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Release Kinetics Of Iodine In Soils For Various Seasons Under Cropped Conditions

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Abstract

Iodine is prone to volatilization and leaching, soils eventually lose iodine. Many research works have examined how iodine is absorbed from the soil, but little is known about the different iodine fractions that are found in soils. In this study, we looked at various iodine fractions (Residual iodine, Organic bound, Oxide bound, Water Extractable and Exchangeable iodine) in soils that were made from various sources of potassium iodate and Chitosan ($C_{56}H_{103}N_9O_{39}$), both separately and together.According to our research, iodine stability is improved by potassium iodate and Chitosan ($C_{56}H_{103}N_9O_{39}$) complex when used together during different seasons of cropping. The static collaboration of $C_{56}H_{103}N_9O_{39}$ and iodate, which inhibits volatilization and steadily stabilizes the amount of iodine in the soil, explains this activity. Further understanding of the movement and behavior of iodine in soil is provided by this study, especially when $C_{56}H_{103}N_9O_{39}$ is added at varying rates or is utilized alone.

Keywords: *Iodine, Chitosan, Potassium iodate, Interaction and Mobility*

1. Introduction

While iodine is not deemed a necessary micro-nutrient for potted plant growth, it holds significant importance in the mental and physical development of individuals. Iodide (I^-) and iodate (IO_3^-) represent the available forms of iodine. Iodine serves as a crucial component of thyroid hormone, playing an indispensable role in human health and contributing to metabolic purposes (Sorrenti et al., 2021). RDA for iodine is established at 120 µg for children aged 6 to 12, 150 µg for grown person around 12, and 200 µg on behalf of significant and nursing females. Adverse charge on iodine renders it substantially vulnerable to filtering and its biochemical and physiochemical properties make it prone to volatilization loss in the soil(Roulier et al.,2019). Indian soils in average contain only 3 mg $kg^{-1}$of total iodine. As Indian soils are deficient in iodine, the crops that are grown in those soils will have less iodine in it which leads to iodine deficiency disorder. So, it is quite important to improve the iodine content in soils as well as commonly consumed crops to overcome iodine deficiency disorder. One such way of improving the iodine content in plants is by biofortifying iodine with fertilizers. Plants can be supplemented with iodine through biofortification, but the iodine utilized must be stable in plants or soil due to substantial losses in the environment.

Iodine has several oxidation states, and its behavior in soil is complicated by factors such as soil composition, texture, pH and redox processes (Nieder et al., 2018). Depletion of surface soil iodide due to leaching, flooding and erosion results in increased iodide deposition in seas. Sea water iodide ions are converted to elemental iodine, which is subsequently volatilized into the atmosphere until rain returns it to the land. In many areas,

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the iodine cycle is sluggish and imperfect, resulting in iodine depletion in soil and drinking water
(Mackeown et al., 2022). Iodine in soil undergoes physical, chemical, and biological transformations as part of its normal biogeochemical cycle, which can limit its allocation to plants but still knowingly increasing its ecological movement (Liu et al., 2023). So, it is quite important to research the nature and behavior of iodine in soil to know its various losses and to minimize the losses to increase its availability in soils.

Gamage et al. (2023) described Chitosan ($C_{56}H_{103}N_9O_{39}$), a genetic polymer that serves as a mediator of trace metal complexing and a biodegradable metal. Chitin is a polysachharide constituent originate in the exoskeletons of lobster such as prawn, lobsters, and beefs beside the cell walls of yeasts (Aliet al., 2022).Iodine absorption will be increased if it is considered a Chitosan-iodate center. Therefore, as part of the current study, a field experiment was overseen to apply iodine at different rates and combinations in order to ascertain the kinetics of iodine in soil.

2. Materials and Methods

In Viraliyur village, Thondamuthur chunk, Coimbatore district, Tamil Nadu (GPS value: 10°.9′99.284″N; 76.7′82.652″E), two ground researchers conducted research throughout the rabi and kharif seasons of 2022 to examine the impact of biofortified iodine on increasing soil iodine fractions. Iodine biofortification was implemented through soil application, foliar spraying, and Chitosan iodate complex mechanisms for the primary crop. The experiments, utilizing hybrid tomato "Shivam," were designed in a randomised block format with triplet repetitions in Palaviduthi soil series.

Various treatments were applied, including potassium iodate (KIO_3) soil submission at 5 and 10 kgha^{-1}, $C_{56}H_{103}N_9O_{39}$-KIO_3 intricate application at 5 and 10 kgha^{-1}, foliar submission of KIO_3 at 0.2% and 0.3% at 60 and 90 days after transplantation (DAT), and combinations of soil and foliar applications. Chitosan spraying and water spraying served as controls.

