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Implications of phosphate solubilizing bacteria, Azotobacter and Azospirillium biofertilizers on strawberry (*Fragaria × ananassa* Duchesne) growth, quality and yield

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ABSTRACT

Aim: The aim of the study was to estimate the effects of bio-fertilizers, Azotobacter, Azospirillium and PSB (phosphate solubilizing bacteria) on strawberry growth, yield, and quality over the years/environments.
Materials and Methods: It was included nine treatments replicated three times using an RCBD. The recommended amount of manure, specifically farm yard manure, was applied and thoroughly mixed into the soil before 15 days, and bio-fertilizers such as Azotobacter, Azospirillium and PSB (phosphate solubilizing bacteria) were applied via root treatment and before transplantation. Strawberry plants' roots were treated before being put in the field.
Results: T7 (50% RDF+2 kg/ha Azotobacter +2 kg/ha PSB +50% top dressing P and K), followed by T8 (50% RDF+2 kg/ha Azospirillim +2 kg/ha PSB + 50% K) and T6 (50% RDF+2kg/ha Azospirillium +50% top dressing P and K), had a significant impact on nearly all economic traits in both years/environments, particularly fruit yield quintal per ha; X10 (Post-harvest life of fruits in days); X11 (Total soluble solids (TSS) °Brix. As a result, three treatments, T7, T8, and T6, were indicated for high fruit output per hectare and better strawberry quality in North Indian conditions.
Conclusion: It was concluded that the three treatments, T7, T8 and T6, may recommended for high fruit yield/ha and improved strawberry quality in North Indian conditions.

Keywords: Biofertilizer; monoecious; Post-harvest; phosphate solubilizing bacteria; straw berry.

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Introduction

The cultivated strawberry (*Fragaria × ananassa* Duchesne) has chromosome number (2n = 8x = 56) which is an octaploid in nature and belongs to Rosaceae family. Strawberry is one of the most nutritious, refreshing delicious, and soft fruits worldwide (Dar et al., 2010; Singh et al., 2024). This fruit plant is a monoecious and octoploid hybrid of two largely dioecious octoploid species *i.e. Fragaria chiloensis* and *Fragaria virgiana.* The strawberry fruit crop is cherished in kitchen gardens and commercial fields for its nutritious fruits containing a tantalizing fragrance (Bhagat and Panigrahi, 2020; Chawla et al., 2020). When compared to other fruit crops, it offers quickest returns and highest returns per unit area on initial investment.

In terms of nutrition, strawberries are a fruit containing a minute amount of calories from carbohydrates, but they are a rich source of fiber, vitamin A (60 International Units/100g of edible portion), vitamin C (30-125 mg/100g of edible portion), and pectin (0.55%), which is present in the form of calcium pectate. The strawberry fruit contains 90% water by their volume. Ellagic acid is a phenol found in plants that have prevented asthma and cancer disease when consumed daily (Kumar et al., 2015, 2021). For optimum growth and development, strawberry crops need daytime temperatures of 22^0 C to 23^0 C and night temperatures of 7^0 C to 13^0 C is required. Fruit yield is significantly reduced by frost damage and winter damage. In sandy loam soil with a range of pH is 5.5 to 6.5, plants thrive. The strawberry fruit is a rich source of minerals and vitamins. The fruit flavor is primarily influenced by three major substances: sugars, acids, and aromatic components. The strawberry fruit has a total sugar content of 0.55% and an acidity range of 0.90% to 1.85%, with malic and citric acids standing out. The most vital feature of crop production, among the many elements that affect strawberry growth and yield, is nutrition. (Rana and Chandel, 2003; Singh et al., 2008; Umar et al., 2010). Maharashtra is one of the states that have higher production of strawberry fruits in India. Additionally, it is produced for commercial purposes in Himachal Pradesh's lower hills as well as Haryana, Jammu and Kashmir Punjab, Uttar Pradesh, and Uttrakhand (Singh and Singh, 2009; Bhagat et al 2020) Since strawberries can be grown on hills and in the plains, strawberries are a common fruit and hold a prominent position in fruit production. It has established itself as the second-most important soft fruit in the world, after grapes.

The world's total acreage and production have expanded significantly during the previous ten years, indicating its popularity because strawberries are very productive and cost-effective; their cultivation has expanded significantly over the past 20 years worldwide, with an annual production of over 7.7 million tons. (FAO, 2022). The fruit is sweet-sour and fragrant when it is fully ripe and mature. Fruits are typically consumed fresh, and their flavor is preferred over their nutritional benefits. Strawberries are processed into a variety of value-added products, including canned strawberries, jam, jelly, ice cream, frozen strawberries, wine, and other soft beverages, as well as utilized in dessert recipes (Umar et al., 2009; Dar et al., 2010; Reddy and Goyal, 2020). Given the importance of the strawberry crop, the study intends to estimate the effects of bio-fertilizers, Azotobacter, Azospirillium and PSB (phosphate solubilizing bacteria) on strawberry growth, yield and quality over the years/environments.

Materials and Methods

The experimental

In agronomic region of northern India, farm experiment was carried out at Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST) Integral University, Lucknow between November-February 2020-21 and November-February 2021-22. The experiment site is situated at latitudes 26^{o} 46′ N and longitudes 80^{o} 55′Eat an altitude of 542 m above sea level. The Lucknow Eco-Climatic Zone in Northern India has a humid subtropical climate (Table 1& Fig 1). The Strawberry variety used for the current experiment was Camarosa, made available for commercial cultivation in India by the University of California South Coast Research and Extension Center near Irvine, California. In most of Northern India, this type is commercially grown and particularly well-liked by farmers.

Treatment and Experimental Details

The experiment was set up RCBD design with three replications and an individual length of plot size of 1.5 m, width of plot 2.5m, and size of per plot 3.75m^{2}. For all treatments, a distance of row to row 45 cm × 45 cm, and plant to plant distance 30 cm × 30 cm. A total of 540 plants were placed in the experimental field. To maintain a uniform plant population in each plot, dead runners were replaced by new ones of the same age. The gap-filling continued till the 15th day of planting. A total of 540 plants were planted in the experimental field. Following planting, the initial irrigation was applied. Weed was kept out of the testing area. One-hand weeding is performed 25 days after planting, with extra weeding undertaken after each harvest. The recommended amount of manures *viz.* farm yard manure applied in the soil before 15 days and mixed thoroughly in the soil and biofertilizers *viz. Azotobacter, Azospirillium*, and PSB (phosphate solubilizing bacteria) were applied through root treatment (Tables 1-2). On the day of planting, working solutions of *Azotobacter, Azospirillim* and PSB were prepared in the morning by dissolving of different doses biofertilizer as per treatment with purified water in separate buckets and before transplanting root treatments were given 10 to 12 minutes and after treated the roots of strawberry plants then plant was planted in the field and Nitrogen, Phosphorus and Potash fertilizer were given as per treatment details (Table 1-2).

In both years, runners of the Camarosa strawberry variety were brought from the Dr. Yashwant Singh Parmar University of Horticulture and Forestry in Nauni, Solan (H. P.). The runners were hardened for two days in the shade before being transplanted into well-prepared beds in open field condition plots, which were dispersed randomly in three replications with nine treatments. Standard culture procedures were maintained throughout the trial to maintain the runner's quality and yield. The runner's roots were then submerged in this mixture for 10 to 12 minutes to inoculate them. The treated runners were then transplanted into the field.

