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Research Article

Influence of potassium iodate and chitosan iodate complex on growth, yield, quality and iodine uptake in 'shivam' hybrid of tomato (*Solanum lycopersicum L.*)

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Abstract
An iodine biofortification experiment was conducted by applying potassium iodate fertilizer in soil and foliar form and chitosan complex forms to investigate the growth, yield, quality and uptake of iodine in shivam hybrid of tomato in Palaviduthi soil series of Coimbatore region. Soil fertilization alone resulted in lower uptake of iodine in fruits because the iodine is susceptible to high volatilization and less phytoavailability and also resulted in less yield and poor quality of fruits. When the chitosan and potassium iodate were applied in combination through foliar form, the quality of the fruits was found to be superior (carotene-1.24 mg $100gm^{-1}$ ascorbic acid- 3.56 mg $100gm^{-1}$, titrable acidity-0.96%), with higher fruit yield (94.81 t ha^{-1}) and uptake of iodine in fruits (0.99ppm). Potassium iodate alone, either in the form of soil or foliar application, increased the quality of fruits, but it did not prevent the loss of various pigments and acids during ripening and also the loss of iodine through volatilization. But chitosan conserved the losses by reducing the respiration rate and oxygen permeability. Further, chitosan formed an electrostatic interaction with potassium iodate, preventing volatilisation and gradually increasing the bioavailability of iodine from soil to fruits. Hence biofortifying iodine in the form of potassium iodate chitosan complex was preferred for enhancing yield, improving quality and increasing the iodine content in fruits.

Keywords: Biofortification, Chitosan, Iodine, Potassium, Tomato

INTRODUCTION

Iodine is a mineral that occurs naturally as iodide and has complicated behaviour in soils. Despite the fact that higher plants do not consider iodine to be a micronutrient, living organisms require it. Iodine is an essential micronutrient for a person's mental and physical development. It is a component of thyroid hormone, which is

essential for human health and plays an indispensable function in metabolism (Antonyak *et al*., 2018). Its primary function is to manufacture thyroid hormones such as thyroxin (T4) and triiodothyronine (T3), which regulate various physiological and biochemical processes. The recommended daily allowance (RDA) of iodine is 120 µg for children 6 to 12 years old, 150 µg for adults over 12 years old, and 200 µg for pregnant and nursing women, according to the World Health Organization (WHO) and the United Nations Children' Fund (UNICEF), 2013.

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. Iodine biofortification by foliar spray and soil application resulted in higher iodine stability during various cooking techniques, whereas iodine provided in the form of iodized salt to non biofortified vegetables resulted in significant iodine losses during the boiling process (Kastori*et al*., 2021).

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). Because of their high nutritional value, tomatoes are one of the most significant "protective foods." It is one of the most adaptable vegetables, with a long history of use in Indian cuisine (Gayathiri *et al*., 2021). The need for tomatoes in our country is growing every day as the population grows. Tomato was chosen for the biofortification study since it can store excess iodine in vegetative tissues and fruits at levels that are more than adequate for human consumption. It is also a widely produced and consumed crop in every household. It is a desirable target crop for a fortification study because of its extensive distribution and fresh consumption (Buturi*et al*., 2021).

The most important characteristics for determining tomato fruit quality are appearance, size, and flavour. According to Mazon*et al*. (2022) the total soluble solids (SS), titrable acidity (TA) and the SS/TA ratio are the major factors assessed to determine fruit flavour and quality. It has been claimed that tomato fruit contains significant amounts of key antioxidants such as lycopene, carotenoids, vitamin C, and minerals, all of which can help to prevent the development of certain human diseases such as prostate, colon, and breast cancers (Tsaniklidis *et al*., 2021). Furthermore, 100 g of tomato can give the human body 40% of the needed daily dose of vitamin C, which can boost the immune system, lower blood pressure, and lower cholesterol (Arumugam *et al*., 2021).

Soil fertility, particularly potassium availability, has an impact on the properties of tomato fruits. This nutrient is strongly associated to fruit quality and plays significant roles in plants such as osmotic control, enzyme activation, photoassimilate transport, carbon dioxide assimilation, and transpiration (Ahammed *et al*., 2022). Potassium is the most efficient cation for tomato plants and plays a vital role in the enhancement of several post-harvest quality attributes in tomato fruits and nearly all vegetables (Zulfiqar *et al*., 2020).

Chitin is a polysaccharide-rich fibrous substance found in the exoskeletons of shellfish such as shrimp, lobsters, and crabs, as well as the cell walls of fungi (Ali *et al*., 2022). The application of chitosan increased the activity of essential nitrogen metabolism enzymes and improved nitrogen transit in functioning leaves, enhancing plant growth and development. The influence of chitosan on plant growth, development, and productivity was primarily related to promoting plant immunity against pathogens such as bacteria (Shahrajabian*et al*., 2021).

In the present investigation, an iodine biofortification strategy was explored utilizing a popular local 'Shivam' hybrid of tomatoes (*Solanum lycopersicum L.*) to know its growth and uptake pattern. The final impacts were also examined in terms of the biofortified tomatoes' quantitative yield and qualitative traits

MATERIALS AND METHODS

Description of the field experiment

A field experiment was carried out in Thondamuthur block of Viraliyur village in the Coimbatore district of Tamil Nadu (GPS value: 10°.9′99.284‴N; 76.7′82.652″ E) to know the effect of potassium iodate and chitosan on growth, yield, quality and uptake of iodine in tomato. Potassium iodate ($KIO_{3)}$ and chitosan was applied in the form of soil, foliar, and chitosan iodate complex.