Solutions containing potassium iodate and $C_{56}H_{103}N_9O_3$ iodate were added to the soil two days after the transplantation procedure. The soil in which the plants were cultivated was an intermediate black clay loam with medium amounts of organic carbon, phosphate, and potassium and a shortage in nitrogen. To improve the soil's nutritional content after transplanting, amendments using potassium iodate and $C_{56}H_{103}N_9O_3$ iodate solutions were added. Its composition was an intermediate black clay loam. The pH of the soil was neutral, and its electrical conductivity was not salty.Fruits were harvested at different ripening stages, including green, pink, and red, for both the primary summer crop and the residual kharif season crop of tomatoes. Following the growing season, tomatoes were harvested at several ripening stages (green, pink, and red) for the main and residual crops. The objective of this research was to examine the effects of the provided solutions on tomato growth and ripening processes in various seasons.
Iodine fractions were assessed according toDuborskaet al. (2020), and iodine application was considered through Inductively coupled plasma optical emission spectroscopy, following Knapp et al. (1998) IBM SPSS® Statistics, version 25, were used in conjunction with one-way ANOVA for statistical analysis.

Table 1 Fractionation of Iodine

S. No	Fractions	Extracting reagent
1	Water Extractable Iodine	Distilled Water
2	Exchangeable Iodine	1M Neutral Normal Ammonium Acetate
3	Oxide bound Iodine	0.04% Hydroxylamine hydrochloride

4	Organic bound Iodine	Solution of $C_4H_{13}NO$, 5% (Extraction)
5	Residual Iodine	Solution of $C_4H_{13}NO$, 5% (Digestion)

3. Result and Discussion

3.1 Water Extractable Iodine

The Water Extractable Iodine corresponds to easily available form of soil iodine and was shown to vary widely, among the application of KIO_3 and $C_{56}H_{103}N_9O_{39}$ iodate composite sources with advancement of crop growth in main and residual crop (Table2 and 3). The water extractable iodine content decreased from green to red ripen stage in all the treatment in main and residual crop except foliar application of potassium iodate alone treatment in main crop. This is because the foliar application of potassium iodate at 60 and 90 DAT reduced the losses in comparison with soil application of potassium iodate alone treatment in main crop. Even though the SA-KIO_3- 5kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT is supplied with foliar treatment of KIO_3 it recorded more loss from pink to red ripen (42%) than green to pink (35.4%) when compared to SA-KIO_3- 10kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT which recorded38% loss from pink to red mature and 41% loss from green to pink stage in main crop. As the excess soil applied potassium iodate might have brought some iodine in soil solution (Lawsonet al. , 2015). The reason for increase in loss is due to non-application of iodine fertilizer to the residual crop. Further the combined Cs-KIO_3 and FA- KIO_3 treatments maintained higher water extractable iodine when compared to other treatments in all the harvest stages of main and residual crop except the green stage of main crop. In green stage the soil applied iodine would have brought more iodine in soil solution as compared to Chitosan applied iodine and as soil iodine is subjected to high volatilization and leaching loss from soil, application of Chitosan forms strong electrostatic interaction with iodine and prevents the loss of iodine from the soil and releases the iodine slowly to the soil in pink and red ripen stages of main crop.

Table 1. Impact of iodine Chitosan complex and potassium iodate on water extractable iodine content (mg kg^{-1}) at various phases of primary crop harvest

Treatment	**Green Stage**	**Pink Stage**	**Red Ripen Stage**	**Treatment Mean**
T_1- Soil Application (SA) – KIO_3 – 5 kg ha $^{-1}$	46.06^{cd}	30.44^{c}	16.53^{g}	31.01
T_2- Soil Application (SA) – KIO_3 - 10 kg ha $^{-1}$	63.43^{b}	41.20^{a}	24.46^{cd}	43.03
T_3-$C_{56}H_{103}N_9O_{399}$-KIO_3 Complex (CsKIO$_3$) - (SA) -5 kg ha $^{-1}$	34.56^{e}	24.34^{e}	21.98^{e}	26.96
T_4- $C_{56}H_{103}N_9O_{39}$-KIO_3 Complex (CsKIO$_3$) - (SA)-10 kg ha $^{-1}$	45.08^{d}	34.32^{b}	28.54^{b}	35.98
T_5- FA-KIO_3-0.2% at 60 and 90 DAT	1.62^{f}	2.98^{f}	2.85^{h}	2.48
T_6- FA-KIO_3-0.3% at 60 and 90 DAT	1.84^{f}	3.34^{f}	2.89^{h}	2.69
T_7- SA- KIO_3-5 kg ha $^{-1}$ + FA-KIO_3- 0.2% at 60 and 90 DAT	47.88^{cd}	30.93^{c}	17.91^{g}	32.24
T_8- SA- KIO_3-10 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60 and 90 DAT	69.80^{a}	41.22^{a}	25.57^{c}	45.53
T_9- $C_{56}H_{103}N_9O_{39}$-KIO_3 Complex (CsKIO$_3$) - (SA)-5 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60	35.85^{e}	25.11^{de}	23.14^{de}	28.03

