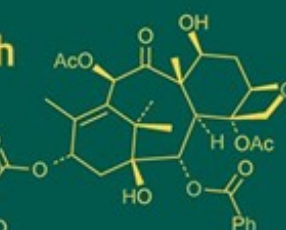
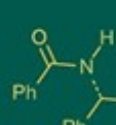


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Performance of strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under different bioenhancer-based nutrient management practices

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ABSTRACT

A field experiment was conducted during the winter season to evaluate the response of different bio-enhancers on the growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa* Duch.). The experiment comprised eight treatments, viz., control, Panchagavya, Jivamrita, Vermiwash, Panchagavya + Jivamrita, Panchagavya + Vermiwash, Jivamrita + Vermiwash and recommended dose of fertilizer (RDF), arranged in a randomized block design. The observations were recorded for important growth, yield and quality attributes of strawberry. Among the treatments, RDF recorded the highest plant height (25.58 cm), number of leaves plant⁻¹ (59.48), number of runners plant⁻¹ (7.03) and plant spread (34.56 cm). Among the bio-enhancer treatments, Jivamrita + Vermiwash showed superior performance, recording 42.09 leaves plant⁻¹, 5.35 runners plant⁻¹ and 32.18 cm plant spread. Similarly, the maximum number of fruits plant⁻¹ (27.42), average fruit weight (16.48 g), fruit yield plant⁻¹ (451.88 g) and fruit yield (361.50 q ha⁻¹) were obtained with RDF, followed by Jivamrita + Vermiwash. Fruit quality was also improved under the different bio-enhancer treatments. RDF recorded the highest TSS (11.12 °Brix), ascorbic acid content (67.42 mg 100 g⁻¹) and fruit firmness (1.01 kg cm⁻²), whereas fruit acidity was lowest (0.68%). Jivamrita + Vermiwash was the most effective bio-enhancer combination, recording 10.56 °Brix TSS, 64.28 mg 100 g⁻¹ ascorbic acid and 0.96 kg cm⁻² fruit firmness. Overall, the findings indicated that integrated application of bioenhancers, particularly Jivamrita + Vermiwash, has considerable potential for improving strawberry growth, productivity and fruit quality and may contribute to more sustainable nutrient management in strawberry production.

Keywords: Strawberry, Bioenhancers, Panchagavya, Jivamrita, Vermiwash, Growth, Yield, Quality

Introduction

Strawberry production, however, requires careful management of plant nutrition because the crop has a high demand for nutrients during vegetative growth, flowering, fruit setting and fruit development. Conventional production systems generally depend heavily on inorganic fertilizers to obtain rapid and adequate plant growth and higher yields. Although mineral fertilizers are essential for supplying nutrients in readily available forms, their excessive or imbalanced use may adversely affect soil health, nutrient-use efficiency and environmental sustainability. Consequently, there is increasing interest in production practices that can complement mineral fertilization while improving nutrient availability, plant growth and fruit quality. The development of sustainable nutrient-management strategies is particularly important in high-value horticultural crops such as strawberry, where productivity and quality are equally important.

In this context, bio-enhancers or plant bio-stimulants have emerged as promising components of sustainable crop production. Bio-enhancers are materials or biological preparations capable of stimulating natural plant processes and improving nutrient-use efficiency, plant growth, stress tolerance, crop productivity and quality. Their beneficial effects may occur through improved nutrient acquisition, stimulation of beneficial microorganisms, enhancement of root activity, hormone-like effects and modification of physiological and metabolic processes. Unlike conventional fertilizers, the principal objective of bio-stimulants is not simply to supply nutrients but to improve the efficiency of plant physiological processes and nutrient utilization. Research on strawberry has demonstrated that different categories of bio-stimulants can positively influence vegetative growth, yield, fruit quality and plant physiological responses.

Among different locally prepared organic bio-enhancers, Panchagavya, Jivamrita and Vermiwash have attracted considerable attention because of their potential to improve plant growth and nutrient availability. Panchagavya is an organic preparation traditionally prepared from products derived from cattle and is considered a source of nutrients, beneficial microorganisms and biologically active compounds. Its application may stimulate vegetative growth and improve physiological activity. Jivamrita is a fermented microbial preparation containing organic substrates and microbial populations that can contribute to nutrient transfor

mation and biological activity in the rhizosphere. Vermiwash, obtained from vermicomposting systems, contains soluble nutrients, microorganisms and biologically active compounds and has been reported to have potential as a plant growth-promoting preparation. The use of such preparations may therefore provide an opportunity to integrate biological processes into crop nutrient management.

