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Influence of chemical and bio-fertilizers on quality attributes of strawberry cv. Winter Dawn

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Abstract

The present study was conducted during two consecutive winter seasons of 2023-24 and 2024-25 at the Department of Agriculture, IIAST, Integral University, Lucknow, Uttar Pradesh, India, to assess the impact of chemical and bio-fertilizer applications on strawberry fruits. The experiment consisted of 10 treatments in a randomized complete block design with 3 replications. Results from present investigation shown that strawberry plants grown under RDF + Vermicompost (3 t/ha) + Azotobacter (5 kg/ha) produced significantly higher total soluble solids (7.83%), TSS: acid ratio (11.51), vitamin C (56.85 mg/100 g), total anthocyanin (49.36 mg/100 g), non-reducing sugar (2.71%), reducing sugar (5.49%), total sugars (8.20%), and the lowest acidity (0.66%). This was followed by RDF + Vermicompost (3 t/ha) + PSB (5 kg/ha). In contrast, the lowest total soluble solids (4.93%), TSS: acid ratio (5.98), vitamin C (40.31 mg/100 g), total anthocyanin (40.37 mg/100 g), non-reducing sugar (1.97%), reducing sugar (3.68%), total sugars (5.65%), and the highest acidity (0.83%) were recorded in the control treatment. It can be concluded from the present investigation that the application of RDF + Vermicompost (3 t/ha) + Azotobacter (5 kg/ha) significantly improved the qualitative attributes of strawberry fruits compared to the control.

Introduction

The cultivated strawberry (*Fragaria* × *ananassa* Duch.) is a hybrid derived from *Fragaria virginiana* Duch. and *Fragaria chiloensis* (L.) Duch. (Reddy and Godara, 2020) and belongs to the *Rosaceae* family. Strawberries provide rapid economic returns in a short period. Regular consumption of strawberries has been shown to help prevent certain cancers, obesity, cardiovascular diseases, diabetes, and oxidative cell damage caused by reactive oxygen species (Giampieri *et al*., 2012).

Modern intensive farming, aimed at maximizing crop yields, relies heavily on expensive chemical fertilizers. However, the excessive and indiscriminate use of synthetic fertilizers and pesticides not only raises production costs but also contributes to soil, water, and environmental pollution through processes like denitrification, runoff, leaching, and volatilization. This, in turn, negatively impacts soil health, biodiversity, and long-term fertility (Seneviratne, 2009). To ensure sustainable crop production and mitigate these issues, bio-fertilizers offer an effective and eco-friendly alternative. Strawberries are rich in nutrients, leading to widespread use of chemical fertilizers in their cultivation. However, excessive reliance on these fertilizers can result in soil and water contamination, soil degradation, and harm to wildlife. Over time, continuous application of chemical fertilizers may also reduce soil fertility, negatively impacting plant growth and yield (Kaur & Kapoor, 2017). A sustainable alternative to chemical fertilizers is bio-fertilizers, which are derived from natural sources such as plant materials, compost, and animal manure. These fertilizers contain beneficial microorganisms, including bacteria, fungi, and algae, that improve soil fertility and support plant health (Yadav *et al.,* 2009). Research has shown that bio-fertilizers enhance the quality and flavor of strawberries. Unlike chemical fertilizers, bio-fertilizers do not leave harmful residues in the soil or water, making them an environmentally friendly option. Additionally, they promote sustainable agriculture by reducing reliance on synthetic fertilizers, which can be costly and harmful to the environment (Singh *et al*., 2019). A comparative study highlights the advantages and disadvantages of both chemical and bio fertilizers in strawberry cultivation. While chemical fertilizers significantly boost yield and provide high nutrient availability, their prolonged use depletes soil fertility and negatively impacts the ecosystem. In contrast, bio fertilizers improve plant health, enrich soil fertility, and have a lower environmental footprint, making them a more sustainable alternative (Yusuf *et al.,* 2003). Integrating bio fertilizers with inorganic fertilizers has proven to be an effective strategy for maintaining strawberry production while enhancing fruit quality. This combination leads to reduced disease incidence, better marketable fruit, and an improved cost-benefit ratio, ensuring long-term agricultural sustainability (Reddy *et al.,* 2020). Based on the considerations, the objective of this study is to evaluate the effects of chemical and bio-fertilizers on the qualitative traits of strawberry cultivar Winter Dawn.

