH secretion promotes iodine absorption by thyroid hormones and boosts T3 (triiodothyronine) and T4 (thyroxine) synthesis and release. In the lack of sufficient iodine, the TSH level remains elevated, resulting in goitre, which is an expansion of the thyroid gland caused by the body's attempt to capture more iodine from the circulation and generate thyroid hormones (Bertinato*et al*., 2021).

A lack of iodine-rich foods causes iodine deficiency disorders, a scarcity of this element in cultivated soils, a shortage of iodine in drinking and irrigation water, significant fixation of this element by soil organic matter, and a lack of appropriate enrichment in finished foods (Mandi *et al*., 2021). Iodine supplementation using iodized table salt is a successful method of including this microelement in the human diet to combat iodine deficiency (Sularz *et al*., 2020). Commercial table salt is added with potassium iodate (KIO_3) to provide 30 mg of iodine per kg of salt (0.003%). It has been found that a total of 50% of the iodine in salt is lost through cooking, shipping, and exposure to light, heat, and moisture (Tadesse*et al*., 2022). According to the World Health Organization (WHO, 2013), the recommended daily intake of iodine for adults is 150 µg. The average daily salt consumption per individual should be around 10 g to satisfy the body's requirement.

Agronomic biofortification of food plants with iodine has been proposed as a new technique to address human iodine insufficiency. Crops can boost the absorption and concentration of this trace element by adding iodine-containing salts or iodine-rich organic materials (e.g., seaweed) to soils (Dávila-Range l*et al*., 2019). Iodine deficiency can be avoided by adding iodine biofortification to commonly consumed crops. Potassium iodide (KI), potassium iodate (KIO_3), potassium per iodate (KIO_4), and iodoacetic acid (CH_2ICOO^-) are significant iodine transporters. The most popular of them is potassium iodate, which is used to biofortify crops (Ojok *et al*., 2019). Chitosan is a biodegradable natural polycationic linear polysaccharide derived from chitin, which is also used as a trace metal complexing agent.If iodine is applied as a chitosan-iodate complex, the absorption of iodine will be boosted (Kanmani*et al*., 2017). Under natural circumstances, 80% of the iodine in a person's body comes from vegetable food, while iodine's bioavailability in diet can reach up to 98%. Tomato (*Solanum lycopersicum L.*) is considered one of the most important vegetable crops globally for fresh market and processed products owing to its health and economic value (Abdelgawad *et al*., 2019). Due to their wide distribution and high fresh food consumption, tomatoes are an ideal target crop for a fortification study. The objective of the present study was to assess the potential of chitosan iodate complex on nutrient uptake in plants and fruits of 'shivam' hybrid tomato.