Experimental design and treatment details

The experiments were carried out using hybrid tomato "Shivam" in Palaviduthi soil series of Coimbatore in randomized block design with three replications. The gross size of the plot is $28m^2$ (7m X 4m). The treatments were T_1- KIO_3-Soil Application(SA)- 5 Kg ha^{-1} , T_2 - KIO_3- Soil Application(SA)- 10 Kg ha^{-1}, T_3- Chitosan-KIO_3 Complex-5 Kg ha^{-1}, T_4- Chitosan-KIO_3Complex-10 Kg ha^{-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)- 5 Kg ha^{-1} + Foliar Application (FA)-KIO- 0.2% @ 60 and 90 DAT, T_8- KIO_3- Soil Application (SA)- 10 Kg ha^{-1} + Foliar Application (FA)-KIO^{-}_3- 0.2% @ 60 and 90 DAT, T_9-Chitosan-KIO_3 Complex-5 Kg ha^{-1} + Foliar Application (FA)-KIO_3-0.2% @ 60 and 90 DAT, T_{10}-Chitosan-KIO_3 Complex-10 Kg ha^{-1} + Foliar Application (FA)-KIO_3-0.2% @ 60 and 90 DAT, T_{11}- KIO_3- Soil Application(SA) - 5 Kg ha^{-1} + Foliar Application (FA)-KIO_3- 0.3% @ 60 and 90 DAT, T_{12}- KIO_3- Soil Application(SA)- 10 Kg ha^{-1}

+ Foliar Application (FA)-KIO_3- 0.3% @ 60 and 90 DAT. T_{13}- Chitosan-KIO_3 Complex-5 Kg ha^{-1} + Foliar Application (FA)-KIO_3-0.3% @ 60 and 90 DAT, T_{14}- Chitosan-KIO_3 Complex-10 Kg ha^{-1} + Foliar Application (FA)-KIO_3 -0.3% @ 60 and 90 DAT, T_{15}- Chitosan Spraying (control) and T_{16}- Water Spraying (Absolute Control). The plants were cultivated in a neutral pH (7.17) non saline (0.45 dSm^{-1}) clay loam soil which was low in nitrogen (185.2 kg ha^{-1}) and medium in phosphorous (16.4 kg ha^{-1}) and potassium(211.6 kg ha^{-1}).

Cultivation practices

The ridges and furrows were made after the field was ploughed and levelled. Drip irrigation was turned on. Tomato hybrid seedlings were transplanted at a spacing of 45 cm x 30 cm when they were around 25 days old. Urea and DAP were used to supply nitrogen, while DAP and muriate of potash were used to supply the whole doses of phosphorus and potassium. Both soil and foliar fertilization with potassium iodate were used. After two days of transplanting, potassium iodate salt was added with soil to obtain dosages of 5 Kg ha^{-1} and 10 Kg ha^{-1} (14gm and 28gm were mixed for each plot, respectively). The solution for the foliar form of potassium iodate was made in the lab with pure potassium iodate salts and kept in polyethylene bottles for later use. To produce the appropriate concentrations of 0.2% and 0.3% of KIO_3 for 15 plots, the KIO_3 solution was diluted with 42 litres of water (420m^2). One plot was complexed with chitosan and potassium iodate in the ratio of 1% chitosan to 0.01% potassium iodate. 1 gm of chitosan was dissolved in 100 mL acetic acid and 0.14 gm KIO_3 (for chitosan iodate complex- 5 Kg ha^{-1}) and 0.28 gm KIO_3 (for Chitosan iodate complex- 10 Kg ha^{-1}) were dissolved in 100 mL distilled water, diluted to 1 L with water, and sprayed. A backpack sprayer was used to apply the foliar fertilizer. The first application occurred before the formation of the green stage (60 DAT), and the second occurred before the formation of the pink stage (90DAT). After two days of transplanting, the chitosan iodate complex solution was fertilized into the soil. Chitosan was sprayed on the plants in the control treatment, and pure water was sprayed on the plants in the absolute control treatment. On the second day of planting, the pre-emergence herbicide pendimethalin (1L ha^{-1}) was sprayed, and three manual weddings were performed at 15, 35, and 65 days after sowing.

Collection and analysis of plant and fruit samples

Five plants were selected randomly from the sampling area and tagged for recording biometric observations at 3 stages *viz.,* green, pink, and red ripen harvest stages of tomato. The observation of plant height was taken at 15DAT, 30DAT, 45DAT and 60DAT. The number of branches per plant, number of fruits per plant, fruit weight and yield were also recorded in those plants. Fruits were usually picked twice a week. The quality parameters like lycopene, carotene, ascorbic acid, titrable acidity and total soluble solids were recorded at different harvest stages.

Titration methods were used to determine the amount of ascorbic acid in tomato samples (Shehata *et al*., 2019). In a nutshell, ten g of tomato fruit tissue was combined with 90 mL of oxalic acid (6%). After filtering the sample with filter paper, 25 mL of the filtrate was titrated with 2, 6–dichlorophenol indophenols. The results were expressed in milligram/100 gram of fresh weight (FW). 5 g of treated tomato fruit was homogenized with 50 mL of distilled water and then filtered to estimate the titratable acidity (TA) percentage in tomato samples. Using phenolphthalein as an indicator, the aliquot was titrated with 0.1 N NaOH (Perdones*et al*., 2016). According to the following formula, the data were reported as a percentage of citric acid:

Acidity% = [(Titre value X Normality X m.eq.wt. of acid) / (Volume of sample)] X 100 Eq.1

Lycopene and carotene

Tomato fruits were homogenized, and one gram of sample was combined with a 10 mL acetone-hexane combination (Abdel Gawad*et al*., 2019). After then, the solution was allowed to separate into non-polar layers. The absorbance at 663, 645, 505, and 453 nm was measured using a spectrophotometer and the lycopene and carotenoid concentration was calculated using the following equations:

Lycopene = - 0.0458 X A 663 + 0.204 X A 645 + 0.372 X A 505 - 0.0806 X A 453,

β -Carotene = 0.216 X A 663-1.22 X A 645- 0.304 X A 505 + 0.452 X A 453. (A denotes Absorbance) Eq. 2

A portable refractometer was used to determine the amount of soluble solids (SS), which was expressed in °Brix (± 0.5) Eq. 3

Statistical analysis

The growth, yield and quality data were subjected to one-way ANOVA. The program IBM SPSS® Statistics, version 25, was used to run all statistical tests.