Material and methods

The experiment was conducted in 2023–24 and 2024–25 in the central humid subtropical zone of India at the Department of Agriculture, IIAST, Integral University, U.P. (26.950°N, 80.990°E, 49 m above sea level). The study used a randomized block design (RBD) with three replications with 10 treatments *viz.*, T0= Control, T1= RDF + FYM (15t/ha) T2= RDF + Vermicompost (3t/ha), T3= RDF + PSB (5kg/ha), T4= RDF + Azotobacter (6kg/ha) T5= RDF + PSB (5kg/ha) + Azotobacter (6kg/ha),T6= RDF + FYM (15t/ha) + PSB (5kg/ha), T7= RDF + FYM (15t/ha) +Azotobacter (6kg/ha), T8= RDF + Vermicompost (3t/ha) + PSB (5kg/ha), T9= RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha). The region experiences temperatures from 5-10°C (min) to 38–40°C (max.) and receives 670 mm annual rainfall. Strawberry runners of the 'Winter Down' variety were sourced from Dr. Y. S. Parmar University, Himachal Pradesh, hardened for 1-3 days, and planted randomly. Standard cultural practices were followed throughout the trial.

Method of Application of Treatments-

Nitrogen, phosphorus, and potash were applied using urea (46% nitrogen), single super phosphate (SSP) (16% phosphorus), and muriate of potash (60% potash).

Parameters observed:

Total soluble solids (TSS), Acidity, TSS: acid ratio, Vitamin C, Total anthocyanin, Non reducing sugar, Reducing Sugar, Total Sugar,

Results and Discussion

Total soluble solids

The Total Soluble Solids (TSS) content varied significantly across different treatments in both years (2023–24 and 2024–25), as shown in Table 1. The pooled mean values indicate that the control treatment (RDF 150:75:100 kg/ha) recorded the lowest TSS value (4.96°Brix), while the application of RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha) resulted in the highest TSS content (8.06°Brix), followed by RDF + Vermicompost (3t/ha) + PSB (5kg/ha) (7.83°Brix). . An increase in TSS with plant growth promoting bacteria might be due to the quick metabolic transformation of starch and pectin into soluble compounds and rapid translocation of sugars from leaves to the developing fruits (Yadav *et al.,* 2016). The results of present study are in harmony with the findings of (Tripathi et al., 2016) who recorded maximum TSS in fruits harvested from the plants grown under organic manures with bio fertilizers, which might be due to the reason that bio fertilizers in combination with

Azotobacter increased the accumulation of carbohydrates and metabolites which were converted into disaccharides leading to higher TSS in strawberry fruits. Similar results were also obtained by authors (Tonutare *et al*., 2014; Hasan *et al*., 2015) in strawberry.

Acidity content (%)

The data highlighted in Table 1 show a substantial alteration in the acidity content of strawberry fruits during both years of the experiment. The strawberry plants treated with chemical and bio-fertilizers (RDF + Vermicompost (3 t/ha) + Azotobacter (5 kg/ha)) recorded the lowest acidity content (0.66%), followed by RDF + Vermicompost (3 t/ha) + PSB (5 kg/ha) (0.68%), compared to other treatments. However, the plants treated with RDF (150:75:100), serving as the control, recorded the highest acidity content (0.83%). The decrease in titratable acidity during fruit ripening can be attributed to the conversion of organic acids and photosynthates into sugars, facilitated by the application of bio fertilizers (Ghosh *et al*., 2011). These results align closely with the findings of Ahmed *et al*., (2018), who reported that the decline in acidity may also result from the utilization of acids as respiratory substrates during ripening, as well as the neutralization of organic acids due to the presence of potassium in plant tissues. Similar observations have been documented in strawberries by Tomic *et al*., (2015) and Kumar *et al*., (2015).

TSS: acid ratio

The improvement in total soluble solids and reduction in acidity content of strawberry fruits leads the enhancement of TSS: acid ratio. The substantial difference in TSS: acid ratio was recorded in strawberry fruits in response to the integrated or alone application of chemical and bio-fertilizers (Table 1). The integrated application of RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha) recorded maximum TSS: acid ratio (12.31), whereas plants incorporated with RDF resulted minimum TSS: acid ratio (5.98). The improvement in the TSS: acid ratio of strawberry fruits with the integrated application of RDF, Vermicompost (3t/ha), and Azotobacter (5kg/ha) may be attributed to a simultaneous increase in total soluble solids and a decrease in acidity. These findings align with the results of Singh *et al*. (2024) on INM in strawberry fruits.