MATERIALS AND METHODS

To know the effect of biofortified iodine in plant and fruit parts ofshivam hybrid tomato, a field experiment was carried out in *kharif* season during the year 2021 in Viraliyur village of Thondamuthur block of Coimbatore district of Tamil Nadu (GPS value: 10°.9′99.284‴N; 76.7′82.652″E). Iodine was biofortified through soil, foliar and chitosan iodate complex mechanism. The experiments were performed in randomized block design with three replications in Palaviduthi soil series using hybrid tomato "Shivam". Each plot had a gross size of $28m^2$. The treatments were T_1- KIO_3-Soil Application(SA)- $5kgha^{-1}$, T_2- KIO_3- Soil Application(SA)- $10Kgha^{-1}$, T_3- Chitosan-KIO_3Complex-$5Kgha^{-1}$, T_4- Chitosan-KIO_3 Complex-$10Kgha^{-1}$, T_5- Foliar Application (FA)-KIO_3-0.2% @ 60 and 90 DAT , T_6- Foliar Application (FA)-KIO_3-0.3% @ 60 and 90 DAT , T_7- KIO_3- Soil Application(SA)- $5Kgha^{-1}$ + Foliar Application (FA)-KIO- 0.2% @ 60 and 90 DAT, T_8- KIO_3- Soil Application(SA)- $10Kgha^{-1}$ + Foliar Application (FA)-KIO^-_3- 0.2% @ 60 and 90 DAT, T_9- Chitosan-KIO_3 Complex-$5Kgha^{-1}$ + Foliar Application (FA)-KIO_3-0.2% @ 60 and 90 DAT, T_{10}-Chitosan-KIO_3 Complex-$10Kgha^{-1}$ + Foliar Application (FA)-KIO_3-0.2% @ 60 and 90 DAT, T_{11}- KIO_3- Soil Application(SA)- $5Kgha^{-1}$ + Foliar Application (FA)-KIO_3 - 0.3% @ 60 and 90 DAT, T_{12}- KIO_3- Soil Application (SA)- $10Kgha^{-1}$ + Foliar Application (FA)-KIO_3- 0.3% @ 60 and 90 DAT. T_{13}- Chitosan-KIO_3 Complex-$5Kgha^{-1}$ + Foliar Application (FA)-KIO_3-0.3% @ 60 and 90 DAT, T_{14}-Chitosan-KIO_3 Complex-$10Kgha^{-1}$ + Foliar Application (FA)-KIO_3-0.3% @ 60 and 90 DAT, T_{15}- Chitosan Spraying (control) and T_{16}- Water Spraying (Absolute Control). All the treatments received the common recommended dose of fertilizer for tomato (N: P_2O_5: K_2O @ 200:250:250 kg ha^{-1}) except control. The plants were grown in medium black clay loam soil, which was low in nitrogen and medium in organic carbon, phosphorous and potassium. The soil was neutral in pH and non-saline in Electrical conductivity. Fruit and plant samples were collected during green, pink and red ripen harvest stages and pooled together to determine the nitrogen, phosphorous and potassium content. The iodine concentration was measured at all the harvest stages using inductively coupled Plasma–optical emission spectrometry following Knapp *et al*., 1998 procedure. The data obtained from plants and fruits were subjected to one-way ANOVA. The programme IBM SPSS® Statistics, version 25 was used to run all statistical tests.

RESULTS AND DISCUSSION

The observations from the present study indicated that the application of Chitosan-KIO_3 Complex-$10Kgha^{-1}$ + FA-KIO_3-0.3% @ 60 and 90 DAT (T_{14})resulted in highest nitrogen uptake in plants and fruits of tomato followed by Chitosan-KIO_3 Complex-$10Kgha^{-1}$ + FA-KIO_3-0.2% @ 60 and 90 DAT (T_{10}) (Table1 and 2). The synergistic interaction between nitrate nitrogen and the iodate ion was responsible for the treatment's highest nitrogen uptake. Spinach plants fertilized with KIO_3 had higher levels of nitrate nitrogen content in their leaves, indicating that iodate and nitrate work together synergistically (Smolen *et al*., 2019). The amount and kind of iodine supplied to the soil significantly impacts the nitrogen metabolism in soil (Grzanka *et al*., 2020). Instead of potassium iodide, potassium iodate (KIO_3) can increase the amount of nitrate nitrogen in the soil (KI). They added that nitrate reductase function might likely be hindered, resulting in increased nitrate nitrogen absorption by plants. Further the foliar application of potassium iodate resulted in lesser uptake of nitrogen when compared to soil application. This is clear considering that iodine has a harmful effect on plants, resulting in chlorosis, inward rolling of leaves, brown areas, and leaf drop (Rehman *et al*., 2021). This may have lowered transpiration, leading to decreased nitrogen uptake by plants since there was less transpiring pull in the soil, which is a crucial factor for N-movement in the soil to reach the root surface.

