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Response of rhizosphere microbial consortium on yield, quality and soil health of sweet orange (C*itrus Sinensis* (l) Osbeck)

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ABSTRACT

The objective of the present paper was to evaluate the "Effect of application Rhizosphere microbial consortium on yield, quality and soil health of Sweet orange (Citrus sinensis (L) Osbeck) orchard" from field experiment was conducted during the year 2014-15. The field experiment was laid out at progressive farmer field.at Parbhani (Maharashtra) on best treatments emerged out from pot culture experiment. And then, thefield experiment was conducted in randomized block design (RBD) with four replications. The results revealed that growth media comprising Ficus species rhizosphere soil was slightly acidic to neutral in pH, highest content of organic carbon and lowest level of lime. Further the Umber rhizosphere soil recorded maximum content of available N, P, K, S and micronutrients and of microbial population viz. Bacteria, Fungi and Actinomycetes. Ficus racemosa L. Ficus religiosa L. and Ficus benghalensis L. were hybridized together in equal proportion and incubated for development of beneficial microbe's consortia. The developed Ficus species rhizosphere soil consortia with recommended doses of NPK showed excellent and significant impact on soil quality parameters, nutrient availability and enhanced the fruit yield and quality of fruit.

Key Words: Rhizosphere, Consortium, *Ficus racemosa* L. *Ficus religiosa* L. and *Ficus benghalensis*

INTRODUCTION

The rhizosphere is the narrow region of soil or substrate that is directly influenced by root secretions and associated soil microorganisms known as the root microbiome. Soil pores in the rhizosphere can contain many bacteria and other microorganisms that feed on sloughed-off plant cells, termed rhizodeposition (Saikia *et al.,* 2021). The proteins and sugars released by roots, termed root exudates. The microbial consortium is two or more microbial groups of living symbiotically microbes called as consortium or A group of different species of microorganisms that act together as a community (Bora *et al.,* 2013; Bora and Bora, 2020). Consortia can be endosymbiotic or ectosymbiotic (Bora *et al.,* 2019; Srivastava and Bora, 2023). The plant rhizosphere is the soil nearest to the plant root system where roots release large quantity of metabolites fromliving root hairs or fibrous root systems. These metabolites actas chemical signals for motilebacteria move to theroot surface but also represent the main nutrient sources to available to support growth and persistence in the rhizosphere (Srivastava *et al.,* 2022; Rahman *et al.,* 2023). Some of the microbes that inhabit this area are bacteria that are able to colonize very efficiently the roots or the rhizosphere soil of crop plants. These bacteria are referred to as plant growth promoting rhizobacteria (PGPR). They fulfil important functions for plant growth and health by various manners. Direct plant growth promotion may result either from improved nutrient acquisition and/or from hormonal stimulation. Diverse mechanisms are involved in the suppression of plant pathogens, which is often indirectly connected with plant growth. This paper describes the different mechanisms commonly used by most PGPR in their natural habitats to influence plant-growth health, yield and quality of fruits.

Citrus is a large group of shrubs or trees belong to the family *Rutaceae.* The Origin of citrus is believed to be the southern Himalaya, north-east of India and China (Gmitter *et al.,* 1990). It is extensively grown under tropical and sub-tropical climatic conditions, where the soil and climatic regimes are favorable for its growth (Shah, 2004; Srivastav and Singh, 2008). Due to its ornamental value, the benefits and importance in terms of fruit juice industries, citrus production increased in India and around the globe. In India, sweet orange fruits are grown in an area of 179 thousand ha, with a production of

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2876 thousand million tones and productivity 18.72 (Mt/ha). In Maharashtra, 2022-23 sweet orange was cultivated on an area of 10.81 lakh ha with production 73.20 lakh tonnes of fruits. In India sweet orange is grown in 28 states but maximum area and production under sweet orange is in Andhra Pradesh, Maharashtra, Telangana, Madhya Pradesh, Tripura and Punjab such as 22.57 lakh tones,10.81, 4.36,1.23,0.19 and 0.35 lakh tones., respectively.