Vitamin C

The integrated application of chemical and bio fertilizers sustainably produced the maximum vitamin C content in strawberry fruits compared to alone application of chemical and bio-fertilizers (Fig 1 A).

Application of RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha) resulted maximum vitamin C content (56.85 mg/100g)), which was followed by application of RDF + Vermicompost (3t/ha) + PSB (5kg/ha) and RDF + Azotobacter (6kg/ha) (55.32 mg/100g & 53.70 mg/100g, respectively). On the other hands, alone application of RDF represents minimum amount of vitamin C content (40.31 mg/100g). The rise in ascorbic acid content could be attributed to the enhanced efficiency of microbial inoculants in fixing atmospheric nitrogen, improving nitrogen availability, and releasing growth-promoting hormones. These factors accelerate physiological processes such as carbohydrate synthesis. The combined application of Azotobacter and vermicompost may further contribute to this increase by facilitating the rapid metabolic conversion of starch and pectin into soluble compounds and promoting the swift translocation of sugars from leaves to developing fruits (Tripathi *et al*., 2016). Similar findings have been reported in strawberries by Hazarika *et al*., (2007) and Singh *et al.,* (2008).

Total anthocyanin

Total anthocyanin content in strawberry fruits were significantly altered by the integrated application of chemical and bio-fertilizers as compared to alone application of chemical (Fig. 1 B). Maximum total anthocyanin content (49.36 mg/100g) in strawberry fruits were noted under the application of RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha), followed by RDF + Vermicompost (3t/ha) + PSB (5kg/ha) and RDF + PSB (5kg/ha) (48.05 mg/100g & 47.16 mg/100g, respectively). However, the plants grown under the RDF recorded lowest amount of total anthocyanin content (40.37 mg/100g). The rise in total anthocyanin content in strawberry fruits might be due to the synergistic impact of macronutrients provided by organic and bio-fertilizers, which enhanced plant vegetative growth. This, in turn, influenced chlorophyll synthesis, promoting photosynthesis and efficient carbon dioxide assimilation, ultimately leading to improved total anthocyanin content (Umar *et al*., 2009).

Reducing Sugar

In terms of reducing sugar content, a similar trend was observed, where T10: RDF + Vermicompost (3 t/ha) + Azotobacter (6 kg/ha) again recorded the highest value (5.49%), significantly surpassing all other treatments. This was followed by T9: RDF + Vermicompost (3 t/ha) + PSB (5 kg/ha) at 5.14% and T5: RDF + Azotobacter (6 kg/ha) at 4.93%, reflecting the role of *Azotobacter* in enhancing sugar conversion processes. The control treatment exhibited the lowest reducing sugar content (3.68%), highlighting the insufficiency of native soil fertility in meeting the metabolic demands of the crop. The application of vermicompost likely improved enzymatic activity and carbohydrate metabolism, facilitating the breakdown of complex carbohydrates into simple sugars like glucose and fructose.

Treatments combining FYM and biofertilizers (e.g., T8: RDF + FYM + Azotobacter) resulted in moderate values (4.23%), further validating the advantage of integrated nutrient management approaches. The statistical parameters showed significant treatment effects with a CD of 0.17 and CV of 2.10% in pooled data, indicating consistent and meaningful variation.

These results corroborate earlier reports where vermicompost and nitrogen-fixing biofertilizers enhanced sugar content due to improved nutrient uptake and enhanced enzymatic activity (Verma et al., 2020; Singh et al., 2019).

Non-reducing Sugar Content (%)

The pooled data for non-reducing sugars revealed significant variations among different nutrient management treatments. The treatment T10: RDF + Vermicompost (3 t/ha) + Azotobacter (6 kg/ha) recorded the highest non-reducing sugar content (2.71%), followed closely by T9: RDF + Vermicompost (3 t/ha) + PSB (5 kg/ha) with 2.61%. These treatments were significantly superior to the control (1.97%) and other inorganic combinations, indicating the positive role of integrating organic and biofertilizer components in enhancing sugar accumulation.

Among the individual biofertilizer treatments, RDF + Vermicompost (3 t/ha) and RDF + FYM (15 t/ha) also showed higher non-reducing sugar contents (2.40% and 2.20%, respectively) compared to the control. Interestingly, RDF + Azotobacter (6 kg/ha) alone recorded a moderate increase (2.11%), suggesting its beneficial but limited role when applied individually.