The potential value of combining bio-enhancers is particularly important because different preparations may operate through complementary mechanisms. Individual application may provide specific benefits, whereas combinations such as Panchagavya + Jivamrita, Panchagavya + Vermiwash and Jivamrita + Vermiwash may enhance nutrient cycling, microbial activity and plant physiological processes more effectively. The concept of combined bio-stimulation is supported by the understanding that microbial and organic bio-stimulants can influence both the rhizosphere environment and plant metabolism. Beneficial microorganisms can improve nutrient acquisition and interact with plants through mechanisms such as nutrient solubilization, production of growth-promoting substances and modification of the rhizosphere. Such responses can ultimately influence vegetative growth, flowering, fruit set and fruit development.

The winter season is particularly important for strawberry cultivation because temperature and environmental conditions during this period strongly influence vegetative development, flowering, fruit setting and fruit maturation. Proper nutritional and biological management during winter can help maintain vigorous plant growth and support continuous reproductive development. Parameters such as plant height, number of leaves, runner production, flowering behaviour, fruit number and fruit weight are useful indicators for evaluating the response of strawberry plants to different nutrient-management strategies. Similarly, quality attributes such as total soluble solids, acidity, ascorbic acid and fruit firmness are important for determining the market and nutritional value of harvested fruits.

Recent research has emphasized the potential of bio-stimulants in strawberry production, but responses are not always uniform and depend on the type of bio-stimulant, formulation, application method, dose, cultivar and environmental conditions. A comprehensive review of strawberry bio-stimulation reported beneficial effects on growth, productivity and fruit quality but also highlighted the need for further evaluation of different biological and organic inputs under specific production conditions. Similarly, studies on microbial plant bio-stimulants have indicated their potential to improve strawberry nutritional and sensory quality while reducing dependence on conventional inputs. These findings indicate that evaluation of locally available and farmer-oriented bio-enhancers under specific agro-climatic conditions is necessary for developing practical recommendations.

Therefore, the present investigation was undertaken to evaluate the response of different bio-enhancers, individually and in combination, on growth, yield and fruit quality of strawberry (*Fragaria × ananassa* Duch.) during the winter season. The study compared Panchagavya, Jivamrita and Vermiwash, their respective combinations, and a recommended dose of fertilizer (RDF) with an untreated control. Growth attributes such as plant height, number of leaves and runners, yield attributes including number of fruits, fruit weight and fruit yield, and quality parameters such as TSS, acidity, ascorbic acid and fruit firmness were considered to assess treatment performance.

Materials and Methods

A field experiment was conducted during the *rabi* season of 2024-25 at the Research Farm of Maharshi School of Agriculture, Maharshi University of Information Technology (MUIT), Lucknow, Uttar Pradesh, India, located at approximately 26.85° N latitude, 80.95° E longitude and 123 m above mean sea level. The experimental soil was sandy loam in texture and nearly neutral in reaction (pH 7.3), containing 0.54% organic carbon, 265 kg ha⁻¹ available nitrogen, 22.4 kg ha⁻¹ available phosphorus and 248 kg ha⁻¹ available potassium. The experiment was laid out in a Randomized Block Design (RBD) with eight treatments and three replications.

The treatments comprised (T₁) control, (T₂) recommended dose of fertilizers (RDF), (T₃) Panchagavya foliar spray (3%), (T₄) Panchagavya soil drenching, (T₅) seaweed extract foliar spray, (T₆) microbial consortium soil application, (T₇) Panchagavya + FYM and (T₈) integrated bio-enhancer package (Panchagavya + seaweed extract + microbial consortium). The RDF consisted of 100 kg N, 60 kg P₂O₅ and 60 kg K₂O ha⁻¹, while FYM was applied at 20 t ha⁻¹. Panchagavya foliar spray was applied at 30, 45 and 60 days after transplanting (DAT), whereas soil drenching was performed at transplanting and 30 DAT. Seaweed extract was applied as foliar spray at 30 and 60 DAT, while the microbial consortium was applied to the soil at transplanting. Healthy runners of strawberry cv. 'Winter Dawn' were planted at 30 × 45 cm spacing on raised beds.