RESULTS AND DISCUSSION

Growth parameters

The results revealed that the treatment T_{14} - Chitosan-KIO_3 Complex-10Kg ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT had higher plant growth and number of branches at all the stages of measurement, followed by T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT (Fig. 1 and 2). Further, there was no significant difference(5%) between different rates of combined chitosan complex and foliar application of KIO_3. Applying chitosan and potassium treatments boosted

Table 1. Effect of potassium iodate and iodine chitosan complex on days to flower, number of fruits and fruit weight

Treatments	Days to flowering	Number of fruits	Fruit Weight(g)
T_1- KIO_3-SA- 5kgha^{-1}	44±0.67^{bc}	8±0.12^{ij}	62.17±0.94^{jk}
T_2- KIO_3-SA- 10Kgha^{-1}	42±1.11^{cde}	9±0.23^{hi}	67.38±1.78^{hijk}
T_3- Chitosan-KIO_3 Complex-5Kgha^{-1}	43±1.55^{bcd}	11±0.39^{fg}	70.21±2.53^{ghi}
T_4- Chitosan-KIO_3 Complex-10Kgha^{-1}	40±1.51^{defg}	11±0.41^{fg}	73.26±2.77^{fgh}
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	42±0.64^{cde}	9±0.13^{hi}	64.15±0.97^{ik}
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	41±1.03^{cdef}	10±0.25^{gh}	68.96±1.73^{hi}
T_7- KIO_3- SA- 5Kgha^{-1} + FA-KIO- 0.2% @ 60 and 90 DAT	39±1.25^{efgh}	12±0.38^{ef}	79.81±2.56^{def}
T_8- KIO_3-SA-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	39±0.81^{efgh}	12±0.24^{ef}	76.27±1.58^{efg}
T_9- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	37±0.77^{ghi}	15±0.31^{bc}	88.72±1.84^{abc}
T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	35±0.92^{ij}	16±0.42^{ab}	91.22±2.41^{ab}
T_{11}- KIO_3- SA- 5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	38±0.58^{fghi}	13±0.19^{de}	82.18±1.25^{cde}
T_{12}- KIO_3 SA-10Kg/ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	38±1.37^{fghi}	14±0.50^{cd}	85.17±3.07^{bcd}
T_{13}- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	36±1.09^{hij}	15±0.45^{bc}	90.11±2.75^{ab}
T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	32±1.33^{j}	17±0.68^{a}	93.68±3.78^{a}
T_{15}- Chitosan Spraying	46±1.15^{ab}	8±0.20^{ij}	60.95±1.53^{jk}
T_{16}- Water Spraying	48±1.26^{a}	7±0.18^{j}	59.87±1.58^{k}
Mean	**40.00**	**11.68**	**75.88**
S.Ed	1.61	0.51	3.21
C.D(0.05)	3.30	1.05	6.56

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

the growth and development of tomato plants. The chitosan, when applied to the leaves, will increase the biochemical activity of plants (El- Serafy, 2020). The presence of amino components in chitosan causes an increase in nitrogen content in leaves, as does the plant's ability to take nitrogen from the soil during chitosan decomposition. The presence of nitrogen in chitosan aided protein synthesis, nucleic acid synthesis, and protoplasm development. That is in charge of inducing cell division and meristematic activity to produce more tissues and organ (Teklic*et al*., 2021). On the other hand, potassium increased the foliage, which indirectly boosted photosynthesis and, as a result, increased tomato plant height (Houmani*et al*., 2022). Further, the involvement of potassium in promoting growth during the early stages of development could have resulted in the formation of additional branches.

Yield parameters

Among the treatments, applying T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT induced early flowering (32nd day). Delayed flowering was noticed in the control treatment (48th day) in tomatoes. The number of fruits per plant, the weight of the fruits and fruit yield were increased significantly by applying chitosan and potassium iodate (Table 1). The number of fruits per plant increased from 7 in control (T16) to 17 in Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT (T_{14}). Fruit yield per plant was1.84 kg in the absence of potassium iodate and chitosan (T_{16}) but increased with the addition of the foliar form of potassium iodate-chitosan complex, reaching 2.56 kg at the highest doses(T_{14})(Table 2). While the chitosan was actively involved in enhancing enzyme actions, assisting in photosynthesis and food generation, the potassium involvement in assisting sugar and starch translocation, maintaining turgor, and reducing water loss has resulted in increase in the number of fruits plant^{-1} and fruit weight which in turn increases the fruit yield (Hasanuzzaman*et al*., 2018). The availability and uptake of water and critical nutrients can be linked to chitosan's stimulating effect on plant growth by modifying cell osmotic pressure and minimizing the formation of damaging free radicals by enhancing antioxidants and enzymatic activities (Chakraborty *et al*., 2020) or as a result of an increase in the key enzymatic activities of nitrogen metabolism (nitrate reductase, glutamine synthetase, and protease), as well as better nitrogen (N) transportation in functioning leaves, which improves the photosynthesis process (Xu*et al*., 2020).

Table 2. Effect of potassium iodate and iodine chitosan complex on fruit yield of tomato

Treatments	Fruit Yield (Kg Plant^{-1})	Fruit Yield (t ha^{-1})
T_1- KIO_3-SA- 5kgha^{-1}	1.84±0.02^{hi}	68.14±0.02^{hi}
T_2- KIO_3-SA- 10Kgha^{-1}	1.92±0.05^{ghi}	71.11±0.05^{ghi}
T_3- Chitosan-KIO_3 Complex-5Kgha^{-1}	2.05±0.07^{efg}	75.92±0.07^{efg}
T_4- Chitosan-KIO_3 Complex-10Kgha^{-1}	2.01±0.08^{fgh}	74.44±0.08^{fgh}
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	1.87±0.03^{hi}	69.25±0.03^{hi}
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	1.98±0.04^{fgh}	73.33±0.05^{fgh}
T_7- KIO_3- SA- 5Kgha^{-1} + FA-KIO- 0.2% @ 60 and 90 DAT	2.09±0.07^{defg}	77.40±0.07^{defg}
T_8- KIO_3-SA-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	2.13±0.04^{def}	78.88±0.04^{def}
T_9- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	2.26±0.05^{bcd}	83.70±0.05^{bcd}
T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	2.41±0.06^{ab}	89.25±0.06^{ab}
T_{11}- KIO_3- SA- 5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	2.13±0.03^{def}	78.88±0.03^{def}
T_{12}- KIO_3 SA-10Kg/ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	2.19±0.08^{cde}	81.11±0.08^{cde}
T_{13}- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	2.34±0.07^{bc}	86.66±0.07^{bc}
T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	2.56±0.10^{a}	94.81±0.10^{a}
T_{15}- Chitosan Spraying	1.78±0.04^{ij}	65.92±0.04^{ij}
T_{16}- Water Spraying	1.66±0.04^{j}	61.48±0.04^{j}
Mean	**2.07**	**76.89**
S.Ed	0.08	0.09
C.D(0.05)	0.17	0.18