and 90 DAT				
T_{10}-$C_{56}H_{103}N_{9}O_{39}$-KIO_3 Complex ($CsKIO_3$) - (SA)-10 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60 and 90 DAT	45.47^{d}	34.62^{b}	28.71^{b}	36.27
T_{11}- SA- KIO_3-5 kg ha $^{-1}$ + FA-KIO_3- 0.3% at 60 and 90 DAT	49.43^{c}	35.75^{b}	19.97^{f}	35.05
T_{12}- SA- KIO_3-10 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	71.43^{a}	43.32^{a}	27.69^{b}	47.48
T_{13}- $C_{56}H_{103}N_{9}O_{39}$-KIO_3 Complex ($CsKIO_3$) - (SA)- 5 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	37.58^{e}	27.15^{d}	24.13^{cd}	29.62
T_{14}- $C_{56}H_{103}N_{9}O_{39}9$-$KIO_3$ Complex ($CsKIO_3$) - (SA)- 10 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	49.46^{c}	35.74^{b}	31.41^{a}	38.87
T_{15}- $C_{56}H_{103}N_{9}O_{39}$ Spraying	2.18^{f}	1.94^{f}	1.61^{h}	1.91
T_{16}- Water Spraying	1.47^{f}	1.17^{f}	0.98^{h}	1.42
Mean	**37.71**	**25.86**	**18.66**	**27.41**
S.Ed	1.85	1.25	0.95	
C.D(0.05)	3.78	2.56	1.94	

Table 2. Impact of iodine $C_{56}H_{103}N_{9}O_{39}$ complex and potassium iodate on the water extractable iodine content (mg kg^{-1}) of residual crop at various harvest stages

Treatments	**Green Stage**	**Pink Stage**	**Red Ripen Stage**	**Treatment Mean**
T_1- Soil Application (SA) – KIO_3 – 5 kg ha $^{-1}$	8.23^{g}	5.11^{g}	2.39^{g}	5.24
T_2- Soil Application (SA) – KIO_3 - 10 kg ha $^{-1}$	11.72^{e}	7.42^{e}	3.41^{e}	7.52
T_3- $CC_{56}H_{103}N_{9}O_{39}$-$KIO_3$ Complex ($CsKIO_3$) - (SA) -5 kg ha $^{-1}$	9.43^{f}	5.86^{f}	2.49^{g}	5.93
T_4- $C_{56}H_{103}N_{9}O_{39}$-KIO_3 Complex ($CsKIO_3$) - (SA)-10 kg ha $^{-1}$	15.47^{b}	10.23^{b}	5.21^{b}	10.30
T_5- FA-KIO_3-0.2% at 60 and 90 DAT	1.35^{h}	0.79^{h}	0.34^{h}	0.83
T_6- FA-KIO_3-0.3% at 60 and 90 DAT	1.41^{h}	0.82^{h}	0.38^{h}	0.87
T_7- SA- KIO_3-5 kg ha $^{-1}$ + FA-KIO_3- 0.2% at 60 and 90 DAT	8.23^{g}	5.19^{g}	2.35^{g}	5.26
T_8- SA- KIO_3-10 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60 and 90 DAT	12.95^{cd}	8.25^{cd}	4.01^{d}	8.40
T_9- $C_{56}H_{103}N_{9}O_{39}$-KIO_3 Complex ($CsKIO_3$) - (SA)-5 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60 and 90 DAT	12.15^{de}	7.95^{de}	4.12^{d}	8.07
T_{10}-$C_{56}H_{103}N_{9}O_{39}$-KIO_3 Complex ($CsKIO_3$) - (SA)-10 kg ha $^{-1}$ + FA-KIO_3-0.2% at 60 and 90 DAT	15.29^{b}	9.98^{b}	5.05^{bc}	10.11
T_{11}- SA- KIO_3-5 kg ha $^{-1}$ + FA-KIO_3- 0.3% at 60 and 90 DAT	9.76^{f}	6.19^{f}	2.89^{f}	6.28
T_{12}- SA- KIO_3-10 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	12.68^{cde}	8.05^{cde}	3.83^{d}	8.19