In the present study, the uptake of phosphorous in the leaves and fruits of tomato was significantly influenced by the application of potassium iodate and chitosan (Table 1 and 2).. Higher uptake of phosphorous was noticed on combined Cs-KIO$_3$ and FA- KIO$_3$ treatments (T_9, T_{10}, T_{13} and T_{14}). Foliar spray of KIO$_3$ resulted in lesser phosphorous uptake in both crops compared to other treatments. Since KIO$_3$ contains 18% potassium, it may have a stimulatory effect on tomato crop plant growth. Iodate ion's influence the orthophosphate anion (Court *et al*., 2018). Further, soil application of KIO$_3$ alone does not adversely affect phosphorous uptake by plants and fruits compared with other treatments. This could be due to the presence of soil organic matter, which holds iodine in the soil and inhibits it from being absorbed by plant roots. As a result, iodate ions added to soil may not affect phosphorus uptake by plant roots (Kutlu *et al*., 2022).

Contrary to the uptake of nitrogen and phosphorous foliar application of KIO$_3$ alone increased the uptake of potassium in tomatoes. It was observed in the present study the highest potassium uptake was recorded in combined Cs-KIO$_3$ and FA- KIO$_3$ treatments (T_9, T_{10}, T_{13} and T_{14}) in both crops' plants and fruits (Table 1 and 2). The increased uptake of K in the crop might result from the increased availability of K in the soil due to the application of potassium iodate, which contains 18% K (Nezami *et al*., 2021). Two foliar sprays of KIO$_3$ along with SA -KIO$_3$ or Cs-KIO$_3$ complex increased the potassium uptake compared to the treatments that received one foliar spray. Soil application of KIO$_3$ resulted in lower uptake of potassium, because the applied potassium might have fixed in the soil. But foliar application of potassium will be directly absorbed by the plant canopy leading to increased uptake and the close synchronisation between the period of foliar spray and the potassium demand (Chen *et al*., 2021). Further, potassium uptake was higher in combined soil and foliar application of potassium iodate rather than in foliar spray of KIO$_3$alone.This could be due to increased potassium availability through the soil as well as a foliar spray of KIO$_3$. Production of organic and inorganic acids leads to solubilization of native nutrient compounds and increased availability of plant nutrients which might have improved tomato plants' ability to draw more nutrients from the soil (Yadav *et al*., 2016).

Chitosan-KIO$_3$ Complex-10 Kg ha^{-1} + FA-KIO$_3$-0.3% @ 60 and 90 DAT (T_{14}) recorded higher uptake in plants and fruits at different harvest stages of tomato in the current study (Fig 1 and 2). The uptake of iodine

Table 1. Effect of potassium iodate and iodine chitosan complex on plant NPK uptake (Kg ha^{-1}) of tomato

Treatments	**N Uptake**	**P Uptake**	**K Uptake**
T_1- Soil Application (SA) – KIO$_3$ - 5Kgha^{-1}	19.87^{jk}	4.58^{k}	36.95^{kl}
T_2- Soil Application (SA) – KIO$_3$ - 10Kgha^{-1}	23.45^{ij}	5.97^{j}	40.76^{jk}
T_3- Chitosan-KIO$_3$ Complex (CsKIO$_3$) – (SA) -5Kgha^{-1}	26.86^{hi}	6.32^{ij}	43.89^{ij}
T_4- Chitosan-KIO$_3$ Complex (CsKIO$_3$) – (SA)-10Kgha^{-1}	29.57^{gh}	6.59^{hij}	46.12^{hi}
T_5- FA-KIO$_3$-0.2% @ 60 and 90 DAT	18.24^{g}	4.25^{hi}	49.47^{gh}
T_6- FA-KIO$_3$-0.3% @ 60 and 90 DAT	18.69^{f}	4.42^{gh}	51.68^{fg}
T_7- SA- KIO$_3$-5Kgha^{-1} + FA-KIO$_3$- 0.2% @ 60 and 90 DAT	39.27^{e}	7.48^{fg}	54.61^{ef}
T_8- SA- KIO$_3$-10Kgha^{-1} + FA-KIO$_3$-0.2% @ 60 and 90 DAT	43.51^{d}	7.81^{ef}	58.79^{de}
T_9- Chitosan-KIO$_3$ Complex (CsKIO$_3$) – (SA)-5Kgha^{-1} + FA-KIO$_3$-0.2% @ 60 and 90 DAT	53.24^{b}	8.92^{cd}	73.56^{c}
T_{10}-Chitosan-KIO$_3$ Complex (CsKIO$_3$) - (SA)-10Kgha^{-1} + FA-KIO$_3$-0.2% @ 60 and 90 DAT	59.88^{a}	9.62^{ab}	83.21^{ab}
T_{11}- SA- KIO$_3$-5Kgha^{-1} + FA-KIO$_3$- 0.3% @ 60 and 90 DAT	47.21^{c}	8.31^{de}	63.46^{d}
T_{12}- SA- KIO$_3$-10Kgha^{-1} + FA-KIO$_3$-0.3% @ 60 and 90 DAT	50.96^{b}	8.59^{cd}	69.87^{c}
T_{13}- Chitosan-KIO$_3$ Complex (CsKIO$_3$) – (SA)-5Kgha^{-1} + FA-KIO$_3$-0.3% @ 60 and 90 DAT	57.69^{a}	9.15^{bc}	78.91^{b}
T_{14}- Chitosan-KIO$_3$Complex(CsKIO$_3$) - (SA)-10Kgha^{-1} + FA-KIO$_3$-0.3% @ 60 and 90 DAT	61.23^{a}	9.88^{a}	86.45^{a}
T_{15}- Chitosan Spraying	17.72^{kl}	4.16^{k}	32.16^{lm}
T_{16}- Water Spraying	15.34^{l}	3.24^{l}	29.24^{m}
Mean	**38.29**	**7.15**	**56.19**
S.Ed	1.75	0.31	2.50
C.D(0.05)	3.58	0.63	5.12