Total Sugar

Integrated application of chemical and bio-fertilizers significantly produced maximum sugars as compared to alone of chemical fertilizers (Table 2). The integrated application of RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha) resulted significantly maximum non-reducing sugar (2.61%), reducing sugar (5.14%), and total sugars (8.20%), which was followed by integrated application of RDF + Vermicompost (3t/ha) + PSB (5kg/ha), while the alone application of RDF represented lowest amount of non-reducing sugar (1.97%), reducing sugar

(3.68%), and total sugars (5.65%). The increase in sugar content in strawberry fruits following inoculation with free-living nitrogen-fixing bacteria, either alone or in combination, may be attributed to a consistent nutrient supply provided by the bio-inoculants throughout the growth period. This steady availability of nutrients enhanced plant vigor, expanded leaf area, and promoted higher assimilate synthesis due to an improved rate of photosynthesis. These effects likely facilitated greater mobility of photosynthetic products from the leaves to the developing fruits, ultimately leading to higher sugar accumulation (Singh and Singh, 2006). Similar findings were also reported by Singh *et al*., (2010) in strawberries.

Conclusion

From both years of investigation, it can be concluded that the integrated use of chemical and bio-fertilizers (RDF + vermicompost 3 t/ha + Azotobacter 5 kg/ha) significantly improved the total soluble solids, TSS: acid ratio, vitamin C, total anthocyanin, non-reducing sugar, reducing sugar, and total sugars while reducing acidity in strawberry fruits. This was followed by RDF + vermicompost (3 t/ha) + PSB (5 kg/ha) compared to the control. Further investigation is required to examine the individual effects of chemical and bio-fertilizer applications on the qualitative attributes of strawberry fruits.

Data availability statement

The data of the present investigation are available on reasonable request to the authors.

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Table 1: Influence of chemical and Bio fertilizers Application on TSS, Acidity and TSS: acid ratio of strawberry cv. Winter Dawn during 2023-24 and 2024-25.

Treatment details	TSS (%)		Pooled	Acidity (%)		Pooled	TSS: acid ratio		Pooled
	2023-24	2024-25		2023-24	2024-25		2023-24	2024-25	
Control	4.93	4.99	4.96	0.84	0.82	0.83	5.87	6.09	5.98
RDF + FYM (15t/ha)	6.35	6.39	6.37	0.71	0.71	0.71	8.94	9.00	8.97
RDF + Vermicompost (3t/ha)	6.29	6.34	6.32	0.73	0.72	0.73	8.62	8.81	8.72
RDF + PSB (5kg/ha)	6.04	6.14	6.09	0.74	0.73	0.74	8.16	8.41	8.29
RDF + Azotobacter (6kg/ha)	5.78	5.81	5.80	0.78	0.78	0.78	7.41	7.45	7.43
RDF + PSB (5kg/ha) + Azotobacter (6kg/ha)	6.35	6.29	6.32	0.77	0.76	0.77	8.25	8.28	8.27
RDF + FYM (15t/ha) + PSB (5kg/ha)	7.10	7.14	7.12	0.73	0.73	0.73	9.73	9.78	9.76
RDF + FYM(15t/ha) +Azotobacter (6kg/ha)	6.68	6.99	6.84	0.71	0.70	0.71	9.41	9.99	9.70
RDF + Vermicompost (3t/ha) + PSB (5kg/ha)	7.78	7.87	7.83	0.68	0.68	0.68	11.44	11.57	11.51
RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha)	8.10	8.01	8.06	0.64	0.67	0.66	12.66	11.96	12.31
SE m±	**0.07**	**0.08**	**0.08**	**0.01**	**0.01**	**0.01**	**0.12**	**0.13**	**0.13**
CD at 5 %	**0.22**	**0.24**	**0.23**	**0.03**	**0.02**	**0.03**	**0.35**	**0.39**	**0.37**
CV	**1.98**	**2.08**	**2.03**	**2.19**	**1.97**	**2.08**	**2.26**	**2.50**	**2.38**