The commercially grown varieties of sweet oranges in India are: 'Jaffa', 'Valencia', 'Hamlin' and 'Malta' in Punjab, Himachal Pradesh, and Rajasthan; 'Sathgudi'orange in Andhra Pradesh; and 'Mosambi', Nucellar and Sathgudi in the Marathwada region of Maharashtra (Srivastava *et al.,* 2009). The soils of this region are mostly derived from basaltic parent material and are commonly deficient in multiple nutrients, including N, P, Fe, Mn, and Zn (Srivastava and Singh, 2004; 2008). That is why the conventional nutrient management strategy mainly based on macronutrient application in citrus orchards has not been very successful in raising the productivity level (Srivastava *et al.,* 2006, 2009). Our earlier studies have shown that rhizosphere effective microbes have the tendency to play multiple roles (Srivastava, 2012; 2013, Keditsu and Srivastava, 2014; Wu and Srivastava, 2012), Srivastava *et al* (1999) suggested microbes-mediated citrus production system to overcome various biotic and abiotic stresses while interacting with an environment. The *Ficus* tree species Banyan (*Ficus benghalensis* L.), Pipal (*Ficus religiosa*L.) and Umber (*Ficus racemosa* L.) are scare tree species and acquire a very auspicious place in Indian culture. These trees acquire a important place because of their longitivity. Even through evergreen tree deciduas trees they remain green and habitat of many birds and serpentine animals like squirrel (*Funambulus palmarum*), Lizards (Sandodia), Salamander (Caudata) and birds such as Sparrow (*Passer domesticus*), Vampire bats (*Desmodus rotundus*), Crow (*Crvus macrohynchos*) etc. Because of their dense leaves the temperature under neath the tree remains in the range of 22° to 27°C throughout the year. The temperature favoursthe multiplication, growth and development of many beneficial soil microbes and increase in organic matter content due to addition of leaves, fruits as leaf litter. Because of increase in organic matter and microbial activity soils underneath the tree become a very good source of bioinoculants. Hence, it was thought to collect the soil underneath the tree and it's in rhizosphere of sweet orange soil as study its effect on growth and yield of sweet orange.

MATERIALS AND METHODS

A field experiment was conducted with following treatments to study the effect of various rhizosphere soils on yield and quality of sweet orange in comparison with current recommendation of application of *Azotobacter*+ *Phosphorus Solublising Bacteria* +*Trichoderma* during 2014 -15. The experiment was conducted on a farmer field at Zari, Tahsil and Dist. Parbhani (M.S.) The site of experiment lise between 19^0 to 20^0 north latitude and 75^0 20" to 77^0 30" east longitude. There were seven treatments replicated into four (Table1). The 28 trees were demarcated for the trial. The age of orchard was 15 years. Similarly, T_2, T_3, T_4, T_5 and T_6 were also tested for their performance on wilting sweet orange trees. RDF: NPK 800:400:400 gm /tree. Half dose of fertilizer at

Table 1: Treatment details using three species of *Ficus*

Treat. No.	Treatment Symbol	Details of treatments
T_1	RDF + NM	NPK + Control (No microorganism)
T_2	RDF + PRS	NPK +*Ficus religiosa* L.(Pipal) rhizosphere soil (60 kg/tree)
T_3	RDF + BRS	NPK + *Ficus benghalensis* L.(Banyan tree)rhizosphere soil (60 kg/tree)
T_4	RDF + URS	NPK + *Ficus racemosa* L. (Umber tree) rhizosphere soil (60 kg/tree)
T_5	RDF + Consortia	NPK + mix from 3 *Ficus* species rhizosphere soil (20 kg each/ tree) (20 kg PRS +20kg BRS + 20 kg URS)
T_6	Without RDF + Consortia	Without NPK mix of 3 Ficus species rhizosphere soil (20 kg each/ tree) (20 kg PRS +20kg BRS + 20 kg URS)
T_7	RDF + Dose of *Azoto.* + *PSB* +*Tricho.*	NPK + dose of *Azotobacter* (100 gm /tree) +PSB (*Phosphorus solublising bacteria*) (100 gm /tree) + *Trichoderma* (100 gm /tree)

Note: RDF: Recommended dose of fertilizer, NM: No microorganism the time of application of rhizosphere soil on 7th January 2014 as basal application. The remaining half dose was applied on 13th July 2014 (187 days after basal application). The field operation performed in experimental field, effect of application of rhizosphere soil to the decline sweet orange tree from farmer field at Zari village Parbhani,

Collection and preparation of soil samples

The soil samples were collected from selected sweet orange orchard in the farmer field. Composite soil sample 0- 20 cm depth were collected from four to five spots and peripheral area or perimeter of each tree, per orchard depending on the area. (Srivastava *et al.,* 1999). The soils samples thus collected by adopting quartering process. Finally, about 1 kg sample was kept for processing. The samples were then placed in clean cloth bags, labeled properly and brought to laboratory. The soil samples after drying in shade were ground with wooden mortar and pestle, pass through 2 mm and 0.5mm sieves and kept in clean polythene bags with proper labeling.