a-j Different letters indicate differences according to the probability value (P)

Table 2. Effect of potassium iodate and iodine chitosan complex on fruit NPK uptake (Kg ha^{-1}) of tomato

Treatments	**N Uptake**	**P Uptake**	**K Uptake**
T_1- Soil Application (SA) – KIO_3 - 5Kgha^{-1}	31.42^{j}	8.32^{kl}	73.25^{jk}
T_2- Soil Application (SA) – KIO_3 - 10Kgha^{-1}	36.57^{i}	8.79^{jk}	76.51^{j}
T_3- Chitosan-KIO_3 Complex ($CsKIO_3$) – (SA) -5Kgha^{-1}	40.91^{hi}	9.43^{j}	89.85^{i}
T_4- Chitosan-KIO_3 Complex ($CsKIO_3$) – (SA)-10Kgha^{-1}	43.41^{h}	9.81^{ij}	93.24^{hi}
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	29.70^{g}	7.52^{hi}	96.98^{ghi}
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	30.45^{g}	8.13^{gh}	99.42^{gh}
T_7- SA- KIO_3-5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	59.78^{f}	11.85^{fg}	109.32^{ef}
T_8- SA- KIO_3-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	62.34^{ef}	12.62^{ef}	104.57^{fg}
T_9- Chitosan-KIO_3 Complex ($CsKIO_3$) – (SA)-5Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	70.24^{bc}	14.97^{bc}	120.98^{cd}
T_{10}-Chitosan-KIO_3 Complex ($CsKIO_3$) - (SA)-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	76.54^{a}	16.24^{a}	131.26^{ab}
T_{11}- SA- KIO_3-5Kgha^{-1} + FA-KIO_3- 0.3% @ 60 and 90 DAT	65.21^{de}	14.24^{cd}	113.29^{def}
T_{12}- SA- KIO_3-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	67.86^{cd}	13.41^{de}	117.52^{de}
T_{13}- Chitosan-KIO_3 Complex ($CsKIO_3$) – (SA)-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	73.95^{ab}	15.76^{ab}	126.54^{bc}
T_{14}- Chitosan-KIO_3Complex($CsKIO_3$) - (SA)-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	78.43^{a}	16.79^{a}	135.89^{a}
T_{15}- Chitosan Spraying	28.65^{j}	7.43^{lm}	69.86^{jk}
T_{16}- Water Spraying	23.34^{k}	6.81^{m}	67.21^{k}
Mean	**53.73**	**11.74**	**101.60**
S.Ed	2.37	0.50	4.37
C.D(0.05)	4.86	1.03	8.92

