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The Long-term Impact of Biofortified Iodine on Tomato (*Lycopersicon esculentum*) Growth, Yield and Quality

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ABSTRACT

Background: Naturally occurring iodide iodine exhibits complex soil behavior. Even though higher plants don't consider iodine a vitamin, living things need it. Iodine is part of the thyroid hormone, which is vital to human health and metabolism. Potassium is the most effective cation for tomato plants and has a crucial role in improving several post-harvest quality characteristics in tomato fruits as well as in almost all vegetables.

Methods: In the present work, we assessed the growth, yield and quality (Ascorbic acid, Titrable acidity and soluble solids) of tomatoesfrom different sources of chitosan and potassium iodate alone and combinations. The field experiment was carried out in the Thondamuthur block of Viraliyur village in the Coimbatore district of Tamil Nadu in 2022. The experiments were performed in randomized block design with three replications in palaviduthi soil series using hybrid tomato "Shivam".

Result: The chitosan iodate complex and foliar application combination enhanced the growth, yield and quality of tomato. Potassium iodate alone applied to soil and foliar, improved fruit quality but did not prevent acid loss during ripening. Chitosan reduces respiration and oxygen permeability to preserve losses. Thus, potassium iodate chitosan complex was favoured for boosting plant growth, fruit yield and quality.

Key words: Biofortification, Chitosan, Iodine, Potassium, Quality.

INTRODUCTION

Iodine is found in soils as both inorganic and organic molecules. They include iodate (IO_3^-) and iodide. Iodine, a vitamin, is essential for cognitive and physical growth, according to Antonyak *et al*. (2018). As part of the thyroid hormone, iodine is essential for human health and metabolic functions (Sorrenti *et al*., 2021). The iodine cycle is slow and incomplete in some areas, causing soil and drinking water iodine loss (MacKeown *et al*., 2022). Agriculture on such soils may deplete iodine, resulting in insufficient iodine intake for humans and animals.

Biofortification has significantly reduced global iodine deficiency in recent decades. Adding iodine-containing salts or organic resources like seaweed to soils helps crops absorb and store this element. In biofortification, regularly consumed crops are fortified with iodine to avoid iodine deficiency (Lawson, 2015). Globally, *Solanum lycopersicum* L., or tomato, is a major vegetable crop. Its health advantages and economic importance stem from its value in fresh market consumption and processed product manufacture (Abdelgawad *et al*., 2019). Due to their nutritious value, tomatoes are called "protective foods". The vegetable is adaptable and has a long history in Indian cuisine (Gayathiri *et al*., 2021). Tomato fruit quality is determined by appearance, size and flavour. Mazon *et al*. (2022) recommend total soluble solids (SS) and titrable acidity (TA) for fruit taste and quality evaluation. This vital vitamin boosts immunity lowers blood pressure and lowers cholesterol.

Tomato quality depends on soil fertility, namely potassium. This nutrient significantly impacts fruit quality and vital plant processes such as osmotic control, enzyme activation, photoassimilates transport, carbon dioxide assimilation and transpiration. A polysaccharide-rich fibrous material, chitin is found in prawns, lobster, crab and fungal exoskeletons and cell walls (Ali *et al*., 2022). Chitosan-iodate compounds enhance iodine absorption. Choosing fertiliser amounts for iodine biofortification is tricky. Krzepilko *et al*.

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(2019) state that plant element concentration is influenced by species, growth circumstances, fertiliser type, soil composition, moisture, pH and redox conditions.

The current work uses potassium iodate and iodine chitosan complexes to biofortify iodine. This biofortification approach will be tested on residual tomato plant and fruit growth, production and quality.