T_{13}-$C_{56}H_{103}N_9O_{39}$-KIO_3 Complex (CsKIO$_3$) - (SA)- 5 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	13.25^{c}	8.63^{c}	4.87^{c}	8.92
T_{14}- $C_{56}H_{103}N_9O_{39}$-KIO_3 Complex (CsKIO$_3$) - (SA)- 10 kg ha $^{-1}$ + FA-KIO_3-0.3% at 60 and 90 DAT	18.27^{a}	11.92^{a}	6.45^{a}	12.21
T_{15}- $C_{56}H_{103}N_9O_{39}$ Spraying	0.98^{h}	0.61^{h}	0.33^{h}	0.64
T_{16}- Water Spraying	0.66^{h}	0.39^{h}	0.20^{h}	0.42
Mean	**9.49**	**6.09**	**3.02**	**6.20**
S.Ed	0.49	0.31	0.16	
C.D(0.05)	1.00	0.65	0.33	

3.2 Exchangeable iodine

After extraction of water extractable iodine, the same soil was added with neutral normal ammonium acetate which is known to derive its exchangeable iodine from the pool of soil iodine (Fig. 1 and 2). In the current study, the exchangeable iodine fraction was highest in the treatments of $C_{56}H_{103}N_9O_{39}$ KIO_3-SA-10kg ha^{-1} + FA-KIO_3- 0.3% at 60 and 90 DAT, then in the treatments of $C_{56}H_{103}N_9O_{39}$ KIO3-SA-10kg ha^{-1} + FA-KIO_3- 0.2% at 60 and 90 DAT. The treatments with absolute control of main and residual crop showed the lowest value. In both the crops the extent of decrease was less in combined Cs-KIO_3 and FA- KIO_3 treatment and high in soil application of KIO_3 alone treatments. On an average there is 42% and 59% loss of exchangeable iodine in pink and red ripen stage of main crop and 53% and 63% loss of exchangeable iodine in pink and red ripen stage of residual crop of soil application of KIO_3 alone treatment. On the other hand, there is only 12% and 8% loss of exchangeable iodine in pink and red ripen stage of main crop and 46% and 48% loss of exchangeable iodine in pink and red ripen stage of residual crop of combined Cs-KIO_3 and FA- KIO_3 treatment. Further the content of exchangeable iodine was more in combined Cs-KIO_3 and FA- KIO_3 treatment when compared to water extractable iodine in main and residual crop indicating the role of Chitosan in absorbing iodate and minimizing its losses by reducing its solubility (Wayset al., 2018).

3.3 Iodine bound to oxides.

The oxide bound iodine was highest in combined SA-KIO_3 and FA- KIO_3 treatments in all the harvest stages of main and residual crop of tomato (Fig. 3 and 4). Irrespective of the treatments imposed in main crop the oxide bound iodine tends to decrease throughout the growth of the crop. The rate of decrease of oxide bound iodine in main crop was more in Chitosan alone and combined Cs-KIO_3 and FA- KIO_3 treatments nearly 12%-35% from green to pink phase and 12%-34% from pink to red ripen phase, whereas for combined SA-KIO_3 and FA- KIO_3 the rate of decrease was more from green to pink stage (19%-21%) and less from pink to red ripen phase (17%-18%) of main crop. This is because the soil applied iodine is highly prone to bound with oxides which are naturally present higher in the soil as in case of $C_{56}H_{103}N_9O_{39}$applied treatments the occurrence of Chitosan will avoid the binding of iodine to oxides in the soil. When the quantity of living carbon in the mud is insufficient, iodine binds largely to mineral oxides in soilDuborskaet al. (2020). The amount of organic carbon present at the post-harvest stage of main and residual crop of SA-KIO_3 and FA- KIO_3 treatments varies between 3.4-3.5g kg^{-1} and 3.0-3.1g kg^{-1} which was very less when compared to combined Cs-KIO_3 and FA- KIO_3 treatments which accounted for about 4.0-4.2g kg^{-1} in main crop and 3.3-3.4g kg^{-1} in residual crop respectively The application of Chitosan increased the organic carbon content in Cs-KIO_3 and FA- KIO_3 treatments which accounted for less iodine adsorption by oxides.