Analysis of attributes

Observations were recorded from five randomly selected plants from each plot for growth, flowering, yield and fruit-quality attributes. Growth parameters included plant height, number of leaves plant⁻¹, leaf area, plant spread, crown diameter, number of crowns plant⁻¹ and root length. Flowering parameters comprised days to first flowering, days to 50% flowering, number of flowers plant⁻¹, flowering duration and fruit-set percentage. Yield attributes included number of fruits plant⁻¹, average fruit weight, fruit yield plant⁻¹, fruit yield plot⁻¹, fruit yield hectare⁻¹.

Fruit-quality characteristics were assessed through fruit length, fruit width, length-to-diameter ratio, individual fruit weight, firmness, colour, external appearance, pedicel length and shelf life. Fruit number was counted manually, fruit weight was recorded using a digital balance, and fruit dimensions were measured using a vernier caliper. The observations recorded for different attributes were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design (RBD). Treatment means were compared using the critical difference (CD) at the 5% level of significance, and the significance of differences among treatment means was determined accordingly.

Growth parameters

Plant height (cm)

Plant height varied considerably among the bio-enhancer treatments. The maximum plant height (25.58 cm) was recorded with RDF (T₈), followed by Jivamrita + Vermiwash (23.21 cm) and Panchagavya + Vermiwash (22.37 cm), whereas the minimum (9.07 cm) was observed under control. The combined application of bio-enhancers resulted in greater plant height than their individual application. The improvement may be attributed to better nutrient availability and enhanced microbial activity in the rhizosphere.

Number of leaves plant⁻¹

The number of leaves plant⁻¹ was highest under RDF (59.48), followed by Jivamrita + Vermiwash (42.09) and Panchagavya + Vermiwash (38.54), while the control recorded the lowest value (31.70). Combined bio-enhancer treatments performed better than individual bio-enhancers. The increased leaf production could be associated with improved nutrient supply and enhanced vegetative growth, particularly nitrogen availability.

Number of runners plant⁻¹

The maximum number of runners plant⁻¹ (7.03) was recorded with RDF, followed by Jivamrita + Vermiwash (5.35) and Panchagavya + Vermiwash (5.09). Control produced the minimum number of runners (3.03). Improved runner production under integrated bio-enhancer treatments may be due to better plant vigour and enhanced nutrient and microbial activity.

Plant spread (cm)

Plant spread followed a similar trend, with the maximum spread (34.56 cm) recorded under RDF and the minimum (18.42 cm) under control. Jivamrita + Vermiwash (32.18 cm) and Panchagavya + Vermiwash (30.65 cm) also produced substantially greater plant spread. The enhanced plant spread indicates improved vegetative de

velopment resulting from balanced nutrient availability and improved rhizosphere conditions.

Table 1. Effect of different bio-enhancers on growth parameters of strawberry.

Treatment	Plant height (cm)	No. of leaves plant ⁻¹	No. of runners plant ⁻¹	Plant spread (cm)
Control	9.07	31.7	3.03	18.42
Panchagavya	10.96	32.94	3.04	20.15
Jivamrita	11.93	33.95	3.09	21.36
Vermiwash	18.76	34.79	3.33	25.72
Panchagavya + Jivamrita	19.74	36.6	3.77	27.84
Panchagavya + Vermiwash	22.37	38.54	5.09	30.65
Jivamrita + Vermiwash	23.21	42.09	5.35	32.18
RDF (100 %)	25.58	59.48	7.03	34.56
SD	6.24	9.01	1.46	5.96
SEM (±)	2.21	3.18	0.52	2.11

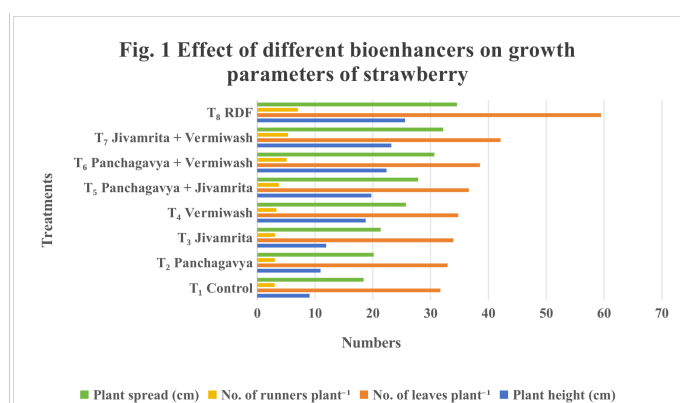


Figure 1. Effect of different bio-enhancers on growth parameters of strawberry.