MATERIALS AND METHODS

Two field experiments were conducted in the summer and kharif seasons of 2022 at Viraliyur village, located in the Thondamuthur block of Coimbatore district, Tamil Nadu, India (GPS coordinates: 10°.9′99.284″N; 76.7′82.652″E), to investigate the impact of residual iodine on growth, yield and quality. The studies were conducted utilizing a randomized block design with three replications and sixteen treatments in the Palaviduthi soil series. The hybrid tomato variety "Shivam" was utilized for the study. The plants were grown in clay loam soil with a neutral pH of 7.17. The soil had a low nitrogen content of 185.2 kg ha^{-1}, while phosphorus and potassium levels were medium, measuring 16.4 kg ha^{-1} and 211.6 kg ha^{-1}, respectively. Additionally, the soil had a non-saline condition with an electrical conductivity of0.45 dSm^{-1}. A random selection of five plants was made from the sample area and thereafter labeled to capture biometric observations at three distinct phases: the green, pink and red ripening harvest stages of tomato. The measurement of plant height and number of branches was recorded at four different time points: 15 days after treatment (DAT), 30 DAT, 45 DAT and 60 DAT. The data on dry matter production and fruit yield were also documented for the aforementioned plants. Typically, fruits were harvested on a bi-weekly basis. The quality criteria, namely ascorbic acid, titrable acidity and total soluble solids, were measured at various stages of harvest. Ascorbic acid was measured in tomato samples using titration. Soluble solids (SS) were measured in °Brix (±0.5) using a portable refractometer. To determine tomato titratable acidity (TA), 5 g of treated tomato fruit was homogenized with 50 mL of distilled water and filtered. The aliquot was titrated with 0.1 N NaOH using phenolphthalein (Perdones*et al*., 2016). The data were reported as a citric acid percentage using this formula:

$$\text{Acidity \%} = \frac{\text{Titre value} \times \text{Normality} \times \text{m.eq.wt. of acid}}{\text{Volume of sample}} \times 100$$

The data obtained were subjected to one-way ANOVA. The programme IBM SPSS® Statistics, version 25 was used to run all statistical tests.

RESULTS AND DISCUSSION

Effect of potassium iodate and iodine chitosan complex on growth, yield and quality of tomato

Growth parameters

Plant height

The results of this study indicated that the application of Chitosan-KIO_3 Complex-10kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT resulted in superior plant development at all measurement periods in residual crops (Fig 1). The rates of combined chitosan complex and KIO3 foliar treatment were not significantly different. Combining chitosan and potassium iodate boosted tomato growth. El-Serafy (2020) found that chitosan boosts plant metabolic activity in leaves. Chitosan's amino contents boost leaf nitrogen and the plant's capacity to acquire nitrogen from the soil during breakdown. In contrast, potassium iodate boosted leaf development, which indirectly increased photosynthetic activity and tomato plant height (Houmani *et al*., 2022).

Number of branches

In residual tomato crops, the combination of Cs-KIO_3 and FA-KIO_3 treatments yielded the highest branch count, followed by SA-KIO_3 and FA-KIO_3. Nitrogen in chitosan aids protein, nucleic acid and protoplasm production (Fig 2). A unique entity stimulates cell division and meristematic activity to grow tissues and organs (Teklic *et al*., 2021).

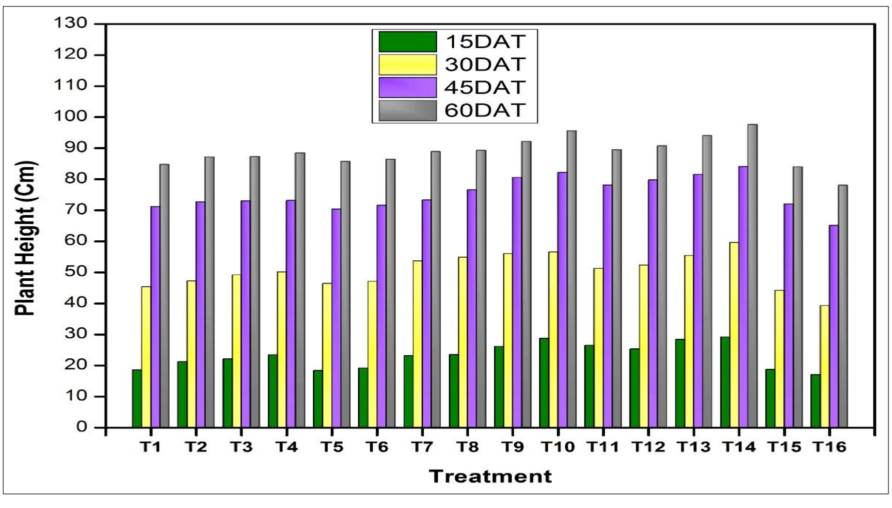

Fig 1: Effect of potassium iodate and iodine chitosan complex on plant height (cm) at different days after transplanting of residual crop.