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

Table 3. Effect of potassium iodate and iodine chitosan complex on titrable acidity content at different harvest stages of tomato (%)

Treatments	Green Stage (85DAT)	Pink Stage (100DAT)	Red Ripen Stage (115DAT)	Treatment Mean
T_1- KIO_3-SA- 5kgha^{-1}	0.82±0.01^{hi}	0.67±0.05^{cde}	0.52±0.01^{i}	0.67
T_2- KIO_3-SA- 10Kgha^{-1}	0.87±0.02^{gh}	0.71±0.09^{abcde}	0.61±0.01^{fgh}	0.73
T_3- Chitosan-KIO_3 Complex-5Kgha^{-1}	0.85±0.03^{gh}	0.69±0.12^{bcde}	0.57±0.02^{hi}	0.70
T_4- Chitosan-KIO_3 Complex-10Kgha^{-1}	0.89±0.03^{fgh}	0.73±0.13^{abcd}	0.63±0.02^{efgh}	0.75
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	0.86±0.01^{gh}	0.75±0.05^{bcde}	0.59±0.01^{gh}	0.73
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	0.91±0.02^{efg}	0.80±0.08^{abcd}	0.65±0.02^{ef}	0.79
T_7- KIO_3- SA- 5Kgha^{-1} + FA-KIO- 0.2% @ 60 and 90 DAT	0.88±0.02^{fgh}	0.78±0.11^{abcd}	0.64±0.01^{efg}	0.77
T_8- KIO_3-SA-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	0.92±0.01^{defg}	0.81±0.07^{abcd}	0.68±0.01^{e}	0.80
T_9- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA -KIO_3-0.2% @ 60 and 90 DAT	0.99±0.02^{abcd}	0.85±0.07^{abcd}	0.74±0.02^{d}	0.86
T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	1.03±0.03^{ab}	0.95±0.09^{ab}	0.83±0.02^{ab}	0.94
T_{11}- KIO_3- SA- 5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	0.95±0.01^{cdef}	0.87±0.05^{abcd}	0.75±0.01^{cd}	0.86
T_{12}- KIO_3 SA-10Kg/ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	0.97±0.03^{bcde}	0.89±0.12^{abc}	0.79±0.03^{bcd}	0.88
T_{13}- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	1.01±0.03^{abc}	0.93±0.11^{abc}	0.81±0.02^{bc}	0.92
T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA -KIO_3-0.3% @ 60 and 90 DAT	1.06±0.04^{a}	0.96±0.14^{a}	0.87±0.03^{a}	0.96
T_{15}- Chitosan Spraying	0.77±0.02^{hij}	0.65±0.08^{d}	0.44±0.01^{j}	0.62
T_{16}- Water Spraying	0.74±0.02^{j}	0.63±0.08^{e}	0.39±0.01^{j}	0.59
Mean	**0.91**	**0.79**	**0.66**	**0.79**
S.Ed	0.03	0.14	0.02	
C.D(0.05)	**0.07**	**0.29**	**0.06**	

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

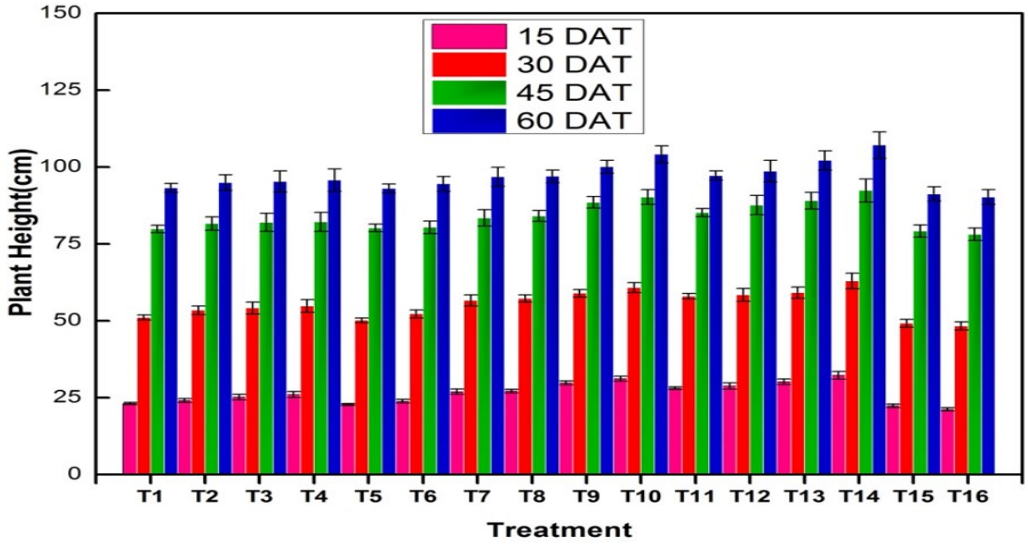

Fig. 1. *Effect of potassium iodate and iodine chitosan complex on plant height (cm) on different days after transplanting*