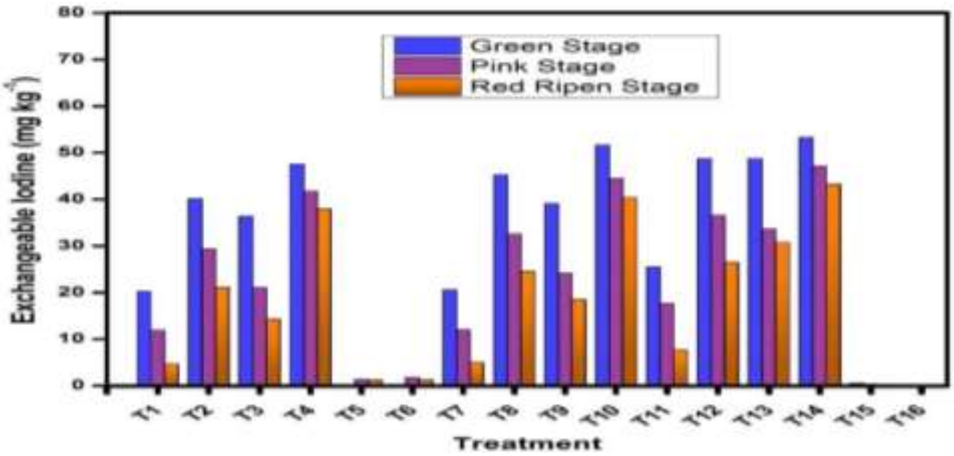

Fig 1. Impact of iodine Chitosan compound and potassium iodate on exchangeable iodine (mg kg^{-1}) at various stages of main crop

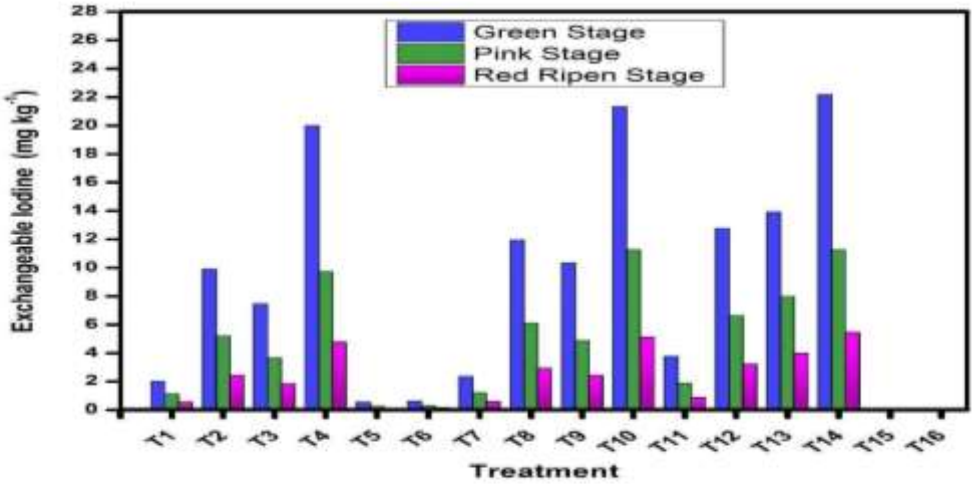

Fig 2. Impact of iodine Chitosan compound and potassium iodate on the exchangeable iodine (mg kg^{-1}) at various phases of the residual crop.

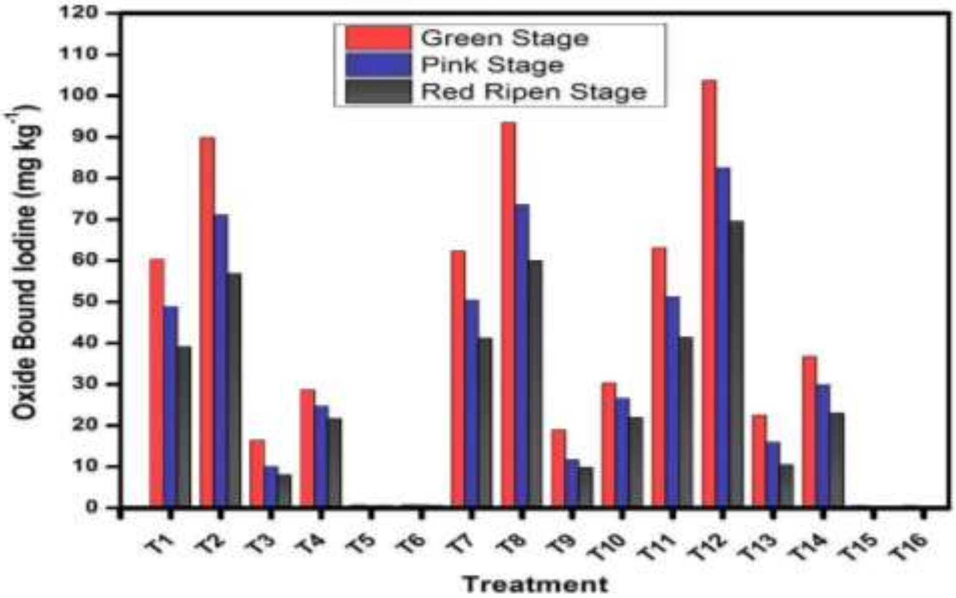

Fig 3. Impact of iodine Chitosan compound and potassium iodate on the amount of iodine bound to oxides (mcg kg^{-1}) at different phases of the main crop.