Potassium may have also helped growth early on, resulting in more branches.

Yield parameters

Dry matter accumulation is a key crop production indicator. Chitosan-KIO_3 Complex-10 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT at 60 and 90 days after transplanting (DAT) increased residual crop dry matter and yield (Table 1). Cakmak *et al*. (2017) found that 18% potassium in KIO_3, which plant roots absorbed, increased plant height and branching. These may cause the crop's peak dry matter output. Due to adequate nutrient levels that enhance photosynthetic activity, light absorption, dry matter synthesis, accumulation and partitioning, Cs-KIO_3 and FA-KIO_3 may have generated the maximum dry matter and yield. Krupa-Ma³kiewicz and Fornal (2018) discovered that chitosan boosted plant fresh and dry weight. Adding potassium iodate to soil boosted fruit production, although not as much as chitosan. More leaves, which assist photosynthesis and create carbohydrates, may explain the rise in fruit yield (Charbonnier *et al*., 2017). Compare to other methods, foliar potassium iodate at 60 and 90 DAT lowers crop output. KIO_3

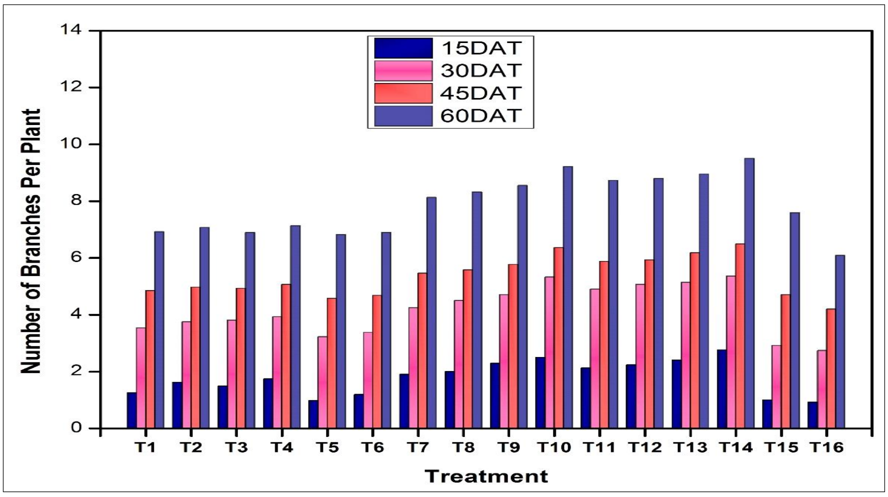

Fig 2: Effect of potassium iodate and iodine chitosan complex on number of branches at different days after transplanting of residual crop.

Table 1: Effect of potassium iodate and iodine chitosan complex on dry matter production (Kg ha^{-1}) and fruit yield (t ha^{-1}) of residual crop.