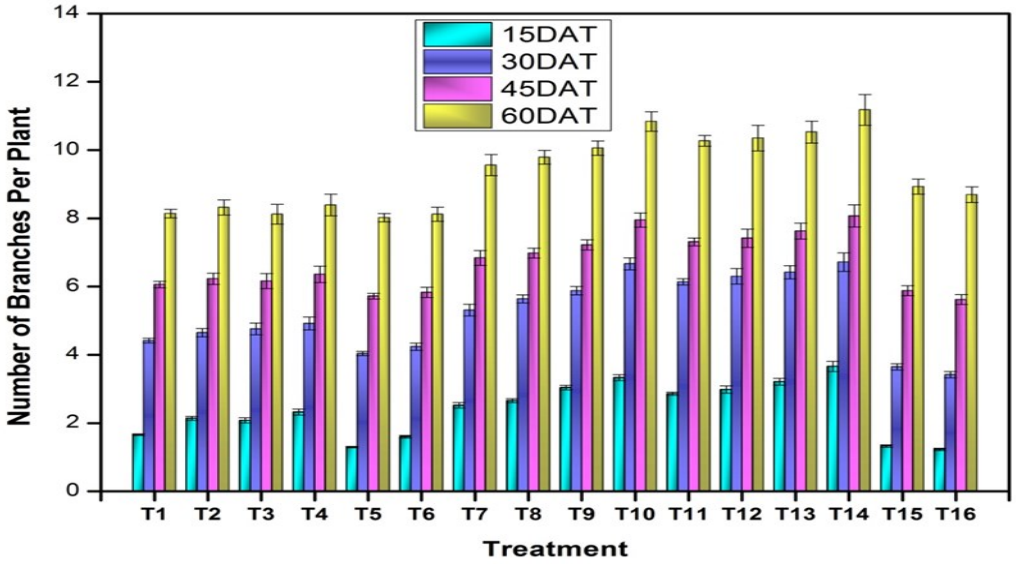

Fig. 2. *Effect of potassium iodate and iodine chitosan complex on number of branches on different days after transplanting*

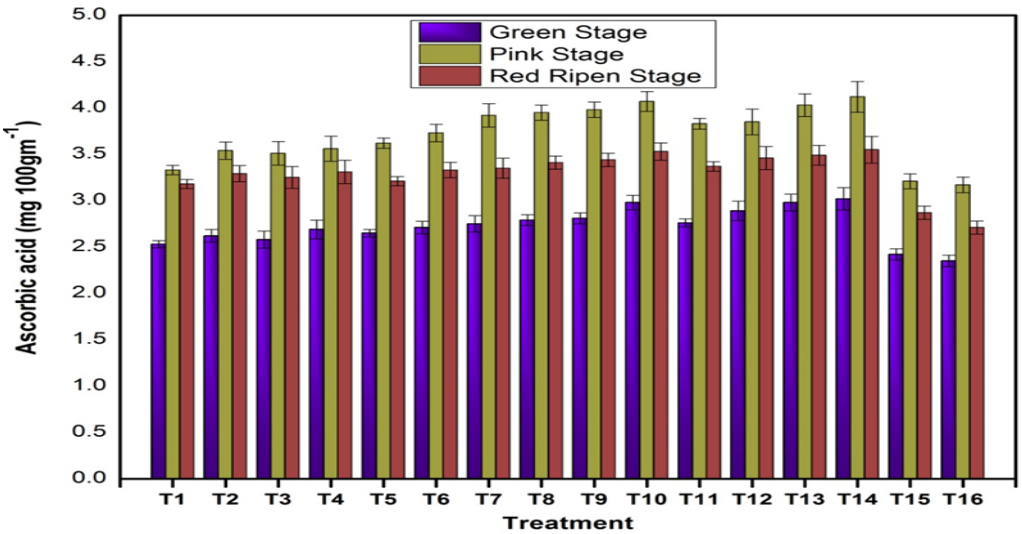

Fig. 3. *Effect of potassium iodate and iodine chitosan complex on ascorbic acid content (mg 100gm^{-1}) at different stages of harvesting*

Quality parameters

The most important antioxidant compound present in tomato fruit is ascorbic acid. The treatment T_{14}- Chitosan-KIO_3 Complex-10 Kg ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT recorded the highest ascorbic acid content at green (3.02 mg $100kg^{-1}$), pink (4.12 mg $100kg^{-1}$) and red ripen (3.55 mg $100kg^{-1}$) stages of tomato (Fig. 3). There was no significant difference in ascorbic acid content between different levels of chitosan iodate complex + FA-KIO_3 treatments and KIO_3–SA+ FA-KIO_3 treatments. The ascorbic acid content in the fruit decreased as the harvest stages of the plant progressed. This is due to the usage of ascorbic acid during the oxidation or respiration process in fruits (Saleem*et al*., 2021). The chitosan-KIO_3 complex, along with the foliar application of KIO_3, also followed the same trend, but the decrease was less pronounced as the chitosan reduced the oxygen permeability in the fruits during the respiration process. Chitosan conserves loss of ascorbic acid from fruits.

Lycopene and β carotene are the carotenoid compounds which tend to increase when the tomato fruit approaches its ripening stage. The red colour of the tomato fruits is mainly due to the presence of lycopene. In the present study, until the pink ripening stage, β carotene concentration was increased. The manufacture of β carotene was down-regulated at the pink ripening stage, allowing for the buildup of its precursor lycopene. Hence there wasan increase in lycopene and a decrease in β carotene concentration from pink to red ripen stage (Fig. 4 and 5). However, the increase in lycopene content was lowered in fruit supplied with chitosan treatment. This could be due to chitosan's role in slowing down fruit ripening and lycopene synthesis by lowering respiration and maturation (Safari *et al*., 2020). The carotenoid pigments in tomato were strongly dependent on temperature, light exposure and maturity stages of tomato. The potassium content in the fruit was discovered to significantly(5%) influence the production of carotenoid compounds. The amount of K in the fruit was determined by the amount of K in the leaves during the pre-inflorescence stages (De souza*et*

Table 4. Effect of potassium iodate and iodine chitosan complex on total soluble solid content at different harvest stages of tomato (% Brix)