Treatment details	Non-reducing (%)		Pooled	Reducing (%)		Pooled	Total sugars		Pooled
	2023-24	2024-25		2023-24	2024-25		2023-24	2024-25	
Control	1.95	1.99	1.97	3.66	3.70	3.68	5.61	5.69	5.65
RDF + FYM (15t/ha)	2.17	2.23	2.20	4.56	4.61	4.59	6.73	6.84	6.79
RDF + Vermicompost (3t/ha)	2.36	2.43	2.40	4.69	4.75	4.72	7.05	7.18	7.12
RDF + PSB (5kg/ha)	2.19	2.24	2.22	4.47	4.54	4.51	6.66	6.78	6.72
RDF + Azotobacter (6kg/ha)	2.09	2.12	2.11	4.91	4.95	4.93	7.00	7.07	7.04
RDF + PSB (5kg/ha) + Azotobacter (6kg/ha)	2.16	2.09	2.13	4.26	4.23	4.25	6.42	6.32	6.37
RDF + FYM (15t/ha) + PSB (5kg/ha)	2.35	2.29	2.32	4.4	4.46	4.43	6.75	6.75	6.75
RDF + FYM(15t/ha) +Azotobacter (6kg/ha)	2.36	2.49	2.43	4.14	4.31	4.23	6.50	6.80	6.65
RDF + Vermicompost (3t/ha) + PSB (5kg/ha)	2.59	2.63	2.61	5.11	5.16	5.14	7.70	7.79	7.75
RDF + Vermicompost (3t/ha) + Azotobacter (5kg/ha)	2.68	2.73	2.71	5.46	5.52	5.49	8.14	8.25	8.20
Sem ±	**0.02**	**0.03**	**0.03**	**0.05**	**0.06**	**0.06**	**0.09**	**0.10**	**0.10**
CD at 5 %	**0.07**	**0.08**	**0.08**	**0.15**	**0.19**	**0.17**	**0.26**	**0.29**	**0.28**
CV	**1.86**	**2.10**	**1.98**	**1.86**	**2.34**	**2.10**	**2.22**	**2.45**	**2.34**

Table 2: Influence of chemical and bio-fertilizers application on non-reducing, reducing and total sugars content in strawberry cv. Winter Dawn during 2023-24 and 2024-25.

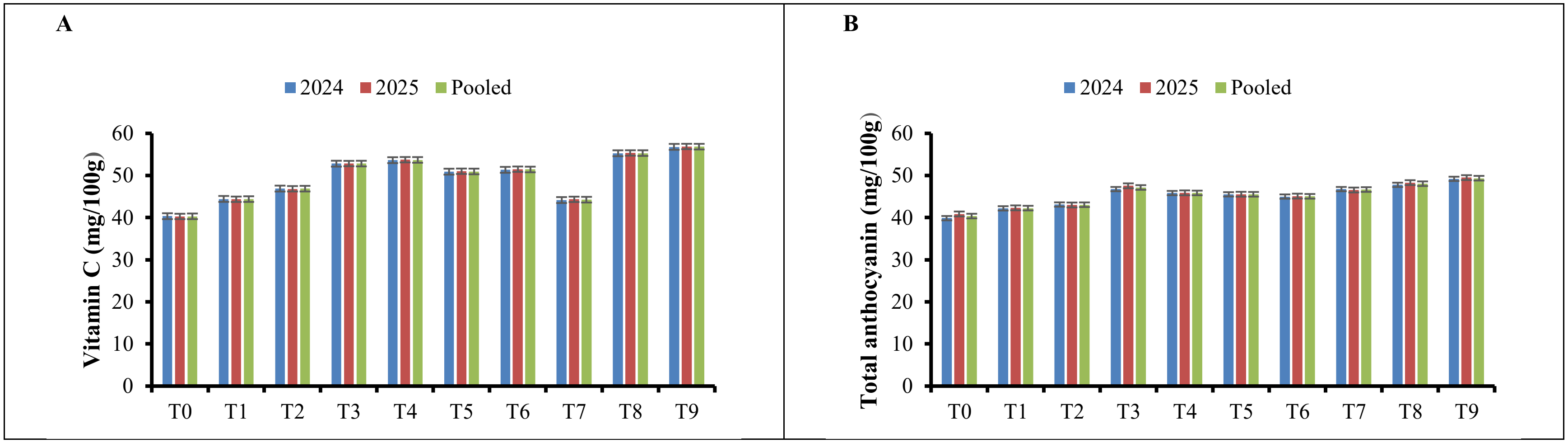

Fig. 1: Influence of chemical and bio-fertilizers on (A) Vitamin C and (B) total anthocyanin content in strawberry cv. Winter Dawn during 2023-24 and 2024-25. Vertical bars represent the standard error of means for three replicates.