Economics analysis

Strawberry was gathered treatment-wise between January 15th and March 15th, 2021 and 2022. The berries taken from the separate plots were washed and their weights were recorded. The cultivation cost and gross return per ha-1 for each treatment were calculated using the inputs and outputs in use during the experimentation period. The net returns ha-1 were computed by subtracting the entire monetary value of the produce (Table 3).

Data Collection and Traits

Observations were made on five randomly selected plants from each treatment to determine the influence of treatments on growth, development, yield, and fruit quality on the fourteen main traits: X1=Plant height (cm)75 DAP; X2=Plant spread (cm) 75DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Total sugar (g). Fruit harvesting was done when the fruits attained more than 75% color. The ripe fruit was harvested early in the morning, complete with a peduncle. Strawberry harvests were harvested and examined for growth parameters such as plant spread, leaves per plant, plant height, and so on. Five plants were picked at random from each treatment (plot), and statistical analysis was carried out using the average data. The height of each plant was determined by measuring it from the base to the tip of the stem. Fruit yield was measured fruits per plant in grams (g) and converted to quintal/ha. The quality was recorded of the following traits TSS Brix observed with the help of a refractometer, Ascorbic acid mg/100 of pulp, Titratable acidity (percent), and Total sugar (g).

Statistical analysis

The pooled data was subjected to analysis of variance (ANOVA), correlations and principal component analysis (PCA) using GRAPES Version 1.1.0 statistical software created by the Department of Agricultural Statistics at KAU in India. The other genetic factors were analyzed using CIMAP-statistical software version 4.0, which was developed by Singh and Chaudhury (1979) and accessible at the institute.

Results and Discussion

The data collected during investigation on many aspects showed some fascinating innovations. The impact of treatments on fourteen economic traits such as X1 = Plant height (cm) 75 DAP; X2 = Plant spread (cm^2) 75 DAP; X3 = Number of leaves per plant; X4 = Fruit length (cm); X5 = Fruit width (cm); X6 = Fruit weight (g); X7 = Number of fruits per plant; X8 = Fruit yield per plant (g); X9 = Yield quintal per ha; X1 = Post-harvest life of fruits in days; X11 = Total soluble solids (TSS) °Brix; X12 = Ascorbic acid mg/100 pulp; X13 = Tritatable acidity (%); X14 = Total sugar (g) related with plant growth, development, yield and fruit quality criteria. The effect of application of bio-fertilizers showed highly significant variations in all fourteen studied traits (X1 to x14) for treatments (T), Years/environments and treatments (T) × Years/environments (E) ($P<0.01$) except trait X2 in Years/environments (E) ($P<0.05$) level of significance (Table 4). At T7, the superiority of treatment T7 (50% RDF+2 kg/ ha *Azotobacter* +2 kg/ ha PSB+50% top dressing P and K) for maximum plant height = 27.40cm followed by T6 (25.66), T8 (25.58), T5 (22.24), T4 (21.17), T3 (19.99), T2 (19.32), T1 (18.58), and T0 (17.38) cm. For plant height, top three ranked treatments were T7 (27.40) followed by T6 (25.66), and T8 (25.58), respectively. The minimum plant height (17.38 cm) was registered under control (T0) treatment (Table 5-7; Fig. 2, 3(a-d), 4 (a-d), 5 (a-c)). Similar results were reported by several research workers on this crop (Kumar and Ahad, 2012; Sharma and Godara, 2017; Reddy and Goyal, 2020).

Similarly, for X2=Plant spread (cm^2) 75 DAP top three ranker treatments were T7 (13.82) followed by T8 (13.10), and T6 (12.80), respectively. The minimum Plant spread (cm) 75 DAP (10.10 cm^2) was registered under control (T0) treatment. Similarly, for the traits, namely X3 (Number of leaves per plant); X4 (Fruit length (cm); X7 (Number of fruits per plant); X8 (Fruit yield per plant (g); X9 (Fruit yield quintal per ha), X11(The total soluble solids (TSS) °Brix), X12 (Ascorbic acid mg/100 of pulp) and X14 (Ascorbic acid mg/100 of pulp), the top three

Table 1. The weather conditions at the experimental site (IIAST, Integral University, Lucknow) and details of different proportions of integrated nutrient management (INM) in Straw berry

Parameters	Units	Details of different proportions of integrated nutrient management	
Altitude	542 m asl	Treatment	Treatment Combination
Longitudes	80° 55′E	T_0	Control
Latitudes	26° 46′ N	T_1	100% RDF
Climate	Humid subtropical climate	T_2	100% RDF+2kg/ha *Azotobacter*
Average annual rainfall	915 mm	T_3	100% RDF+2kg/ha *Azospirillium*
Soil	Sandy loam	T_4	100% RDF+2kg PSB
Sand	48.15 %	T_5	50% RDF+*Azotobacter* 2kg+50% top dressing each of P and K
Silt	21.34 %	T_6	50% RDF+2kg/ha *Azospirillium*+50% top dressing P and K
Clay	30.51 %	T_7	50% RDF+2 kg/ ha *Azotobacter* +2 kg/ ha PSB+50% top dressing P and K
Average temperature	16.90°C	T_8	50% RDF+2 kg/ ha *Azospirillim* +2 kg/ ha PSB + 50% K
pH (1:2.5)	1:2.5	7.27	-
Soils to solution ratio	Ratio	1:12	-
Electrical conductivity	dSm^{-1}	0.48 ds/m	-
Organic carbon	Percent	0.46 %	-
Available Nitrogen	$kgha^{-1}$	207.56	-
Available Phosphorus	$kgha^{-1}$	15.36	-
Exchangeable Potassium	$kgha^{-1}$	219.00	-

Table 2. Effect of integrated nutrient management (INM) practices on soil nutrient status of the soil

Treatments	Organic carbon (%)	Available N ($kgha^{-1}$)	Available P ($kgha^{-1}$)	Available K($kgha^{-1}$)
T_0: Control	0.45	189.5	14.35	205.4
T_1: 100% RDF	0.44	199.21	16.21	218.4
T_2: 100% RDF + 2kg/ha *Azotobacter*	0.46	201.5	17.25	214.5
T_3: 100% RDF + 2kg/ha *Azospirillium*	0.46	214.2	16.98	220.1
T_4: 100% RDF + 2kg PSB	0.46	215.9	18.12	218.5
T_5: 50% RDF + *Azotobacter* 2kg + 50% top dressing each of P and K	0.47	218.4	20.11	235.1
T_6: 50% RDF + 2 kg/ ha *Azotobacter* +2 kg/ ha PSB + 50% top dressing P and K	0.47	219.5	21.22	237.2
T_7: 50% RDF + 2 kg/ ha *Azotobacter* +2 kg/ ha PSB + 50% top dressing P and K	0.47	220.1	20.87	239.2
T_8: 50% RDF + 2 kg/ ha *Azospirillim* +2 kg/ ha PSB + 50% K	0.48	222.6	21.55	240.5
SEm±	0.01	5.7	1.4	6.5
CD (P=0.05)	0.03	17.1	4.2	19.4

Table 3. Effect of integrated nutrient management practices on Economics of Strawberry

Treatments	Gross Return Yield (USD $ ha-1)	Net return (USD $ ha-1)	B:C ratioUSD $ ha-1)
Control	22439	19936	1.00
100% RDF	27047	23969	1.20
100% RDF + 2kg/ha *Azotobacter*	31025	28416	1.42
100% RDF + 2kg/ha *Azospirillium*	36760	33670	1.69
100% RDF + 2kg PSB	43876	40794	2.04
50% RDF + *Azotobacter* 2kg + 50% top dressing each of P and K	50400	47346	2.37
50% RDF+ 2 kg/ ha *Azospirillium* + 50% top dressing P and K	56978	53917	2.70
50% RDF + 2 kg/ ha *Azotobacter* +2 kg/ ha PSB + 50% top dressing P and K	64413	61355	3.07
50% RDF + 2 kg/ ha *Azospirillim* +2 kg/ ha PSB + 50% K	59557	56591	2.84
SEm±	1625.2	1625.2	
LSD (P=0.05)	4875.6	4875.6	