2.2 Yield parameters

Number of fruits plant⁻¹

The number of fruits plant⁻¹ was highest with RDF (27.42), followed by Jivamrita + Vermiwash (24.36) and Panchagavya + Vermiwash (22.18). The control recorded the lowest number of fruits (12.84). The superiority of combined bio-enhancers over individual applications suggests that their complementary effects may have improved flowering, fruit setting and subsequent fruit development.

Average fruit weight (g)

Average fruit weight ranged from 11.72 g under control to 16.48 g with RDF. Among bio-enhancer treatments, Jivamrita + Vermiwash recorded the highest fruit weight (15.86 g), followed by Panchagavya + Vermiwash (15.24 g). Better fruit development under these treatments may be related to improved nutrient availability and enhanced physiological activity of plants.

Fruit yield plant⁻¹ (g)

Fruit yield plant⁻¹ was maximum under RDF (451.88 g), followed by Jivamrita + Vermiwash (386.35 g) and Panchagavya + Vermiwash (338.02 g). The control recorded the lowest fruit yield (150.50 g plant⁻¹). Higher yield under combined bio-enhancers may be attributed to their favourable influence on vegetative growth, fruit number and individual fruit weight.

Fruit yield (q ha⁻¹)

The highest fruit yield (361.50 q ha⁻¹) was recorded with RDF, whereas the lowest yield (120.40 q ha⁻¹) was obtained under control. Jivamrita + Vermiwash produced 309.08 q ha⁻¹, followed by Panchagavya + Vermiwash (270.42 q ha⁻¹). The enhanced yield un-

der integrated treatments reflects the combined contribution of improved plant growth, fruit setting and fruit development.

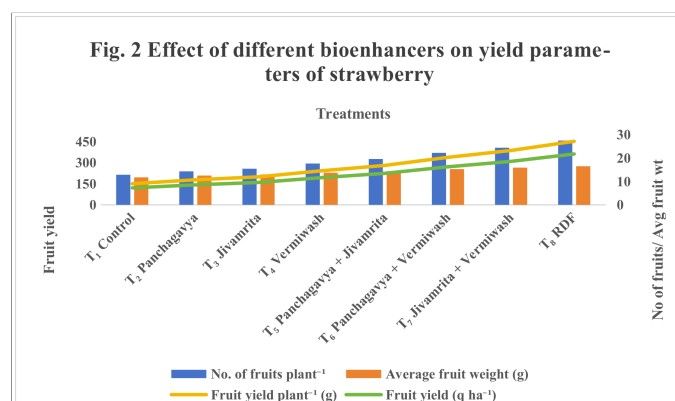


Figure 2. Effect of different bio-enhancers on yield parameters of strawberry.

3 Quality parameters

TSS (°Brix)

TSS increased progressively with improved nutrient and bio-enhancer management. The maximum TSS (11.12 °Brix) was recorded under RDF, followed by Jivamrita + Vermiwash (10.56 °Brix) and Panchagavya + Vermiwash (10.18 °Brix), while control recorded 7.84 °Brix. Higher TSS may indicate improved accumulation of soluble sugars and other soluble solids during fruit development.

Acidity (%)

Fruit acidity showed a decreasing trend with increasing treatment efficiency. The highest acidity (0.86%) was recorded under control, whereas the lowest value (0.68%) was observed with RDF. Jivamrita + Vermiwash and Panchagavya + Vermiwash recorded 0.70 and 0.72%, respectively. The reduction in acidity may be associated with progressive fruit maturity and conversion or utilization of organic acids during ripening.