Observations recorded

Harvesting was carried out at once. Yield in respects of number of fruits per tree, weight of fruit (kg/tree) and productivity (t ha^{-1}) was recorded. Total soluble solids were recorded with the help of hand refractometer (Erma Tokkyo A 30 ^{0}C) by taking a drop of juice on the refractometer and observing it against light. The titratable acidity of the juice extract was determined according to method by titrating the extract against 0.1 N NaOH using phenolphthalein as an indicator. Ten ml of juice from each sample was diluted to 250 ml and aliquot of 10 ml was taken for titration. This aliquot was titrated against N/10 NaOH solution.

Ascorbic acid content was analyzed by titrimetric method. 2, 6 indophenol diphenol (the dye) was titrated against standard ascorbic acid. Present in 100 ml juice was calculated (AOAC, 1965). The capacity of an extract of the sample to reduce standard solution of dye as determined by titration, was directly proportional to the ascorbic acid content in 10 gm of sample (fruit juice) was taken and made up to 100 ml by adding 3 % (HPO_3) and the same was filtered. An aliquot of 10 ml of extract was titrated against a standard dye until pink colour persisted at least for 15 seconds. Results were expressed as mg 100 g^{-1} of fruit juice.

RESULTS AND DISCUSSION

The research was undertaken under the title of “Rhizosphere hybridization and nutrient dynamics in sweet orange” during the year 2014-2015. In this research project, the study was conducted in the field experiment on farmer’s field at Zari Ta. & Dist. Parbhani was conducted to study the effect of application rhizosphere microbial consortium on yield, quality and Soil health of sweet orange (*Citrus sinensis* (L) Osbeck) orchard” The observations in all the experiments conducted were recorded, tabulated, statistically analyzed, presented, interpreted and discussed in the below under following subheads.

Effect on fruit yield and yield parameters

The data on weight of fruit, diameter of fruit, number of fruits per tree, and yield per tree (Table 2, Figure 1, Figure 2 and Figure 3. The treatments administered to sweet orange found to have significant influence on these parameters. Among the PRS, BRS and URS, URS proved to be better in improving these parameters.

The average number of fruits per tree (599.85), weight of fruit (188.50 gm), diameter of fruit (7.04 cm) and fruit yield (16.18 kg/tree) were recorded in the field experiment. The minimum and significantly maximum values of these parameters viz., number of fruits per tree, weight of fruit, diameter of fruit and yield of fruit were recorded in control (T_1) and treatment T_5 i.e. RD of NPK + Consortia of 3 *Ficus* species rhizosphere soil and they are 344.75 and 786.25, 139.77 gm and 223.19 gm, 6.12 cm and 7.73 cm and 48.19 kg and 175.55 kg, respectively. The second-best treatment was application of only Consortia made from 3 *Ficus* species rhizosphere soil followed by convential method of biofertilizer application. These results are in accordance with Srivastava *et al.,* (2000), Srivastava and Singh 2003, 2004, 2004b and 2008).

Table 2: Fruit yield and quality parameter of sweet orange as influenced b y various treatments of rhizosphere microbial consortium

Treatment	No. of fruit per tree	Weight of Fruit (gm)	Diameter of fruit (cm)	Yield /tree (kg)	Vit.C (mg 100 mg^{-1} juice)	TSS (^{0}Brix)	Acidity (mg 100 mg^{-1} juice)
T_1	344.75	139.77	6.12	48.19	39.87	7.59	0.76
T_2	484.50	164.09	6.53	77.06	43.35	9.57	0.54
T_3	579.75	178.28	7.07	101.83	46.21	9.72	0.48
T_4	591.25	191.89	7.16	111.76	45.89	9.88	0.44
T_5	786.25	223.19	7.73	175.55	57.15	10.89	0.42
T_6	762.70	213.34	7.44	162.64	53.16	10.20	0.40
T_7	649.75	208.95	7.24	135.69	48.47	9.94	0.46
S.Em. ±	24.37	3.09	0.12	3.09	1.54	0.15	0.01
CD at 5 (%)	72.39	9.17	0.36	9.17	4.58	0.46	0.02
Mean	599.85	188.50	7.04	116.10	47.73	9.68	0.50

T_1: NPK, T_2: NPK + (PRS), T_3: NPK + (BRS), T_4: NPK + (URS), T_5: NPK + Consortia, T_6: Without NPK + Consortia, T_7: NPK + dose of Azotobacter + PSB + Trichoderma