Treatments	Green Stage (85DAT)	Pink Stage (100DAT)	Red Ripen Stage (115DAT)	Treatment Mean
T_1- KIO_3-SA- 5kgha^{-1}	2.9±0.04^{gh}	3.5±0.05^{i}	3.2±0.04^{h}	3.20
T_2- KIO_3-SA- 10Kgha^{-1}	3.4±0.09^{ef}	3.9±0.10^{h}	3.7±0.10^{g}	3.67
T_3- Chitosan-KIO_3 Complex-5Kgha^{-1}	3.2±0.11^{fg}	4.1±0.14^{gh}	4.5±0.15^{e}	3.93
T_4- Chitosan-KIO_3 Complex-10Kgha^{-1}	3.6±0.13^{de}	4.6±0.17^{def}	4.9±0.18^{d}	4.37
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	3.5±0.05^{ef}	4.3±0.06^{fg}	3.9±0.05$^{f\,g}$	3.90
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	3.7±0.09^{de}	4.5±0.11^{def}	4.0±0.10^{efg}	4.07
T_7- KIO_3- SA- 5Kgha^{-1} + FA-KIO- 0.2% @ 60 and 90 DAT	3.7±0.11^{de}	4.4±0.14^{efg}	4.1±0.13^{ef}	4.07
T_8- KIO_3-SA-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	3.9±0.08^{cd}	4.7±0.10^{de}	4.3±0.08^{e}	4.30
T_9- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	4.1±0.08^{bc}	4.8±0.10^{cd}	5.4±0.11^{c}	4.77
T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.4±0.11^{ab}	5.4±0.14^{ab}	5.9±0.15^{b}	5.23
T_{11}- KIO_3- SA- 5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	3.5±0.05^{ef}	4.3±0.06^{fg}	4.1±0.06^{ef}	3.97
T_{12}- KIO_3 SA-10Kg/ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	3.7±0.13^{de}	4.5±0.16^{def}	4.3±0.15^{e}	4.17
T_{13}- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.3±0.13^{b}	5.1±0.15^{bc}	5.7±0.17^{bc}	5.03
T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.7±0.2^{a}	5.6±0.22^{a}	6.3±0.25^{a}	5.53
T_{15}- Chitosan Spraying	2.8±0.07^{hi}	3.4±0.08^{i}	3.7±0.09^{g}	3.30
T_{16}- Water Spraying	2.5±0.06^{i}	2.7±0.07^{j}	2.3±0.06^{i}	2.50
Mean	**3.61**	**4.36**	**4.39**	**4.12**
S.Ed	0.15	0.18	0.19	
C.D(0.05)	0.31	0.38	0.39	

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

al., 2021). The developing fruit, acting as an intensive K sink, appears to use K as an immediate operational reservoir. A sequence of enzyme processes produces lycopene in the fruit. The internal ionic strength of the cell, which is principally controlled by the amount of K in the cytoplasm and vacuoles, influences enzymatic activity. The lycopene production was sensitive to the exact K concentration in the cytoplasm or dependent on other limiting factors such as light intensity and quality, ambient temperature patterns, and water availability to the plant (Paes de melo *et al*., 2022). The higher content of ascorbic acid does not influence the bioavailability of carotenoids. Even though there is no significant difference in content between soils or foliar applied KIO_3 treatments + Chitosan iodate complex treatments, the loss of β carotene was less in chitosan-KIO_3 complex treatments.

The application of potassium iodate and chitosan significantly influenced the titrable acidity (TA) content. The mean titrable acidity content is higher in the green stage (Table 3). In general, the titrable acidity content of the tomato fruit decreases from green stage (0.91%) to red ripen stage (0.66%). The reduction in titrable acidity is mainly due to the use of titrable acids during the respiration process and metabolism of fruits. The production of ethylene during ripening process also decreased the titrable acidity content of the fruit. The combination of chitosan and potassium iodate treatments resulted in lesser titrable acidity than other treatments. This is because the chitosan tends to reduce the respiration rate due to changes in internal oxygen and carbondioxide composition of tissues(Galus*et al*., 2021). The larger-sized tomato fruit has higher acidity when compared to lower-sized fruit.

The total soluble solids (SS) content is one of the main indicators for assessing the quality of tomato fruit. The highest total soluble solid content was observed in treatment T_{14}- Chitosan-KIO_3 Complex-10 Kg ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT at the green, pink and red ripen stage (Table 4). Irrespective of the chitosan-supplied treatments, the total soluble solid content increased from green to pink stage and decreased from

Table 5. Effect of potassium iodate and iodine chitosan complex on soluble solid/ titrable acid ratio at different harvest stages of tomato

Treatments	Green Stage (85DAT)	Pink Stage (100DAT)	Red Ripen Stage (115DAT)	Treatment Mean
T_1- KIO_3-SA- 5kgha^{-1}	3.54	5.22	6.15	4.97
T_2- KIO_3-SA- 10Kgha^{-1}	3.91	5.49	5.97	5.12
T_3- Chitosan-KIO_3 Complex-5Kgha^{-1}	3.76	5.94	7.17	5.62
T_4- Chitosan-KIO_3 Complex-10Kgha^{-1}	4.04	6.30	7.31	5.89
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	4.07	5.73	6.61	5.47
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	4.07	5.63	6.15	5.28
T_7- KIO_3- SA- 5Kgha^{-1} + FA-KIO- 0.2% @ 60 and 90 DAT	4.20	5.64	6.41	5.42
T_8- KIO_3-SA-10Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	4.24	5.80	6.32	5.46
T_9- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	4.14	5.65	7.30	5.70
T_{10}-Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.27	5.68	7.11	5.69
T_{11}- KIO_3- SA- 5Kgha^{-1} + FA-KIO_3- 0.2% @ 60 and 90 DAT	3.68	4.94	5.47	4.70
T_{12}- KIO_3 SA-10Kg/ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	3.81	5.06	5.44	4.77
T_{13}- Chitosan-KIO_3 Complex-5Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.26	5.48	7.04	5.59
T_{14}- Chitosan-KIO_3 Complex-10Kgha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT	4.43	5.83	7.41	5.89
T_{15}- Chitosan Spraying	3.64	5.23	7.25	5.37
T_{16}- Water Spraying	3.38	4.29	5.90	4.52
Mean	**3.97**	**5.50**	**6.56**	**5.34**