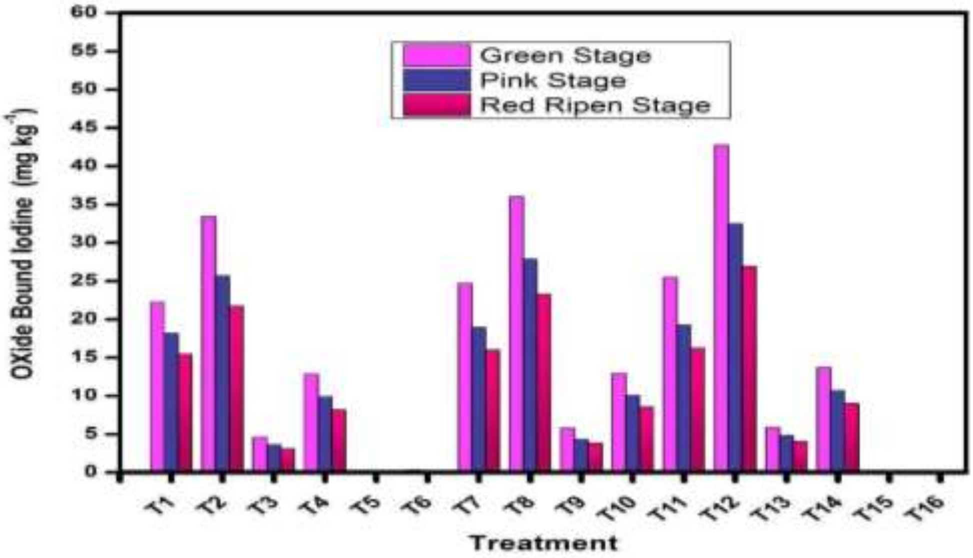

Fig 4. Impact of iodine Chitosan compound and potassium iodate on the iodine content bound to oxides
(mg kg^{-1}) at different stages of the residual crop.

3.4 Iodine obliged to organic matter.

The organic matter substance of the soil shows a fundamental character in retaining iodine from soils. The application of potassium iodate along with Chitosan significantly improved the organic bound iodine in main produce and reserved the iodine in the remaining produce with less loss when compared to foliar and soil application of potassium iodate alone and combined treatments (Fig. 5 and 6). As opposite to the oxide bound iodine the presence of Chitosan increased the organic matter adsorption of iodine and reduced the adsorption of oxide iodine in soils which resulted in more organic bound iodine in Chitosan-iodate treatments when compared to other treatments in both the crops. Further the loss of organic bound iodine was very less in pink to red ripen stage than green to pink stage of main crop in combined Cs-KIO_3 and FA- KIO_3 applied treatments. In residual crop organic bound iodine decreased from green to red ripen stage with much decrease from pink to red ripen stage, as the lack of application of Chitosan-potassium iodate complex decreased the organic matter iodine content in residual crop (Davila Ragelet al., 2020). Further as the soil and foliar application of potassium iodate has accounted for more loss of organic matter iodine in the soils of main crop and hence retention of iodine is very less in the residual crop. It is due to the absence of the Chitosan which results in more losses of iodine in the soil and foliar KIO_3 treatments.

3.5 Residual iodine

Yet another fraction of Iodine is residual iodine, which is derived by digesting the residual soil after being extracted with various reagents and represents the unavailable fraction of soil iodine pool. As compared to the other fractions, this pool of soil iodine is totally unavailable or can be made available by weathering process. In other words, this fraction cannot be extracted by normal extractants. This study reveals that the residual iodine content was highest in $C_{56}H_{103}N_9O_{39}$-KIO_3intricate at 10 kg/ha + FA-KIO_3 at 0.3% during 60 and 90 days after transplanting (DAT), followed by $C_{56}H_{103}N_9O_{39}$-KIO_3 complex at 5 kg/ha + FA-KIO_3 at 0.3% during 60 and 90 DAT for both the main and residual crops (Fig. 7 and 8). The enduring iodine portion is contemplated stable as iodine becomes integrated into other mineral arrangements.