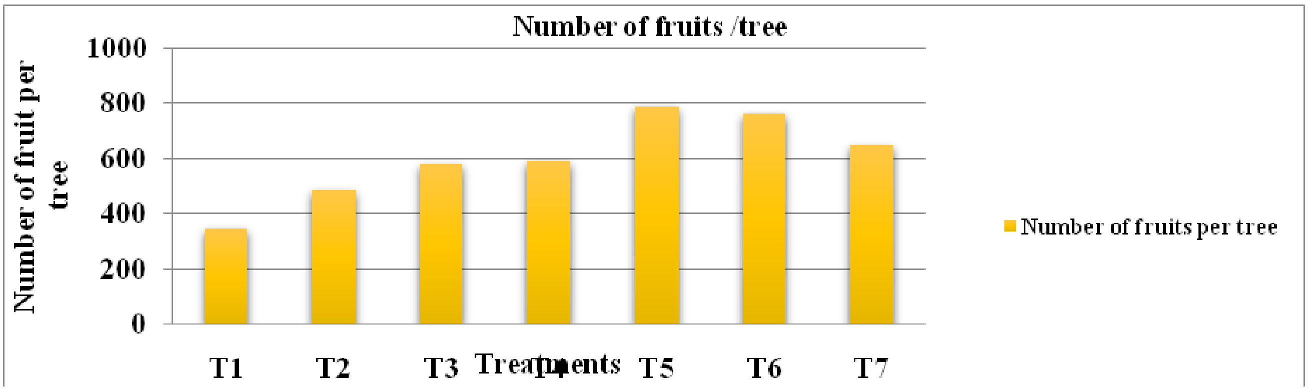

Figure 1: Effect of various treatments of rhizosphere consortium on number of fruits /tree

Effect on Fruit quality parameters

In the present research programme some of fruit quality parameters like Vitamin-C content, TSS of fruit and Acidity of fruit were studied and data there of are presented in Table 2**.** The data revealed that the sweet orange receiving RD of NPK with Consortia of 3 *Ficus* species (*Ficus racemosa* L. (Umber tree), *Ficus benghalensis* L. (Banyan tree) and *Ficus religiosa* L. (Pipal tree) shown significant improvement in fruit quality i.e. increase in Vitamin-C, increase in TSS and decrease in Acidity over all other treatments. Second and third best treatments are T_6 and T_7 (only Consortia and conventional application of biofertilizers). Among rhizosphere soils URS found to be better rhizosphere soil followed by BRS and PRS. The improvement in fruit quality due to combined application of organic and inorganic fertilizers were also reported previously in number of studies (Srivastava *et al.,* 2007; 2012, Srivastava and Hota, 2020).

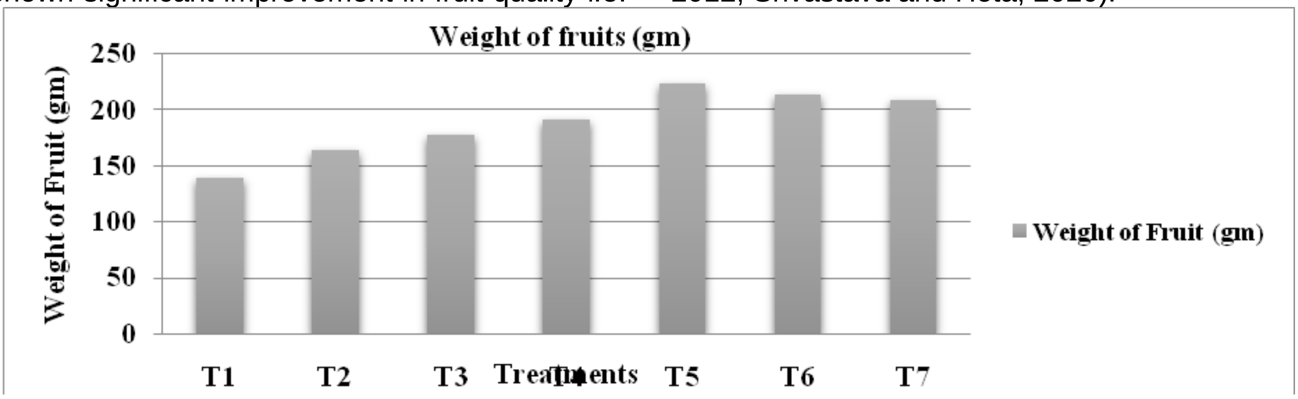

Figure 2: Effect of various treatments of rhizosphere consortium on weight of fruit