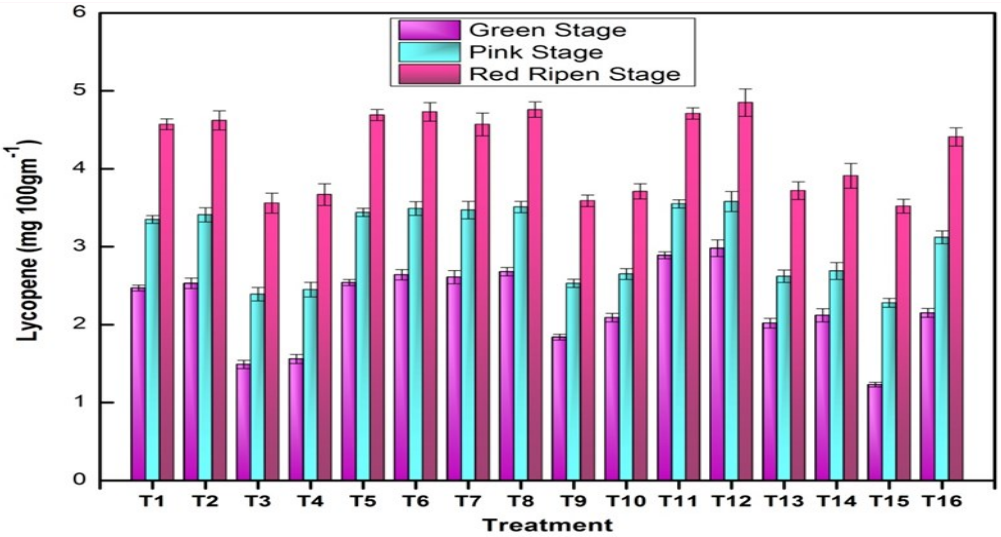

Fig. 4. *Effect of potassium iodate and iodine chitosan complex on lycopene content (mg 100gm^{-1}) at different stages of harvesting*

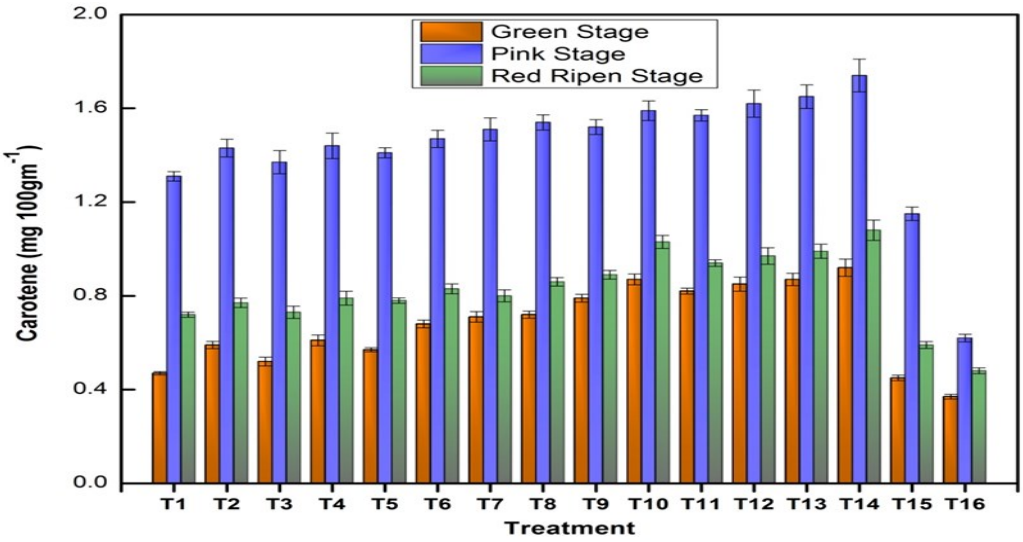

Fig. 5. *Effect of potassium iodate and iodine chitosan complex on β carotene content (mg 100gm^{-1}) at different stages of harvesting*

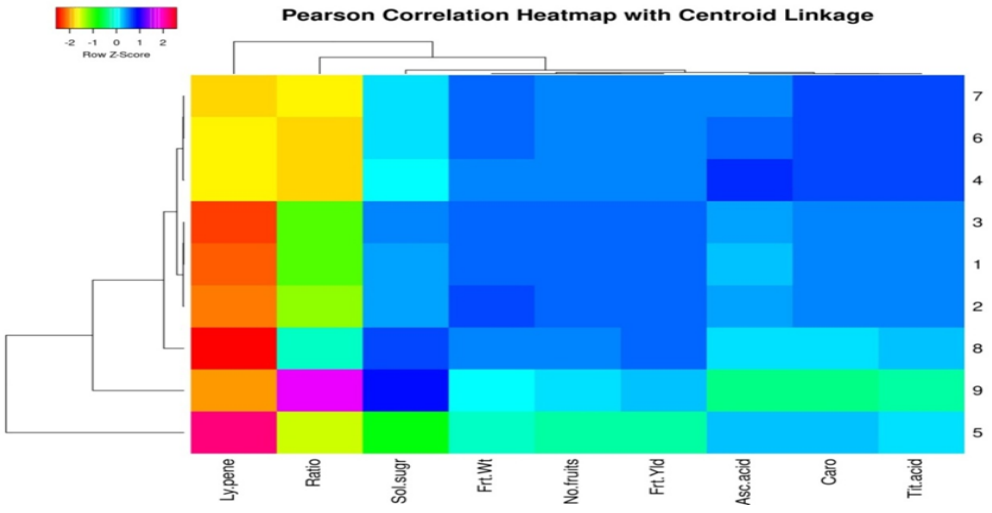

Fig. 6. *Correlation heat map between physiochemical quality and yield attributes of tomato fruit at red ripen stage(n=10). Positive relationships are denoted in pink color and negative relationship in red color.*

Table 6. Effect of potassium iodate and iodine chitosan complex on partitioning of iodine at different harvest stages in fruits (ppm)