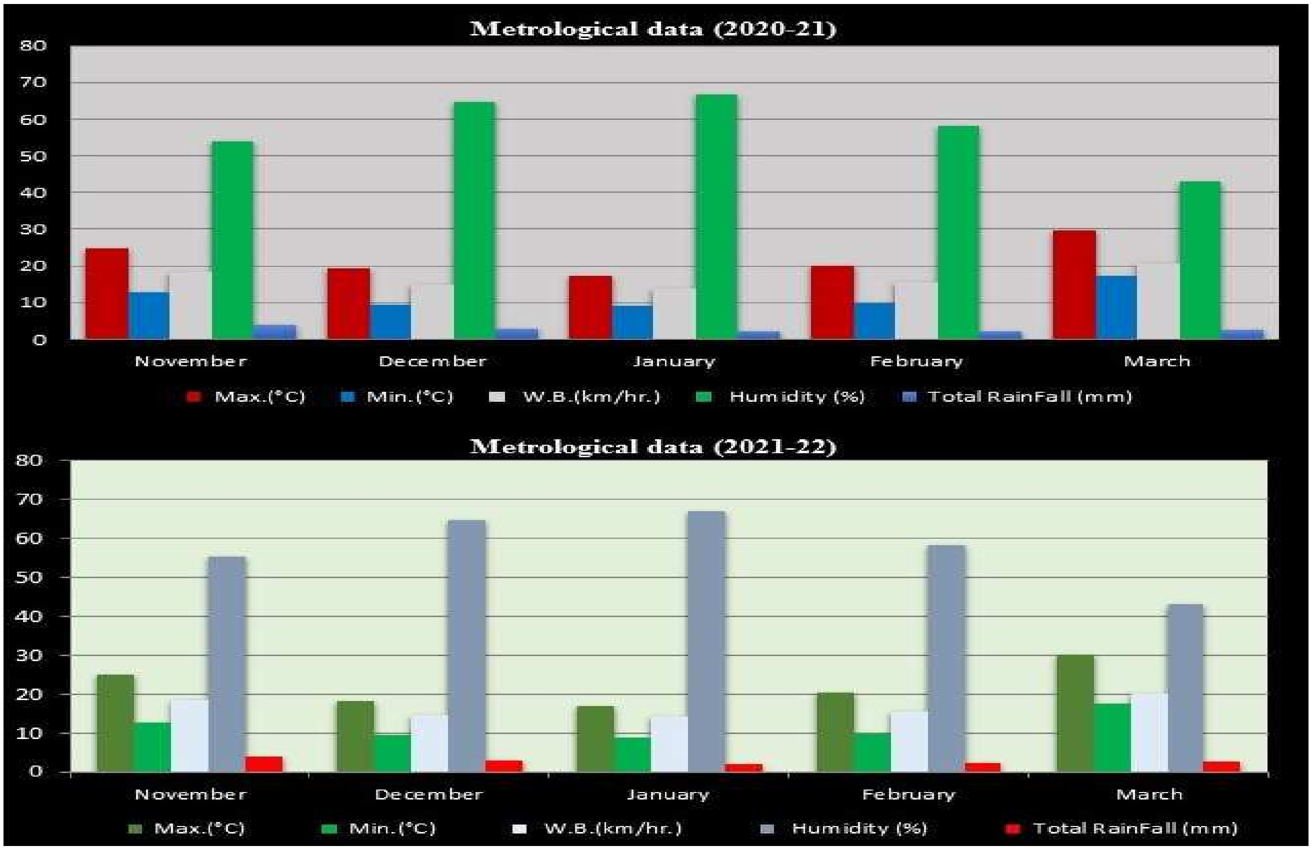

Fig. 1. Metrological data in the studied periods for the experimental trials on strawberry crop

Fig. 2. Performance of fruit size variation at different treatments in strawberry

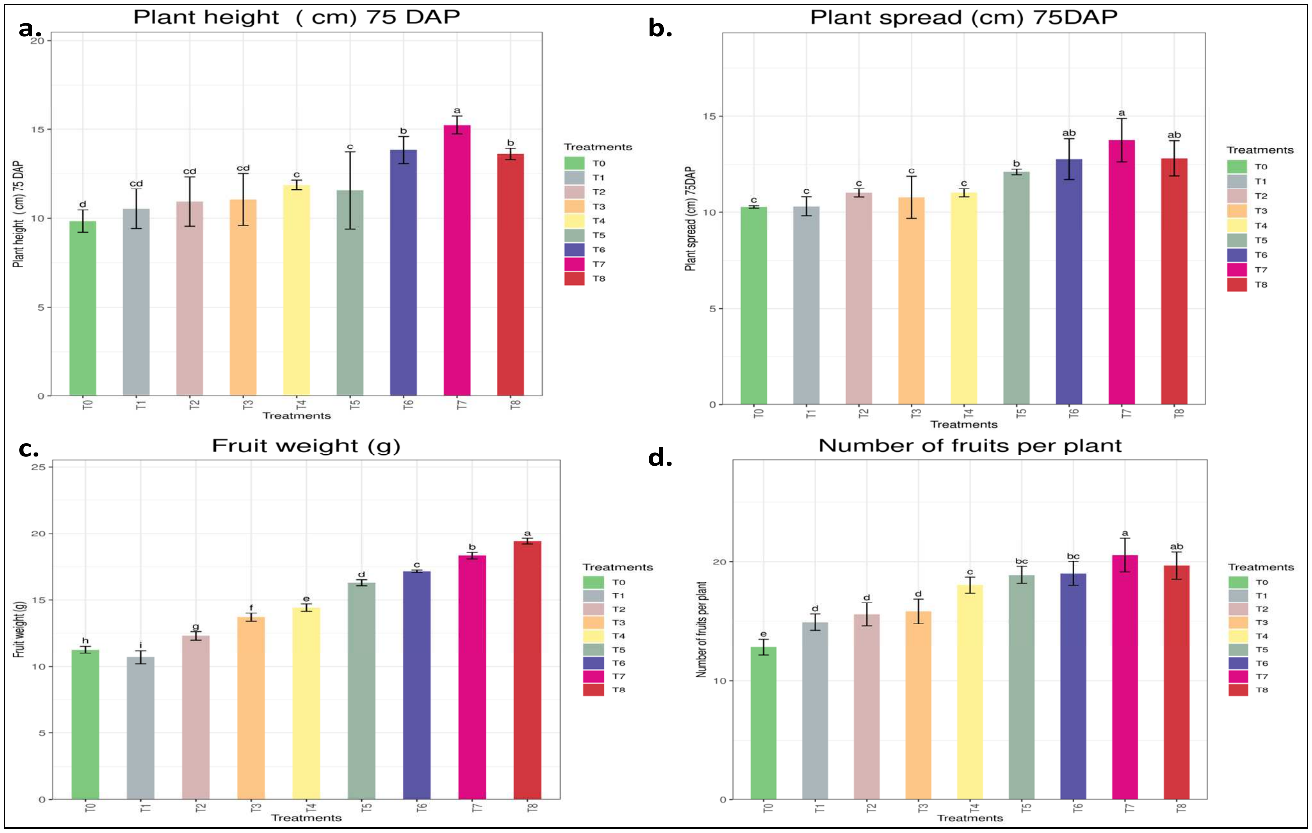

Fig 3 (a-d). Treatment wise mean performance of different economic traits in strawberry