The rate of residual iodine decrease in both main and residual crops was more pronounced in soil application of KIO_3 alone and combined SA-KIO_3 and FA-KIO_3 treatments. This reduction accounted for approximately 20%-37% from the green to pink stage and 27%-39% from pink to red ripening stage in the main crop. For the residual crop, it amounted to 30%-43% from the green to pink stage and 35%-46% from the pink to red ripening stage. The higher rate of decrease in potassium iodate from both soil and foliar applications suggests the instability of iodine fertilizer compared to the more stable Chitosan based application (Macias et al., 2016).

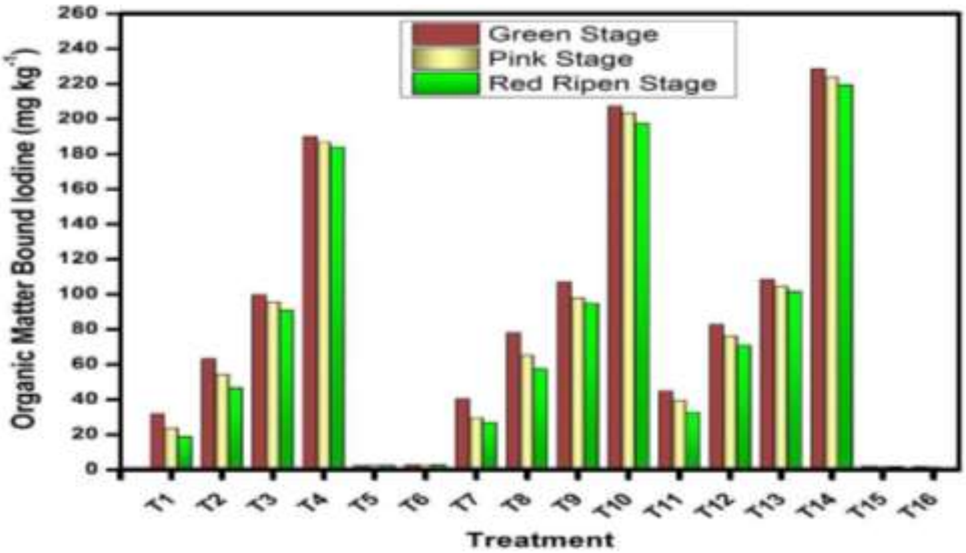

Fig 5. Impact of iodine Chitosan compound and potassium iodate on the amount of iodine bound to organic matter (mg kg^{-1}) during different phases of the main crop.

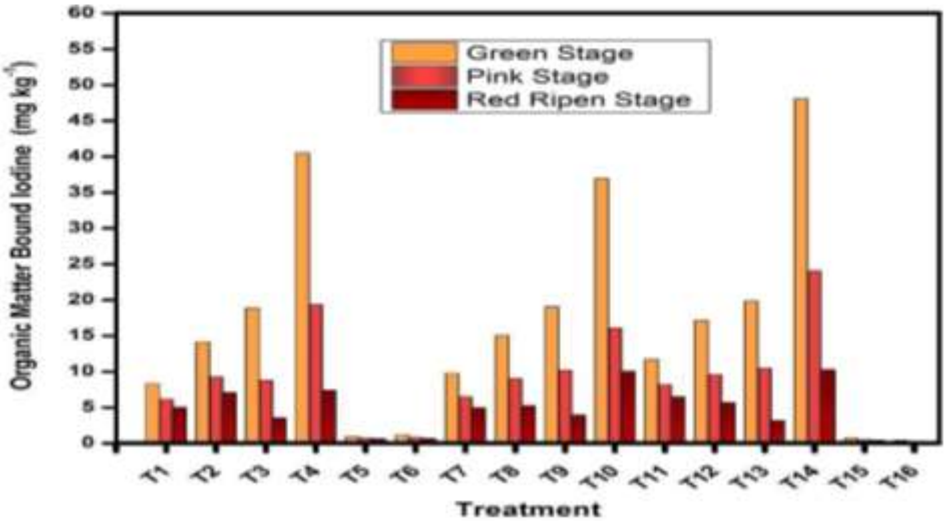

Fig 6. The effect of iodine Chitosan compound and potassium iodate on the iodine bound to organic matter
(mg kg^{-1}) at different stages of the residual crop.