Treatments	Green Stage (85DAT)	Pink Stage (100DAT)	Red Ripen Stage (115DAT)	Treatment Mean
T_1- KIO_3-SA- 5 Kg ha^{-1}	0.136±0.002^{i}	0.173±0.002^{h}	0.150±0.001^{j}	0.153
T_2- KIO_3-SA- 10 Kg ha^{-1}	0.220±0.005^{i}	0.310±0.004^{h}	0.280±0.002^{j}	0.270
T_3- Chitosan-KIO_3 Complex-5 Kg ha^{-1}	0.230±0.012^{h}	0.350±0.011^{g}	0.310±0.010^{h}	0.297
T_4- Chitosan-KIO_3 Complex-10 Kg ha^{-1}	0.290±0.017^{g}	0.490±0.016^{f}	0.410±0.015^{g}	0.397
T_5- FA-KIO_3-0.2% @ 60 and 90 DAT	0.018±0.006^{h}	0.025±0.007^{f}	0.021±0.001^{ij}	0.021
T_6- FA-KIO_3-0.3% @ 60 and 90 DAT	0.024±0.012^{fg}	0.030±0.014^{e}	0.028±0.004^{i}	0.027
T_7- KIO_3- SA- 5 Kg ha^{-1} +	0.430±0.017^{f}	0.570±0.018^{e}	0.510±0.016^{f}	0.503
T_8- KIO_3-SA-10 Kg ha^{-1} +	0.530±0.013^{d}	0.590±0.014^{cd}	0.530±0.013^{d}	0.550
T_9- Chitosan-KIO_3 Complex-5 Kg ha^{-1} + FA-	0.650±0.014^{d}	0.730±0.015^{c}	0.670±0.014^{c}	0.683
T_{10}-Chitosan-KIO_3 Complex-5 Kg ha^{-1} + FA-KIO_3-0.2% @ 60 and 90 DAT	0.883±0.022^{b}	0.976±0.023^{b}	0.910±0.021^{b}	0.923
T_{11}- KIO_3- SA- 5 Kg ha^{-1} +	0.490±0.009^{e}	0.660±0.009^{d}	0.570±0.009^{e}	0.573
T_{12}- KIO_3 SA-10 Kg ha^{-1} +	0.622±0.027^{c}	0.701±0.030^{b}	0.662±0.025^{cd}	0.662
T_{13}- Chitosan-KIO_3 Complex-5 Kg ha^{-1} + FA-	0.650±0.025^{bc}	0.980±0.025^{b}	0.730±0.025^{bc}	0.697
T_{14}- Chitosan-KIO_3 Complex-10 Kg ha^{-1} + FA-	0.940±0.038^{a}	0.002±0.040^{a}	0.990±0.040^{a}	0.970
T_{15}- Chitosan Spraying	0.002±0.000^{j}	0.001±0.000^{i}	0.001±0.000^{k}	0.002
T_{16}- Water Spraying	0.001±0.000^{j}	0.001±0.000^{i}	0.001±0.000^{k}	0.001
Mean	**0.500**	**0.523**	**0.440**	**0.487**
S.Ed	0.026	0.026	0.024	
C.D(0.05)	0.053	0.054	0.050	

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

pink to red ripen stage. Application of potassium increased the soluble solid content in the fruit as potassium favours the transport of sucrose in the fruit. The solubilization of cellulose and hemicelluloses in cell walls or water loss might have increased the total soluble solid content in the fruit (Jiang *et al*., 2022). The decrease in total soluble solid content after the pink stage in soil alone, foliar alone and soil + foliar alone treatments of potassium and control are due to the usage of sugar in the respiration process of fruits. On the other hand, there is an increase in total soluble solid content in chitosan alone and chitosan iodate complex + FA-KIO_3 treatments as the chitosan preserves the total soluble solid content in fruits by reducing respiration process (Shah and Hashmi, 2020)

The interaction between soluble solids, acidity and volatile components results in the flavor of tomato fruits (Hagenguth *et al*., 2022). A high SS/TA ratio in the T_{14}-Chitosan-KIO_3 Complex-10 Kg ha^{-1} + FA-KIO_3-0.3% @ 60 and 90 DAT suggests that tomato fruits have a mixture of sugar and acid that correlates with a moderate flavour, with sugars shining out in taste (Table 5). It depends on the preference of the consumers whether they need more acid content or not because some culinary dishes call for fruits with more acidic flavours, which appeal to customers' tastes when combined with other ingredients(Grahl *et al*., 2020). Further, the Pearson correlation heatmap revealed a negative correlation between ascorbic acid and SS/TA ratio and between carotene and SS/TA ratio (Fig.6).

The crucial factor for enriching tomatoes with iodine was the foliar potassium iodate treatment timing. If the time gap is larger between spray and harvest date, less iodine was found in the fruits. In the present study, two foliar sprays were given- one was before green stage and another was before the pink stage which increased the iodine content in fruits of tomato at the green and pink stages (Table 6). Further, the reduction of iodine in fruits at the red ripen stage is due to the lack of foliar spray of iodine. As plants prefer long-distance transport

of iodine, the mobility of iodine in the xylem is considered to be higher than in phloem (Lyons, 2018). So normally, the iodine content is more in leaves as they have higher transpiration than in phloem, preferred low transpiring fruits.

Correlation heatmap

Based on physicochemical quality and yield attributes of tomato fruit at the red ripening stage, a correlation heat map was derived with centroid linkage. The correlation heatmap revealed that the lycopene was negatively correlated with all the parameters having a weak negative correlation with ascorbic acid (-0.01), carotene (-0.02) and titrable acidity(-0.07) (Fig.6). On the other hand, ascorbic acid and carotene were said to have a strong positive correlation with yield attributes and quality parameters except for SS/TA ratio(-0.04 and -0.05) and lycopene (-0.01 and-0.02). Further SS/TA ratio indicated a moderate or no correlation (0.003) between titrable acidity and ratio.

Conclusion

The assistance of potassium in translocation of sugars and starch, turgor maintenance and controlling internal ionic strength along with chitosan assisting in photosynthesis, food generation and enhancing enzyme actions and activity of antioxidants paved the way for the improvement of growth, yield (94.81 t ha^{-1}), quality (carotene-1.24 mg $100gm^{-1}$ ascorbic acid- 3.56 mg $100gm^{-1}$, titrable acidity-0.96%), and uptake of iodine (0.99ppm) in 'shivam hybrid' of tomato. Further, **t**he chitosan molecule's stability and conserving capacity make it a valuable product for biofortifying iodine in crops. The chitosan iodate complex and foliar application of potassium iodate combination not only improved the iodine content in fruits but also improved its quality. The stability of the chitosan was governed by its electrostatic interaction with iodate and its complexing capacity, whereas the conserving capacity was governed by the prevention of acid and pigment losses in fruits during the ripening process.

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Conflict of interest

The authors declare that they have no conflict of interest.

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