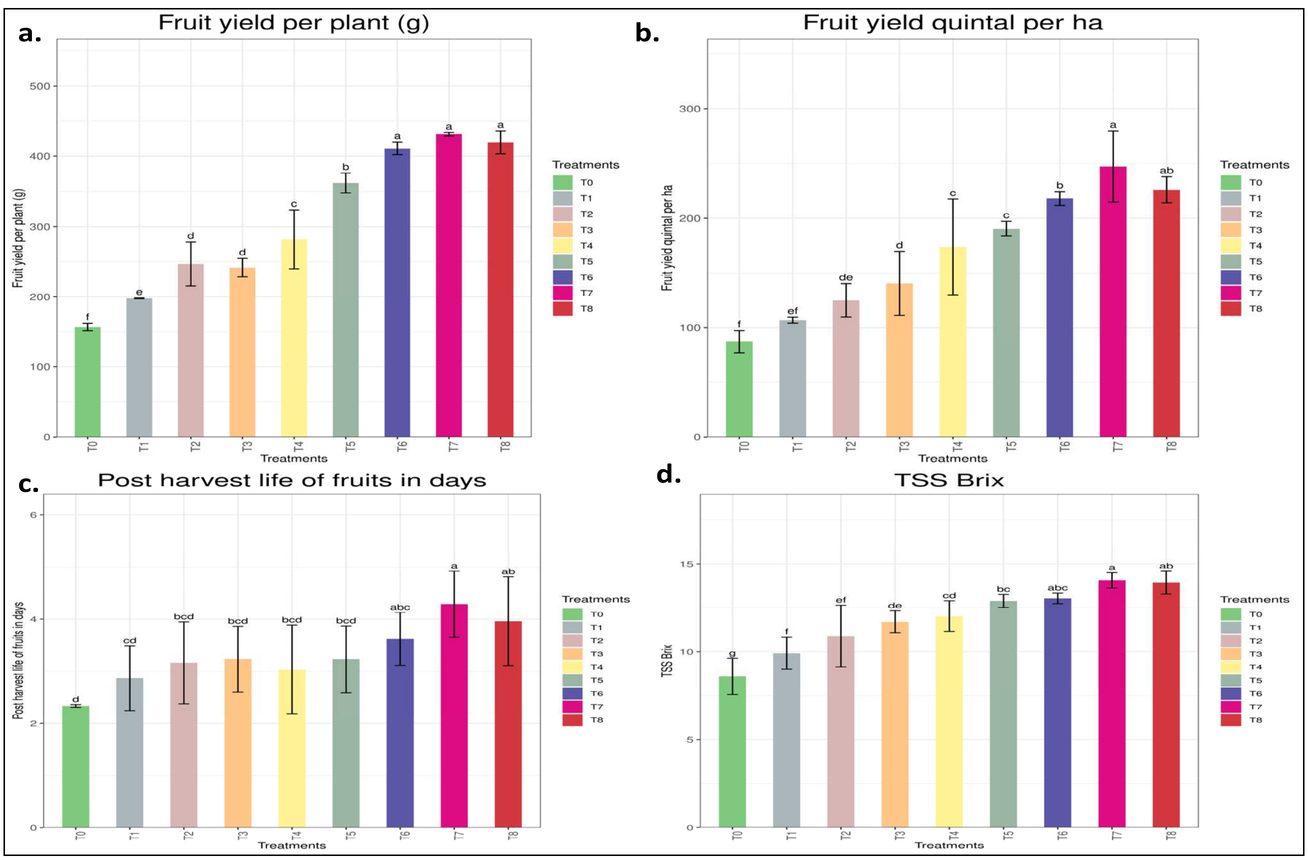

Fig. 4. (a-d). Treatment-based mean performance of many economic traits in strawberry

Table 4. Combined analysis of variance between fourteen traits over the years/environments in straw berry

Source of variation	d.f.	Characters mean sum of squares						
		X1	X2	X3	X4	X5	X6	X7
Replication within (E)	4	3.62	0.263	2.94	0.09	0.023	0.109	0.109
Treatment (T)	8	75.27**	9.653**	75.00**	4.82**	2.334**	64.824**	64.824**
Years/Environments (E)	1	2339.93**	1.689*	2158.73**	5.42**	0.322**	72.964**	72.964**
T × E	8	11.20**	1.272**	8.45**	0.31**	0.136**	1.232**	1.232**
Error	32	1.00	0.258	1.00	0.04	0.009	0.107	0.107
		X8	X9	X10	X11	X12	X13	X14
Replication within E	4	49.59	464.025	0.902	1.017	0.448	0.0001	0.044
Treatment (T)	8	83893.81**	24617.08**	28.075*	24.078**	43.016**	0.005**	1.121**
Years/Environment (E)	1	66908.16**	13632.03**	1634.404**	1.698**	2.237*	0.047**	0.217**
T × E	8	2063.76**	387.95*	9.349**	2.547**	2.495**	0.005**	0.337**
Error	32	344.17	185.297	1.000	0.329	0.473	0.001	0.027

*-p<0.05; **p<0.01 level of significance; X1=Plant height (cm) 75 DAP; X2=Plant spread (cm²) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X1=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Total sugar (g).

Table 5. Mean performance of the treatments on the fourteen traits in straw berry

Traits	Treatments									Top three performer treatments		
X1	T7	T6	T8	T5	T4	T3	T2	T1	T0	T7	T6	T8
Transformed mean ($\bar{x}$)	27.40	25.66	25.58	22.24	21.17	19.99	19.32	18.58	17.38	27.40	25.66	25.58
Grouping	a	ab	ab	bc	bcd	cd	cd	cd	d	a	ab	ab
X2	T7	T8	T6	T5	T4	T2	T3	T1	T0	T7	T8	T6
$\bar{x}$	13.82	13.10	12.80	12.35	11.51	11.28	11.16	10.32	10.10	13.82	13.10	12.80
Grouping	a	b	bc	c	d	d	d	e	e	a	b	bc
X3	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	33.67	33.06	31.55	30.64	29.10	27.31	26.65	25.10	23.62	33.67	33.06	31.55
Grouping	a	a	ab	abc	bcd	cde	de	e	e	a	a	ab
X4	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	5.58	5.22	4.73	4.56	4.02	3.68	3.51	3.38	2.93	5.58	5.22	4.73
Grouping	a	ab	bc	bc	cd	de	de	de	e	a	ab	bc
X5	T7	T8	T5	T6	T4	T3	T2	T1	T0	T7	T8	T5
$\bar{x}$	4.25	4.17	3.57	3.52	3.29	2.93	2.76	2.72	2.56	4.25	4.17	3.57
Grouping	a	a	b	b	bc	cd	d	d	d	a	a	b
X6	T8	T7	T6	T5	T4	T3	T2	T1	T0	T8	T7	T6
$\bar{x}$	20.32	20.01	19.18	17.27	15.47	14.54	13.72	12.11	11.85	20.32	20.01	19.18
Grouping	a	a	a	b	c	cd	d	e	e	a	a	a
X7	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	22.89	22.22	21.39	20.60	19.42	18.09	17.46	16.22	14.71	22.89	22.22	21.39
Grouping	a	ab	bc	cd	de	ef	fg	g	h	a	ab	bc
X8	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	494.20	469.76	452.32	401.68	325.55	281.86	251.96	212.79	174.76	494.20	469.76	452.32
Grouping	a	a	ab	b	c	cd	de	ef	f	a	a	ab
X9	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	272.09	251.51	240.62	212.84	185.29	155.24	131.02	114.22	94.76	272.09	251.51	240.62
Grouping	a	ab	b	c	d	e	ef	fg	g	a	ab	b
X10	T9	T8	T10	T7	T5	T4	T3	T1	T0	T9	T8	T10
$\bar{x}$	15.61	14.52	14.44	12.50	12.08	11.37	11.05	10.63	9.93	15.61	14.52	14.44
Grouping	a	ab	bc	cd	de	ef	fg	g	h	a	ab	bc
X11	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	14.04	13.84	13.38	13.01	12.16	11.24	10.50	9.36	8.50	14.04	13.84	13.38
Grouping	a	a	a	ab	bc	cd	d	e	e	a	a	a
X12	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	55.15	54.54	54.15	53.672	52.137	50.84	49.642	48.832	47.908	55.15	54.54	54.15
Grouping	a	a	ab	ab	bc	cd	de	de	e	a	a	ab
X13	T0	T1	T3	T2	T6	T4	T5	T8	T7	T0	T1	T3
$\bar{x}$	0.71	0.68	0.65	0.65	0.65	0.65	0.64	0.62	0.60	0.71	0.68	0.65
Grouping	a	ab	bc	bc	bc	bc	bc	cd	d	a	ab	bc
X14	T7	T8	T6	T5	T4	T3	T2	T1	T0	T7	T8	T6
$\bar{x}$	7.71	7.48	7.41	7.16	7.02	6.86	6.77	6.60	6.40	7.71	7.48	7.41
Grouping	a	ab	bc	cd	de	ef	ef	fg	g	a	ab	bc