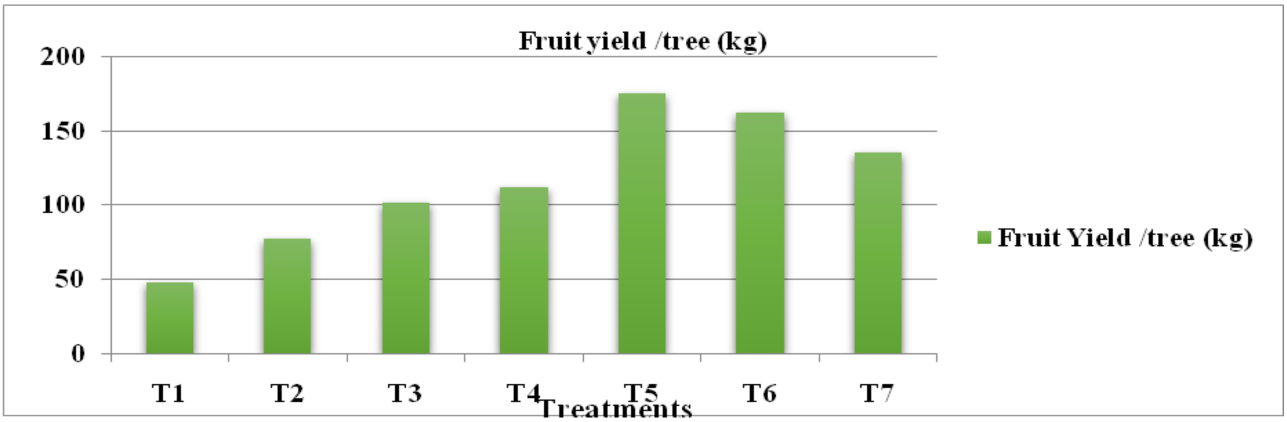

Figure 3: Effect of various treatments of rhizosphere consortium on fruit yield/ tree

Effect on availability of nitrogen in soil

The available nitrogen content in various treatments from initial observation to harvesting stage was varied between 738.82 to 1009.87 kg N ha^{-1} (Table 3). In respect of treatments, availability of N was maximum in T_4 treatment (RD of NPK +URS). Even through the T_5 treatment which supplies RD of NPK + Value added consortium made from 3 *Ficus* rhizosphere soil initially recorded less available N status than T_4 treatment in later stages i.e. 2nd, 3rd, 4th Observation (90, 180 and 270 days) the available N content was increased.

Table 3: Effect of application of value-added consortium on available nitrogen and phosphorus P_2O_5 (kg ha^{-1}) in soil of sweet orange orchard from field experiment

Treatments	Available N (kg ha^{-1})				Available P_2O_5 (kg ha^{-1})			
	First Observ. (Initial)	Second Observ.	Third Observ.	Fourth Observ. (Harvesting)	First Observ. (Initial)	Second Observ.	Third Observ.	Fourth Observ. (Harvesting)
	(0)	(90 Days)	(180 Days)	(270 Days)	(0)	(90 Days)	(180 Days)	(270 Days)
T_1	736.32	737.3	742.43	684.32	14.78	14.70	14.86	8.41
T_2	987.16	996.5	1013.54	904.91	22.45	22.51	22.64	16.75
T_3	1035.46	1039.5	1048.34	928.78	24.72	24.82	24.95	18.99
T_4	1173.25	1181.4	1092.48	967.12	25.84	25.96	26.22	19.86
T_5	1378.53	1386.5	1396.36	1258.32	35.58	35.79	36.18	28.73
T_6	1366.89	1372.7	1384.56	1243.52	34.96	35.68	35.73	27.57
T_7	1189.30	1192.7	1212.73	1082.13	27.65	27.97	28.36	20.71
S.Em.±	22.71	26.73	30.87	15.43	0.46	0.77	0.77	0.62
C.D. at 5 (%)	67.49	79.41	91.74	45.85	1.38	2.29	2.29	1.83