a-j Different letters indicate differences according to the probability

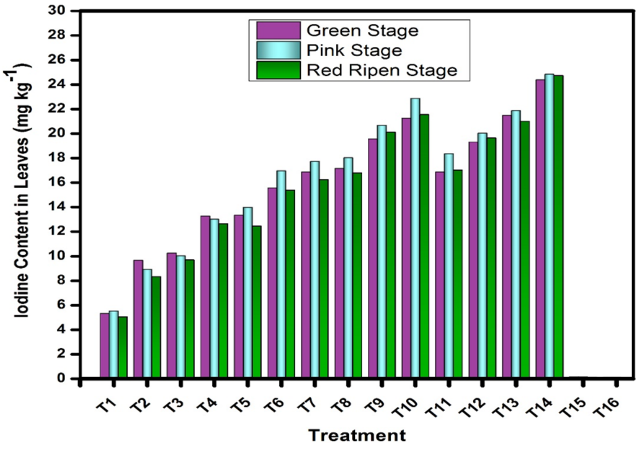

Fig. 1. *Effect of potassium iodate and iodine chitosan complex on plant iodine uptake (mg kg^{-1})*

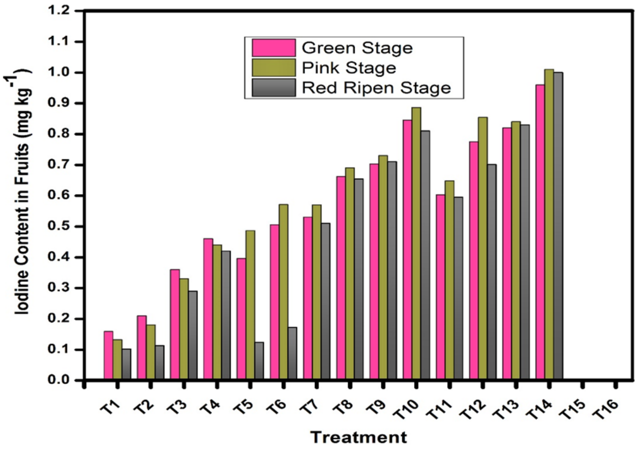

Fig. 2. *Effect of potassium iodate and iodine chitosan complex on fruit iodine uptake (mg kg^{-1})*

in plants and fruits were higher in chitosan iodate complex supplied treatments because there was no leaching and volatilization of iodate ion due to the strong interaction between cationic amino group of chitosan and iodate ion (Limchoowong *et al*., 2018). The major iodine species complexed by chitosan was IO_3^-. The movement of iodine from roots is mainly through xylem vessels via mass flow driven by the transpiration of leaves (Gonzali *et a*l., 2017). The foliar application of KIO_3 increased the iodine content in the plants compared to KIO_3 soil alone and chitosan iodate complex alone treatments. The cuticular waxes of leaves served as an entry point for foliar-applied iodine.

Conclusion

The Chitosan-KIO_3 Complex-10 Kg ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 (T_{14}) enhanced the uptake of nitrogen (61.23 and 78.43 Kg ha^{-1}), phosphorous (9.88 and 16.79 Kg ha^{-1}), potassium (86.45 and 135.89 Kg ha^{-1}), and iodine content in plants and fruits of tomato. It is due to the integration of chitosan and inorganic sources, which attributed balanced carbon to nitrogen and carbon to phosphorous ratios, increased organic matter build-up and increased cation exchange capacity. It also increased nutrient retention by reducing leaching losses. There was also an increase in microbial activity which led to increased nitrogen fixation, phosphorus solubilization, potassium mobilization and iodine retention. Biofortification of iodine in the form of chitosan potassium iodate complex in tomatoes can improve the iodine content in the fruit, which will be helpful in overcoming iodine deficiency.

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Conflict of interest

The authors declare that there is no competing interest.

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