X1=Plant height (cm) 75 DAP; X2=Plant spread (cm²) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp.

Table 6. Mean performance of the treatments (T), years/environments (E), and treatments × environments (T × E) over the environments in straw berry

Treatments (T)	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
T_0	9.93	10.10	13.95	2.93	2.56	20.98	14.71	174.76	94.76	2.28	8.50	47.91	0.71	6.40
T_1	10.63	10.32	14.84	3.38	2.72	12.88	16.22	212.79	114.22	2.59	9.36	48.83	0.68	6.60
T_2	11.05	11.28	15.73	3.51	2.76	14.79	17.46	251.96	131.02	2.69	10.50	49.64	0.65	6.77
T_3	11.37	11.16	16.21	3.68	2.93	15.72	18.09	281.86	155.24	2.86	11.24	50.84	0.65	6.86
T_4	12.08	11.51	17.19	4.02	3.29	16.80	19.42	325.55	185.29	2.79	12.16	52.14	0.65	7.02
T_5	12.50	12.35	18.08	4.56	3.57	19.35	20.60	401.68	212.84	3.17	13.01	53.67	0.64	7.16
T_6	14.52	12.80	18.58	4.73	3.52	21.22	21.39	452.32	240.62	3.47	13.38	54.15	0.65	7.41
T_7	15.61	13.82	19.69	5.58	4.25	22.63	22.89	494.20	272.09	3.95	14.04	55.15	0.60	7.71
T_8	14.44	13.10	19.36	5.22	4.17	22.15	22.22	469.76	251.51	3.69	13.84	54.54	0.62	7.48
Environments (E)														
E1	12.06	11.65	18.12	3.86	3.23	17.40	17.26	305.34	168.29	3.30	11.89	51.94	0.68	7.06
E2	12.86	12.00	16.02	4.49	3.38	19.60	21.18	375.74	200.06	2.80	11.67	51.81	0.62	7.03
T × E														
T_0× E1	9.84	10.29	14.91	2.95	2.58	12.42	12.83	156.68	87.05	2.33	8.60	48.89	0.72	6.39
T_1× E1	10.54	10.31	15.91	3.13	2.74	13.18	14.91	197.76	106.75	2.87	9.91	50.01	0.70	6.61
T_2× E1	10.94	11.01	16.80	3.16	2.77	15.10	15.57	246.69	124.98	3.16	10.89	49.93	0.68	6.70
T_3× E1	11.06	10.78	17.62	3.20	3.03	15.71	15.82	241.39	140.44	3.23	11.70	50.25	0.67	6.82
T_4× E1	11.87	11.02	18.39	3.76	3.13	16.17	18.04	281.70	173.77	3.04	12.02	51.62	0.69	6.94
T_5× E1	11.57	12.10	19.28	3.90	3.29	18.91	18.89	362.00	190.40	3.23	12.89	53.28	0.68	7.17
T_6× E1	13.84	12.77	19.70	4.14	3.18	21.52	19.02	411.02	218.04	3.62	13.03	53.76	0.69	7.53
T_7× E1	15.25	13.76	20.36	5.48	4.18	22.03	20.57	431.19	247.20	4.29	14.06	55.28	0.62	7.83
T_8× E1	13.62	12.81	20.09	5.04	4.17	21.55	19.68	419.64	225.95	3.96	13.93	54.44	0.64	7.58
T_0× E2	10.03	9.92	12.99	2.90	2.53	29.54	16.58	192.83	102.46	2.22	8.41	46.93	0.69	6.41
T_1× E2	10.71	10.33	13.76	3.64	2.70	12.58	17.54	227.83	121.69	2.32	8.81	47.66	0.66	6.60
T_2× E2	11.15	11.55	14.66	3.86	2.75	14.47	19.35	257.23	137.06	2.21	10.10	49.35	0.61	6.84
T_3× E2	11.69	11.54	14.80	4.15	2.82	15.73	20.35	322.32	170.04	2.48	10.77	51.43	0.63	6.91
T_4× E2	12.28	11.99	15.99	4.29	3.46	17.43	20.80	369.40	196.80	2.54	12.29	52.65	0.60	7.10
T_5× E2	13.42	12.61	16.88	5.22	3.84	19.78	22.32	441.36	235.29	3.11	13.12	54.06	0.61	7.14
T_6× E2	15.20	12.83	17.47	5.33	3.85	20.92	23.76	493.62	263.20	3.32	13.72	54.54	0.60	7.29
T_7× E2	15.96	13.87	19.02	5.67	4.32	23.22	25.21	557.20	296.97	3.60	14.02	55.02	0.58	7.59
T_8× E2	15.26	13.38	18.62	5.40	4.18	22.75	24.75	519.88	277.06	3.42	13.75	54.64	0.60	7.38

X1=Plant height (cm) 75 DAP; X2=Plant spread (cm²) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp.