Treatments	Dry matter production (Kg ha^{-1})	Fruit yield (t ha^{-1})
T_1- Soil application (SA) - KIO_3 - 5 kg ha $^{-1}$	2972^{ef}	54.11^{ij}
T_2- Soil application (SA) - KIO_3 - 10 kg ha $^{-1}$	3067^{def}	56.82^{ghij}
T_3- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1}	3159^{cde}	60.73^{efg}
T_4- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1}	3294^{bcd}	60.02^{efgh}
T_5- FA-KIO_3 - 0.2% at 60 and 90 DAT	2592^{gh}	55.40^{hij}
T_6- FA-KIO_3 - 0.3% at 60 and 90 DAT	2643^{gh}	58.66^{fgh}
T_7- SA- KIO_3 - 5 kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT	2789^{fgh}	61.93^{defg}
T_8- SA- KIO_3 - 10 kg ha^{-1} + FA-KIO_3-0.2% at 60 and 90 DAT	2873^{fg}	63.15^{def}
T_9- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	3971^{a}	66.87^{bcd}
T_{10}-Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	4119^{a}	71.40^{ab}
T_{11}- SA- KIO_3 - 5 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	3442^{bc}	63.10^{def}
T_{12}- SA- KIO_3 - 10 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	3567^{b}	64.29^{cde}
T_{13}- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	4073^{a}	69.31^{bc}
T_{14}- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	4235^{a}	75.85^{a}
T_{15}- Chitosan spraying	2581^{h}	52.54^{ik}
T_{16}- Water spraying	2235^{i}	48.18^{k}
Mean	3225.75	61.39
S.Ed	138.62	2.58
C.D (0.05)	283.12	5.28

Table 2: Effect of potassium iodate and iodine chitosan complex on ascorbic acid content (mg 100 gm^{-1}) at different harvest stages of residual crop.

Treatments	Green stage	Pink stage	Red ripen stage	Treatment mean
T_1- Soil application (SA) - KIO_3 - 5 kg ha^{-1}	1.77^{fgh}	2.62^{f}	2.29^{gh}	2.23
T_2- Soil application (SA) - KIO_3 - 10 kg ha^{-1}	1.84^{befg}	2.76^{def}	2.37^{fgh}	2.32
T_3- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1}	1.95^{cde}	2.93^{bcd}	2.55^{cdef}	2.48
T_4- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1}	2.01^{abcd}	2.96^{bcd}	2.60^{bcde}	2.52
T_5- FA-KIO_3-0.2% at 60 and 90 DAT	1.86^{ef}	2.82^{def}	2.32^{gh}	2.33
T_6- FA-KIO_3-0.3% at 60 and 90 DAT	1.91^{cdef}	2.91^{de}	2.40^{efg}	2.41
T_7- SA- KIO_3-5 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	1.93^{cdef}	3.09^{abc}	2.41^{efg}	2.48
T_8- SA- KIO_3-10 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	1.94^{bcde}	3.10^{abc}	2.46^{defg}	2.50
T_9- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	1.97^{bcde}	3.11^{abc}	2.66^{abcd}	2.58
T_{10}-Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3 - 0.2% at 60 and 90 DAT	2.10^{ab}	3.17^{abc}	2.78^{ab}	2.68
T_{11}- SA- KIO_3 - 5 kg ha $^{-1}$ + FA-KIO_3 - 0.3% at 60 and 90 DAT	1.93^{cdef}	2.98^{abcd}	2.43^{efg}	2.45
T_{12}- SA- KIO_3 - 10 kg ha $^{-1}$ + FA-KIO_3 - 0.3% at 60 and 90 DAT	2.02^{abcd}	3.00^{abcd}	2.50^{defg}	2.51
T_{13}- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	2.05^{abc}	3.13^{abc}	2.73^{abc}	2.64
T_{14}- Chitosan-KIO_3 complex($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	2.14^{a}	3.22^{a}	2.84^{a}	2.73
T_{15}- Chitosan spraying	1.69^{gh}	2.80^{def}	2.18^{h}	2.22
T_{16}- Water spraying	1.63^{h}	2.68^{ef}	2.46^{defg}	2.26
Mean	1.92	2.96	2.50	2.46
S.Ed	0.08	0.12	0.10	
C.D (0.05)	0.16	0.25	0.21	

Table 3: Effect of potassium iodate and iodine chitosan complex on total soluble solid content (%) at different harvest stages of residual crop.