Ascorbic acid (mg 100 g⁻¹)

Ascorbic acid content was highest under RDF (67.42 mg 100 g⁻¹), followed by Jivamrita + Vermiwash (64.28 mg 100 g⁻¹) and Panchagavya + Vermiwash (61.84 mg 100 g⁻¹). The lowest value (48.62 mg 100 g⁻¹) was recorded under control. Improved nutrient availability and better physiological activity under integrated treatments may have favoured the synthesis and accumulation of vitamin C.

Table 2. Effect of different bio-enhancers on yield parameters of strawberry.

Treatment	No. of fruits plant ⁻¹	Average fruit weight (g)	Fruit yield plant ⁻¹ (g)	Fruit yield (q ha ⁻¹)
Control	12.84	11.72	150.5	120.4
Panchagavya	14.26	12.48	177.96	142.37
Jivamrita	15.38	12.96	199.32	159.46
Vermiwash	17.64	13.72	242.02	193.62
Panchagavya + Jivamrita	19.52	14.36	280.31	224.25
Panchagavya + Vermiwash	22.18	15.24	338.02	270.42
Jivamrita + Vermiwash	24.36	15.86	386.35	309.08
RDF (100 %)	27.42	16.48	451.88	361.5
SD	5.14	1.68	106.46	85.16
SEM (±)	1.82	0.60	37.64	30.11

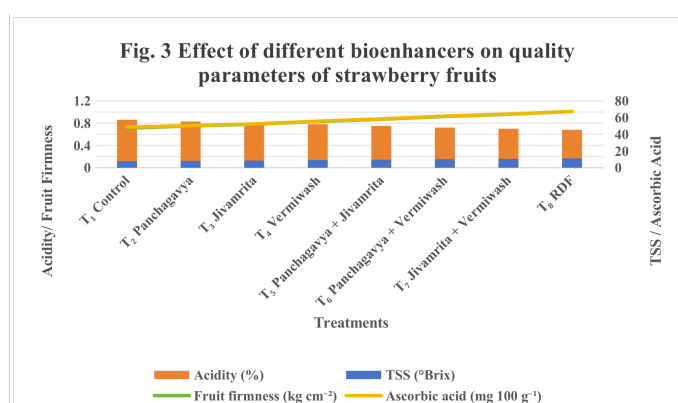
Fruit firmness (kg cm²)

Fruit firmness was maximum under RDF (1.01 kg cm²), followed by Jivamrita + Vermiwash (0.96 kg cm²) and Panchagavya + Vermiwash (0.92 kg cm²). Control recorded the lowest firmness (0.71 kg cm²).

Higher firmness under improved nutrient management may contribute to better fruit quality, handling tolerance and post-harvest keeping quality

Table 3. Effect of different bioenhancers on quality parameters of strawberry fruits.

Treatment	TSS (°Brix)	Acidity (%)	Ascorbic acid (mg 100 g ⁻¹)	Fruit firmness (kg cm ⁻²)
Control	7.84	0.86	48.62	0.71
Panchagavya	8.26	0.83	50.48	0.75
Jivamrita	8.54	0.81	52.36	0.78
Vermiwash	9.18	0.78	55.72	0.83
Panchagavya + Jivamrita	9.62	0.75	58.46	0.87
Panchagavya + Vermiwash	10.18	0.72	61.84	0.92
Jivamrita + Vermiwash	10.56	0.7	64.28	0.96
RDF (100%)	11.12	0.68	67.42	1.01
SD	1.16	0.065	6.78	0.105
SEM (±)	0.41	0.023	2.40	0.037

**Figure 3.** Effect of different bio-enhancers on quality parameters of strawberry fruits.**Conclusion**

The present investigation indicated that the application of bio-enhancers had a favourable influence on the growth, yield and fruit-quality attributes of strawberry cv. *Winter Dawn* during the winter season. Among the evaluated treatments, RDF (T₈) recorded the highest plant growth, fruit yield and quality attributes, while Jivamrita + Vermiwash (T₇) performed best among the bio-enhancer treatments. The combined application of bio-enhancers was generally more effective than their individual application, indicating a possible complementary effect on nutrient availability and plant physiological activ-

ity. Thus, integrated bio-enhancer application, particularly Jivamrita + Vermiwash, appears to be a promising approach for improving strawberry productivity and fruit quality under winter growing conditions.

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