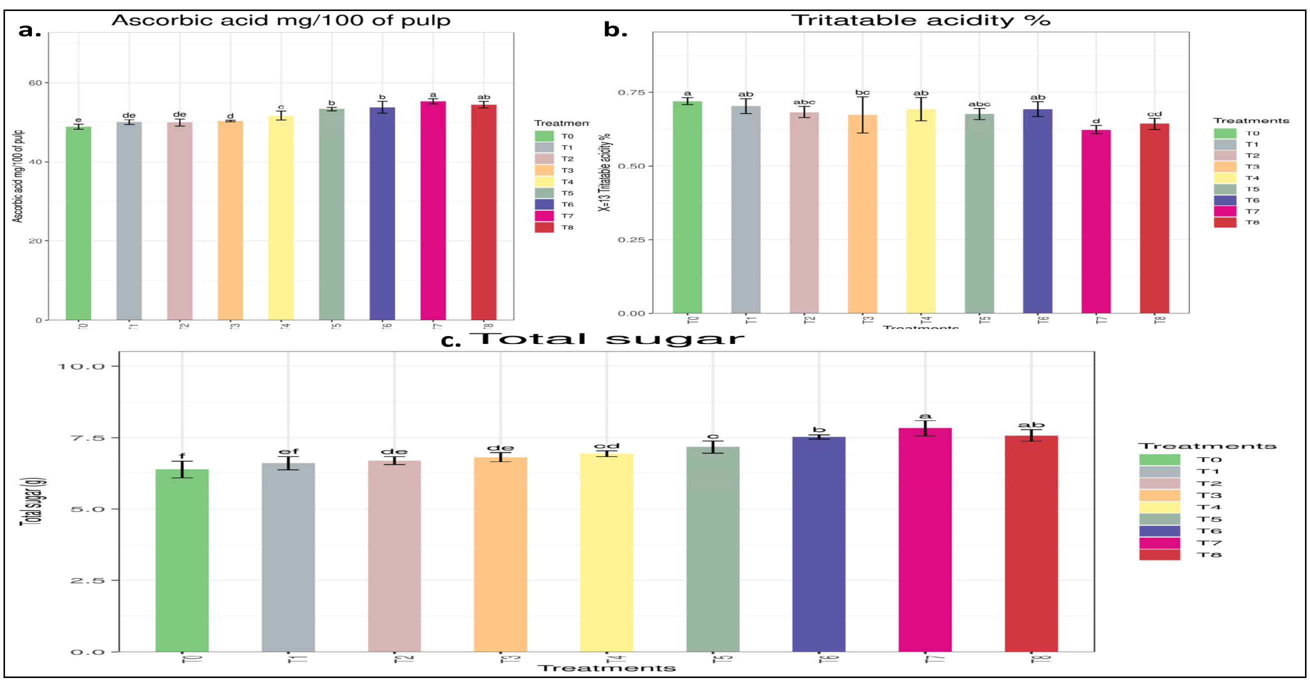

Fig. 5 (a-c). Treatment-specific mean performance of many economic traits in strawberry

Table 7. Mean performance of the treatments (T), years/environments (E) and treatments × environments (T × E) over the environments in straw berry

Traits	Parameters	Environment (E)	Treatments (T)	T × E	Traits	Parameters	Environment (E)	Treatments (T)	T × E
X1	SE	0.03	0.07	0.09	X9	SE	2.70	5.73	8.10
	SED	0.04	0.09	0.13		SED	3.82	8.10	11.46
	CD(P=05)	0.09	0.19	0.26		CD(P=05)	7.68	16.28	23.03
	CD(P=01)	0.12	0.25	0.35		CD(P=01)	10.24	21.71	30.71
X2	SE	0.10	0.21	0.30	X10	SE	0.08	0.17	0.24
	SED	0.14	0.30	0.42		SED	0.11	0.24	0.33
	CD(P=05)	0.28	0.60	0.85		CD(P=05)	0.22	0.47	0.67
	CD(P=01)	0.38	0.80	1.13		CD(P=01)	0.30	0.63	0.90
X3	SE	0.13	0.27	0.39	X11	SE	0.11	0.23	0.32
	SED	0.18	0.39	0.55		SED	0.15	0.32	0.46
	CD(P=05)	0.37	0.78	1.10		CD(P=05)	0.31	0.65	0.92
	CD(P=01)	0.49	1.03	1.46		CD(P=01)	0.41	0.86	1.22
X4	SE	0.04	0.09	0.13	X12	SE	0.13	0.28	0.40
	SED	0.06	0.13	0.18		SED	0.19	0.40	0.56
	CD(P=05)	0.12	0.26	0.37		CD(P=05)	0.38	0.80	1.13
	CD(P=01)	0.16	0.35	0.49		CD(P=01)	0.50	1.06	1.50
X5	SE	0.02	0.04	0.05	X13	SE	0.00	0.01	0.01
	SED	0.03	0.05	0.08		SED	0.01	0.01	0.02
	CD(P=05)	0.05	0.11	0.15		CD(P=05)	0.01	0.03	0.04
	CD(P=01)	0.07	0.14	0.20		CD(P=01)	0.02	0.04	0.05
X6	SE	1.39	2.94	4.16	X14	SE	0.03	0.07	0.09
	SED	1.96	4.16	5.89		SED	0.04	0.09	0.13
	CD(P=05)	3.94	8.37	11.83		CD(P=05)	0.09	0.19	0.26
	CD(P=01)	5.26	11.15	15.77		CD(P=01)	0.12	0.25	0.35
X7	SE	0.14	0.30	0.43	CV (%)	Traits	%	Traits	%
	SED	0.20	0.43	0.61		X1	5.91	X8	5.29
	CD(P=05)	0.41	0.87	1.22		X2	4.37	X9	7.62
	CD(P=01)	0.54	1.15	1.63		X3	3.92	X10	13.40
X8	SE	3.47	7.35	10.40		X4	5.35	X11	4.74
	SED	4.90	10.40	14.70		X5	2.79	X12	1.32
	CD(P=05)	9.85	20.90	29.56		X6	38.96	X13	3.80
	CD(P=01)	13.14	27.86	39.41		X7	3.88	X14	2.28

SE= Standard error; SED= Standard error difference; CS= Critical difference; CV= Coefficient of variation; X1=Plant height (cm) 75 DAP; X2=Plant spread (cm^2) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp.

ranked treatments were T7 (50% RDF+2 kg/ ha *Azotobacter* +2 kg/ ha PSB+50% top dressing P and K) followed by T8 (50% RDF+2 kg/ ha *Azospirillim* +2 kg/ ha PSB + 50% K), and T6 (50% RDF+2kg/ha *Azospirillium*+50% top dressing P and K), respectively.

The other traits like X5 (Fruit width (cm), T7 (4.25), T8 (4.17), T5 (3.57); X6 (Fruit weight (g), T8 (20.32), T7 (20.01), T6 (19.18); X10 (Postharvest life of fruits in days), T9 (15.61), T8 (14.52), T10 (14.44), respectively.

The minimum mean values were registered under the control (T0) treatment for the all above traits (Table 5-7, Fig. 3a-d, 4a-d, 5a-c). On the other hand for the trait X13 (Tritatable acidity (%), the top ranker was T0 (0.71) followed by T1 (0.68), and T2, T3, T4, and T6 (0.65) means none of the treatments were superior. The respective grouping for all treatments were also worked out and presented (Tables 8-11). The superiority of the treatments (T7, 8 and 6) was also demonstrated by principal component analysis, which calculated the Eigen Values, Principal Component, Percent contribution of variables to PCs, percentage of variance, cumulative percentage of variance, and correlation between variables and PCs in strawberry (Fig 7a-e). Our findings are consistent with those of numerous strawberry crop researchers (Mitra, 1991; Negiet al., 2021; Reddy et al., 2021; Howeidi et al., 2023; Singh et al., 2023; Singh et al., 2024).