Treatments	Green stage	Pink stage	Red ripen stage	Treatment mean
T_1- Soil application (SA) - KIO_3 - 5 kg ha $^{-1}$	2.12^{hi}	2.73^{i}	2.40^{i}	2.42
T_2- Soil application (SA) - KIO_3 - 10 kg ha $^{-1}$	2.49^{fg}	3.06^{h}	2.77^{h}	2.77
T_3- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1}	2.34^{gh}	3.20^{gh}	3.36^{e}	2.97
T_4- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1}	2.63^{ef}	3.59^{def}	3.68^{d}	3.30
T_5- FA-KIO_3 - 0.2% at 60 and 90 DAT	2.56^{fg}	3.38^{fg}	2.93^{gh}	2.96
T_6- FA-KIO_3 - 0.3% at 60 and 90 DAT	2.71^{ef}	3.51^{def}	3.03^{fgh}	3.08
T_7- SA - KIO_3 - 5 kg ha $^{-1}$ + FA-KIO_3- 0.2% at 60 and 90 DAT	2.70^{ef}	3.43^{efg}	3.08^{efg}	3.07
T_8- SA - KIO_3 - 10 kg ha $^{-1}$ + FA-KIO_3- 0.2% at 60 and 90 DAT	2.85^{de}	3.69^{cde}	3.26^{ef}	3.27
T_9- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA)-5 kg ha $^{-1}$ + FA-KIO_3 - 0.2% at 60 and 90 DAT	2.98^{cd}	3.74^{cd}	4.05^{c}	3.59
T_{10}-Chitosan - KIO_3 complex ($CsKIO_3$) - (SA)-10 kg ha $^{-1}$ + FA-KIO_3 - 0.2% at 60 and 90 DAT	3.21^{b}	4.21^{ab}	4.47^{ab}	3.96
T_{11}- SA - KIO_3 - 5 kg ha ^{1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	2.56^{fg}	3.37^{fg}	3.08^{efg}	3.00
T_{12}- SA - KIO_3 - 10 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	2.71^{ef}	3.51^{def}	3.27^{ef}	3.16
T_{13}- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	3.14^{bc}	3.95^{bc}	4.28^{bc}	3.79
T_{14}- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	3.44^{a}	4.37^{a}	4.76^{a}	4.19
T_{15}- Chitosan spraying	2.04^{ij}	2.65^{i}	2.78^{h}	2.49
T_{16}- Water spraying	1.82^{j}	2.11^{j}	1.71^{j}	1.88
Mean	2.64	3.41	3.31	3.12
S.Ed	0.11	0.14	0.15	
C.D (0.05)	0.23	0.29	0.30	

Table 4: Effect of potassium iodate and iodine chitosan complex on titrable acidity content (%) at different harvest stages of residual crop.

Treatments	Green stage	Pink stage	Red ripen stage	Treatment mean
T_1- Soil application (SA) - KIO_3 - 5 kg ha^{-1}	0.53^{ef}	0.47^{gh}	0.41^{hi}	0.50
T_2- Soil application (SA) - KIO_3 - 10 kg ha^{-1}	0.57^{de}	0.51^{fg}	0.48^{efg}	0.51
T_3- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1}	0.56^{de}	0.49^{fg}	0.44^{gh}	0.52
T_4- Chitosan-KIO_3 complex ($CsKIO_3$) - (SA)- 10 kg ha^{-1}	0.58^{cde}	0.53^{ef}	0.49^{def}	0.53
T_5- FA-KIO_3 - 0.2% at 60 and 90 DAT	0.56^{de}	0.53^{ef}	0.46^{fg}	0.53
T_6- FA-KIO_3 - 0.3% at 60 and 90 DAT	0.59^{cd}	0.5^{fg}	0.51^{de}	0.54
T_7- SA- KIO_3 - 5 kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT	0.58^{cde}	0.56^{de}	0.50^{def}	0.56
T_8- SA- KIO_3 - 10 kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT	0.60^{cd}	0.59^{cd}	0.53^{cd}	0.59
T_9- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3-0.2% at 60 and 90 DAT	0.63^{bc}	0.61^{bc}	0.58^{b}	0.64
T_{10}- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3-0.2% at 60 and 90 DAT	0.67^{ab}	0.65^{a}	0.62^{a}	0.64
T_{11}- SA- KIO_3 - 5 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	0.63^{bc}	0.63^{abc}	0.57^{b}	0.62
T_{12}- SA- KIO_3 - 10 kg ha^{-1} + FA-KIO_3 - 0.3% at 60 and 90 DAT	0.63^{bc}	0.64^{ab}	0.56^{bc}	0.61
T_{13}- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 5 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	0.66^{ab}	0.62^{bc}	0.58^{bc}	0.63
T_{14}- Chitosan - KIO_3 complex ($CsKIO_3$) - (SA) - 10 kg ha^{-1} + FA-KIO_3-0.3% at 60 and 90 DAT	0.70^{a}	0.67^{a}	0.65^{a}	0.55
T_{15}- Chitosan spraying	0.50^{f}	0.44^{hi}	0.38^{ij}	0.42
T_{16}- Water spraying	0.44^{g}	0.40^{i}	0.36^{j}	0.47
Mean	0.59	0.55	0.51	0.55
S.Ed	0.02	0.02	0.021	
C.D (0.05)	0.05	0.04	0.043	