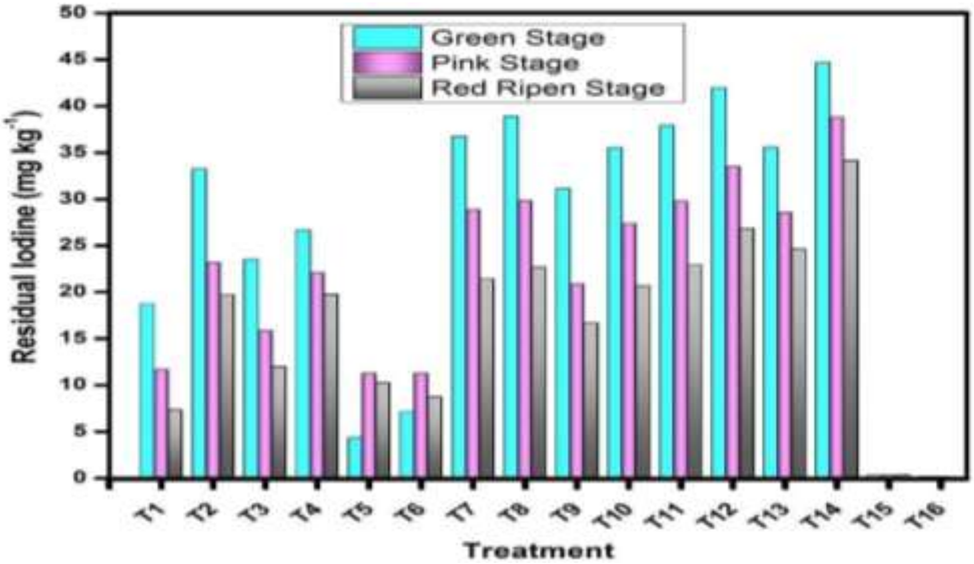

Fig 7. Impact of iodine Chitosan compound and potassium iodate on the amount of residual iodine
(mg kg^{-1}) throughout different stages of the main crop's harvest.

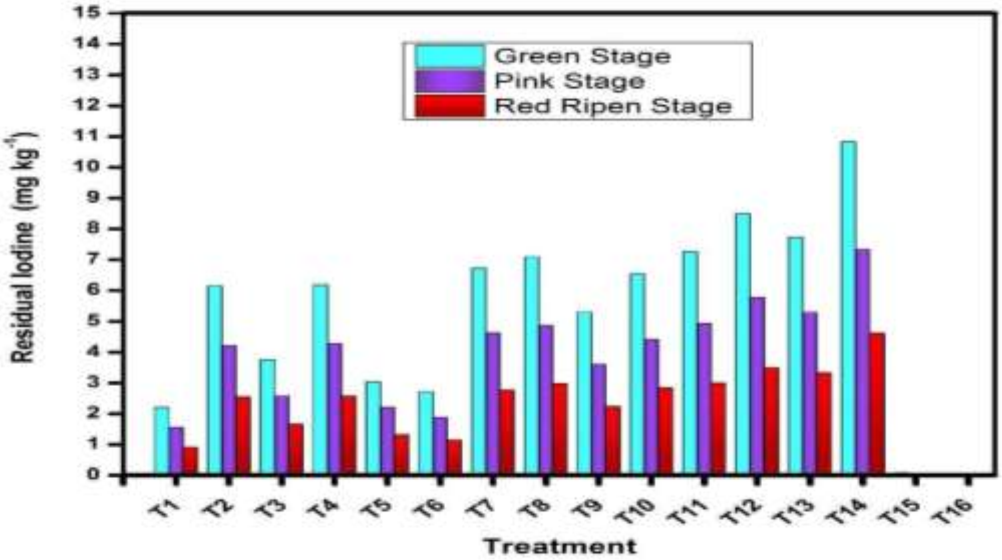

Fig 8. Effects of iodine Chitosan formation and potassium iodate on residual iodine subject (mg kg^{-1}) at different stages of harvest in residual crop.

4. Conclusion

The average distribution of different iodine fractions in soils indicated that the exchangeable, organic bound and residual iodine are dominant in combined Cs-KIO_3 and FA- KIO_3 treatments, whereas water extractable and oxide bound iodine are dominant in combined SA-KIO_3 and FA- KIO_3 treatments in main and residual crop. Further the average distribution of iodine in Chitosan alone and combined Cs-KIO_3 and FA- KIO_3 treatments follows the order of organic bound iodine > residual iodine > exchangeable iodine > water extractable iodine > oxide bound iodine in main crop and organic bound iodine >exchangeable iodine > water extractable iodine > oxide bound iodine >residual iodine in residual crop. Iodine is more readily available when it is provided as chitosan iodate compound.Chitosanhas the capacity to complex iodine and reduce its losses. To conclude, the application of Chitosan along with potassium iodate has increased the dynamics of iodine in soil by preventing volatilization and leaching.

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