Table 8. Values of each variable in strawberry

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
X1	-0.266	0.182	0.433	-0.364	-0.047	-0.191	-0.505	-0.045	0.173
X2	-0.269	-0.049	0.17	-0.139	0.343	0.827	-0.004	0.053	-0.041
X3	-0.271	-0.002	-0.197	-0.009	-0.068	-0.036	-0.067	-0.414	-0.406
X4	-0.27	0.008	0.217	0.181	-0.293	0.124	0.295	-0.182	0.408
X5	-0.265	0.058	0.169	0.7	-0.398	0.096	-0.198	0.035	-0.188
X6	-0.265	0.277	-0.164	0.437	0.686	-0.195	-0.192	0.053	0.222
X7	-0.271	-0.045	-0.203	-0.118	-0.125	-0.072	-0.02	-0.453	0.393
X8	-0.271	0.187	-0.067	-0.123	0.057	0.1	0.302	-0.31	-0.265
X9	-0.271	0.16	-0.078	-0.097	-0.168	-0.036	-0.08	0.424	-0.395
X10	-0.267	-0.031	0.465	-0.043	0.219	-0.407	0.57	0.093	-0.164
X11	-0.267	-0.032	-0.488	-0.151	0.012	-0.135	-0.028	-0.017	-0.126
X12	-0.269	0.134	-0.347	-0.091	-0.216	0.063	0.272	0.509	0.359
X13	0.247	0.895	0.03	-0.077	-0.105	0.089	0.095	-0.11	-0.016
X14	-0.271	-0.019	0.124	-0.24	-0.088	-0.065	-0.266	0.16	0.019

X1=Plant height (cm) 75 DAP; X2=Plant spread (cm^2) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp

Table 9. Principal component, Eigen Values, percentage of variance, and cumulative percentage of variance in straw berry

Prin_comp	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	13.506	96.47	96.47
PC2	0.214	1.532	98.002
PC3	0.138	0.986	98.989
PC4	0.08	0.568	99.557
PC5	0.031	0.221	99.778
PC6	0.015	0.106	99.884
PC7	0.013	0.094	99.978
PC8	0.003	0.022	100

Table 10. Percent contribution of variables on PCs in straw berry crop

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
X1	7.053	3.312	18.752	13.229	0.217	3.653	25.503	0.205
X2	7.257	0.244	2.898	1.931	11.773	68.329	0.001	0.282
X3	7.359	0	3.87	0.007	0.469	0.127	0.449	17.152
X4	7.306	0.006	4.714	3.28	8.563	1.545	8.731	3.329
X5	7.04	0.34	2.869	48.933	15.851	0.914	3.922	0.121
X6	7.027	7.683	2.675	19.101	47.027	3.784	3.681	0.284
X7	7.342	0.202	4.129	1.401	1.572	0.516	0.04	20.516
X8	7.322	3.501	0.451	1.513	0.329	0.998	9.128	9.58
X9	7.34	2.558	0.613	0.946	2.828	0.13	0.646	17.978
X10	7.12	0.097	21.594	0.188	4.782	16.567	32.493	0.873
X11	7.144	0.1	23.775	2.293	0.015	1.817	0.077	0.029
X12	7.223	1.804	12.027	0.831	4.684	0.397	7.384	25.883
X13	6.123	80.116	0.091	0.6	1.108	0.8	0.895	1.209
X14	7.344	0.037	1.543	5.747	0.783	0.424	7.049	2.56

X1=Plant height (cm) 75 DAP; X2=Plant spread (cm^2) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp.

Table 11. Correlation between variables and PCs in Straw berry

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
X1	0.976	0.084	0.161	0.103	0.008	-0.023	-0.058	0.003
X2	0.99	-0.023	0.063	0.039	-0.06	0.101	0	-0.003
X3	0.997	-0.001	-0.073	0.002	0.012	-0.004	-0.008	0.023
X4	0.993	0.004	0.081	-0.051	0.052	0.015	0.034	0.01
X5	0.975	0.027	0.063	-0.197	0.07	0.012	-0.023	-0.002
X6	0.974	0.128	-0.061	-0.123	-0.121	-0.024	-0.022	-0.003
X7	0.996	-0.021	-0.076	0.033	0.022	-0.009	-0.002	0.025
X8	0.994	0.087	-0.025	0.035	-0.01	0.012	0.035	0.017
X9	0.996	0.074	-0.029	0.027	0.03	-0.004	-0.009	-0.024
X10	0.981	-0.014	0.173	0.012	-0.038	-0.05	0.065	-0.005
X11	0.982	-0.015	-0.181	0.043	-0.002	-0.016	-0.003	0.001
X12	0.988	0.062	-0.129	0.026	0.038	0.008	0.031	-0.028
X13	-0.909	0.415	0.011	0.022	0.019	0.011	0.011	0.006
X14	0.996	-0.009	0.046	0.068	0.016	-0.008	-0.03	-0.009

X1=Plant height (cm) 75 DAP; X2=Plant spread (cm^2) 75 DAP; X3= Number of leaves per plant; X4= Fruit length (cm); X5= Fruit width (cm); X=6 Fruit weight (g); X7 Number of fruits per plant; X=8 Fruit yield per plant (g); X9= Yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; X13= Tritatable acidity (%); X14= Ascorbic acid mg/100 of pulp

The positive and negative correlations between different variables have a substantial impact on strawberry crop productivity and quality. They also have an impact on treatments and the environment, whether directly or indirectly. Except for X13 (titratable acidity (%)), all variables exhibited positive and extremely significant associations (Fig. 6, 7(a-e). The X13 (Tritatable acidity (%) trait) had the most significant negative relationships with all traits. As a result, before deciding on treatment combinations, it is important to analyze the relationships between different aspects. Many workers have reported comparable findings in different crops (Sahoo and Singh, 2005; Khalil and Agah, 2017; Singh et al., 2023; Patel et al., 2024a and 2024b; Singh et al., 2024).