foliar spray may increase leaf and fruit iodine deposition without tissue absorption.

Quality parameters

Ascorbic acid

The main antioxidant in tomato fruit is ascorbic acid. The Chitosan-KIO_3 Complex at 10 kg ha^{-1} and FA-KIO_3 at 0.3% produced the highest ascorbic acid levels in tomatoes during green, pink and red ripening (Table 2).Ascorbic acid in fruits has a key function in oxidation or respiration (Saleem *et al*., 2021). As the plant ripened from pink to crimson, fruit ascorbic acid levels decreased. The chitosan-KIO_3 complex and KIO_3 foliar spray showed a similar trend, although with a smaller drop. Chitosan reduces oxygen permeability in fruits during respiration, as observed by Krupa-Małkiewicz and Fornal (2018). Chitosan slows fruit ascorbic acid decomposition (Mageshen *et al*., 2022).

Total soluble solids

Total soluble solids (TSS) concentration is a major indicator of tomato fruit quality. Table 3 shows that the Chitosan-KIO_3 Complex-10 kg ha^{-1} + FA-KIO_3-0.3% treatment had the highest concentration of total soluble solids at 60 and 90 DAT during tomato ripening stages (green, pink and red). The fruit's soluble solid content increased when potassium iodate was used because potassium helps transport sucrose. The fruit's total soluble solid content may grow due to cellulose and hemicellulose solubilization inside cell walls or water loss as suggested by Jiang *et al*. (2022). Treatments like potassium iodate applied to the soil, foliar application alone and soil and foliar treatments reduce total soluble solid content after the pink stage because fruits use sugar during respiration. However, chitosan alone and the chitosan iodate complex + FA-KIO_3 treatments increase soluble solids. Chitosan reduces respiration, preserving fruit soluble solids. (Shah and Hashmi, 2020).

Titrable acidity

Potassium iodate and chitosan affected TA levels. Typically, tomato fruit titrable acidity decreases from green (0.59%) to red ripened (0.51%) in the leftover crop (Table 4). Titrable acidity decreases largely because fruits use it during respiration and metabolism. Ethylene production during fruit ripening lowers titrable acidity, according to Chauhan and Chauhan (2020). The combination of chitosan and potassium iodate reduced titrable acidity less than other treatments. Chitosan affects respiration rate, which is thought to be affected by tissue oxygen and carbon dioxide levels (Galus *et al*., 2021).

CONCLUSION

In the shivam hybrid of tomato, potassium helps move sugars and starch, maintains turgor pressure and regulates internal ionic balance, while chitosan boosts photosynthesis, food production and antioxidant activity. This has led to increased growth, yield (75.85 t ha^{-1}) and quality (ascorbic acid-3.56 mg100 g^{-1}, titrable acidity-0.55% and total soluble solids-4.19%). Using a potassium iodate chitosan complex for biofortification improves fruit quality and yield more effectively. Chitosan's durability and preservation properties make it ideal for biofortifying agricultural goods with iodine.

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Data availability

All datasets generated or analyzed during this study are included in the manuscript.

Ethics statement

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare that there is no conflict of interest.

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