Effect on availability of phosphorusin soil

The available P_2O_5 content in the soils of sweet orange orchards under the influence of various treatments are presented in Table 3. It was revealed that individual *Ficus* species rhizosphere soil and hybridized soils were very rich in available P_2O_5 content. Among the various *Ficus* species URS recorded highest content of phosphorus followed by BRS. Further the availability of P_2O_5 drastically increased when the three *Ficus* species rhizosphere soils are mixed together in equal proportion and applied with RD of NPK (T5). In all the treatments, increase in available P_2O_5 was observed from 90 to 180 days. At 270 days i.e. at harvesting the available phosphorus content was found to be decreased. The decrease was from 26.99 to 20.15 kg ha^{-1}. The improvement in availability of phosphorus content coincides with the high content of P_2O_5 in rhizosphere soil and its microbial synergetic interactions releasing exudates and various enzymes

Effect on availability of potassium in soil

The perusal of data presented in Table 4 showed that the available potassium content in soils of sweet orange orchards at first observation ranged between 539.15 kg ha^{-1} in control to 1956.63 kg ha^{-1} in treatment received RD of NPK + consortia made from three *Ficus* species. The application of URS to sweet orange improved the available potassium content from 1574.29 to 1581.43 and 1581.43 to 1598.63 kg ha^{-1}from initial to 2nd Observation and 2nd to 3rd Observation covering 180 days. Similar pattern of improvement in available K_2O content was recorded in BRS and PRS treatments but with lower value. There was synergetic effect of hybridization of three *Ficus* rhizosphere soil which has reflected in significant increase in availability of potassium. At harvest the available K_2O content was reduced to 1449.10 kg ha^{-1}.

Effect on availability of sulphur in soil

The data reported in Table 4 showed that available sulphur content in soils of sweet orange orchard was influenced significantly. At initial stage it was ranged from 8.75 to 29.28 mg kg^{-1}. Further the treatment T_5 (NPK + consortia) stood first in supplying the available sulphur to sweet orange followed by T_6 (Without RD of NPK + Consortia). Among all rhizosphere soils, URS possesses high sulphur content than other soils.

The data presented in Table 3 and Table 4 supported our hypothesis of nutrient mineralization in the rhizosphere would be promoted by rhizosphere effects of all tree species. Enhanced availability of N, P, K and S in rhizosphere soil application and consortia application primarily resulted from the rhizosphere priming effect on soil organic matter decomposition (Phillips and Fahey, 2006). Further varied nutrient status in *Ficus* species might be due to difference in organic carbon content, enzymatic activity, microbial population, root exudates and root hair density. The accumulation of nutrients in the rhizosphere solution can thus be attributed to positive differences between the nutrient inputs, principally by mineral weathering, organic matter mineralization, mass flow and diffusion as well as nutrient output principally by root uptake. Srivastava (2023) and Srivastava and Bora (2023).

Table 4: Effect of application of value-added consortium on available K_2O (kg ha^{-1}) and available sulphur (mg kg^{-1}) in soil of sweet orange orchard from farmers field experiment

Treatments	Available K_2O (kg ha^{-1})				Available sulphur (mg kg^{-1})			
	First observation (Initial)	Second observation	Third observation	Fourth observation (Harvesting)	First observation (Initial)	Second observation	Third observation	Fourth observation (Harvesting)
	(0)	(90 Days)	(180 Days)	(270 Days)	(0)	(90 Days)	(180 Days)	(270 Days)
T_1	539.15	533.68	540.52	453.89	8.75	8.20	10.49	6.68
T_2	1085.38	1090.74	1114.43	985.07	17.54	17.68	18.81	15.27
T_3	1259.09	1262.87	1279.39	1146.65	19.90	20.22	21.43	17.54
T_4	1574.29	1581.43	1598.63	1449.10	23.78	24.10	26.28	20.70
T_5	1956.63	1968.63	1981.26	1824.51	29.28	29.63	31.19	24.66
T_6	1910.13	1918.42	1942.37	1798.07	28.43	28.49	28.63	22.98
T_7	1579.34	1585.97	1601.20	1468.57	26.23	26.50	26.68	20.96
S.Em.±	45.43	30.86	32.12	34.50	0.59	0.54	0.56	0.31
CD at 5(%)	134.97	91.70	95.44	102.52	1.74	1.60	1.65	0.92
Mean	1414.86	1420.25	1436.83	1303.69	21.99	22.12	23.36	18.40

CONCLUSION

Three *Ficus* species viz., *Ficus racemosa* L.2. *Ficus religiosa* L. and *Ficus benghalensis* L. hybridized together in equal proportion and incubated for development of beneficial microbes Consortia. RD of NPK + Consortia of 3 *Ficus* species rhizosphere soil showed very good and significant impact on improvement of fruit yield and quality of sweet orange fruits. These studies provided some useful insights about the concept of rhizosphere hybridization.

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