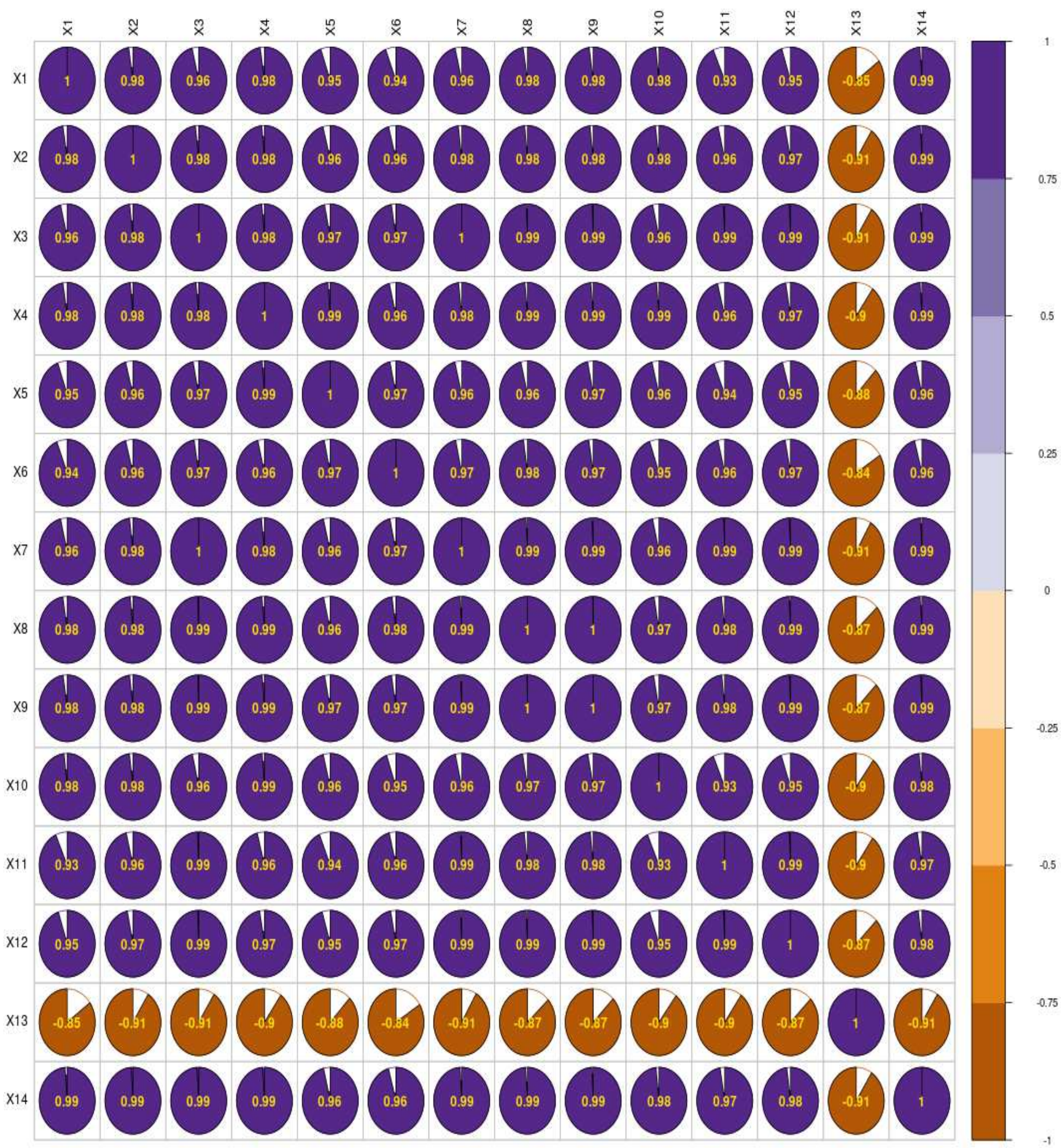

Fig. 6. Correlogram of the fourteen traits in strawberry crop

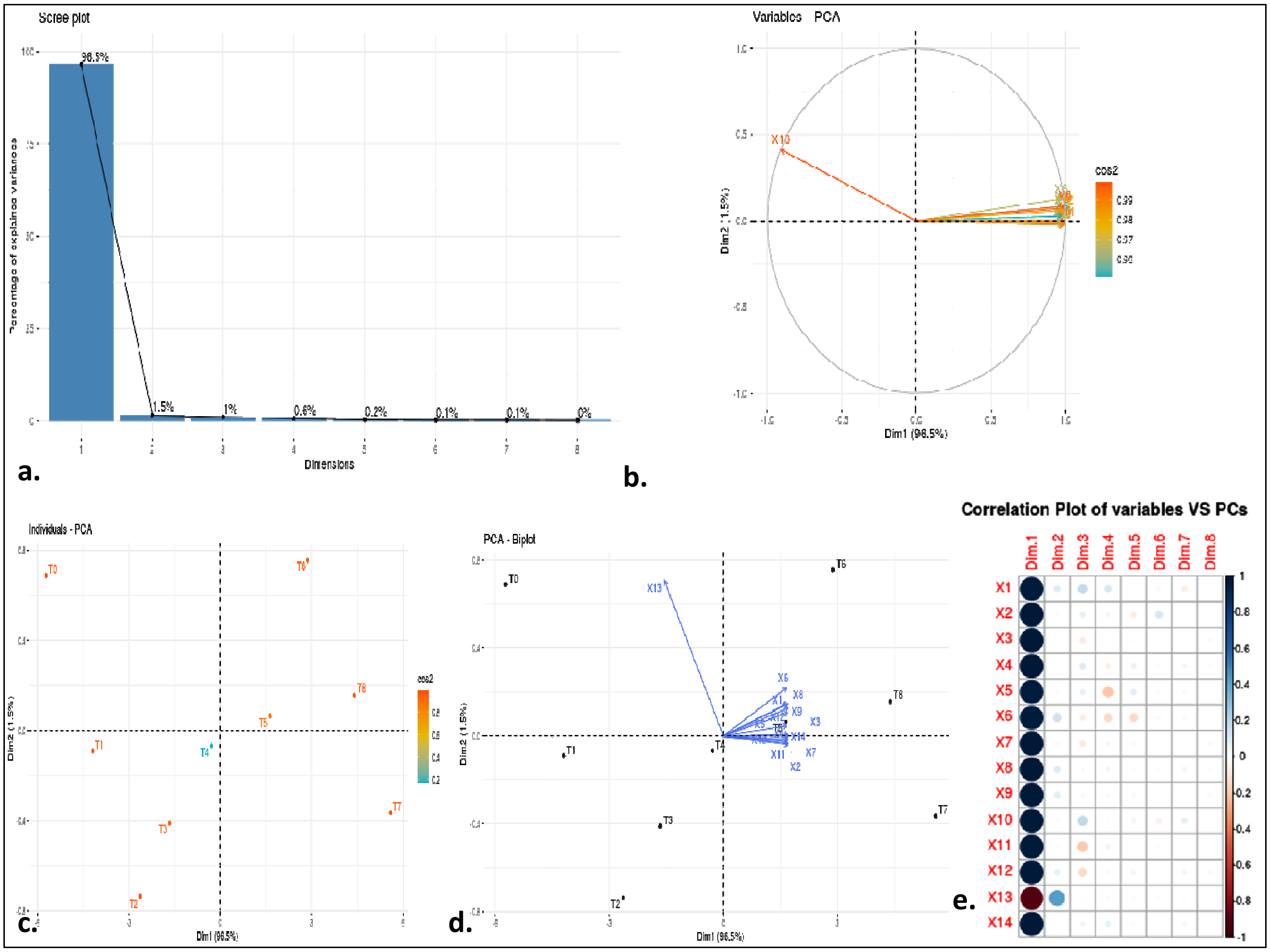

Fig. 7 (a-e). Scree plot, variables PCA, Individuals PCA, PCA biplot, and correlation plot of variables VS PCs in strawberry crop

In a nutshell, the treatment T7 (50% RDF+2 kg/ ha *Azotobacter* +2 kg/ ha PSB+50% top dressing P and K) followed by T8(50% RDF+2 kg/ ha *Azospirillim* +2 kg/ ha PSB + 50% K) and T6 (50% RDF+2kg/ha *Azospirillium*+50% top dressing P and K) were the highly impactful nearly all economic traits in both years/environments especially most economic traits like fruit yield quintal per ha; X10=Post harvest life of fruits in days; X11= The total soluble solids (TSS) °Brix; X12=Ascorbic acid mg/100 of pulp; and X14= Ascorbic acid mg/100 of pulp. Therefore, the three treatments, namely T7 followed by T8 and T6 were recommended for high fruit yield/ha and better quality in strawberry in the North Indian conditions.

Conclusions

The amount of manure, specifically farm yard manure, was applied to the soil before 15 days and thoroughly mixed in, and bio-fertilizers such as Azotobacter, Azospirillium, and PSB (phosphate solubilizing bacteria) were applied via root treatment and before transplantation. After treating the roots of strawberry plants, they were planted in the field. T7 (50% RDF+2 kg/ha Azotobacter +2 kg/ha PSB +50% top dressing P and K), followed by T8 (50% RDF+2 kg/ha Azospirillim +2 kg/ha PSB + 50% K) and T6 (50% RDF+2kg/ha Azospirillium +50% top dressing P and K), had a significant impact on nearly all economic traits in both years/environments, particularly fruit yield quintal per ha; X10 (Post-harvest life of fruits in days); X11 (Total soluble solids (TSS) °Brix. As a result, the three treatments, T7, T8, and T6, were recommended for high fruit yield/ha and improved strawberry quality in North Indian conditions.

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