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Enhancing dragon fruit (*Hylocereus costaricensis*) with vermicompost and biofertilizer: A study on physico-chemical improvements

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ABSTRACT

An experiment was conducted during 2022 and 2023 at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh to evaluate the impact of vermicompost and biofertilizers on the physical and chemical characteristics of dragon fruit, providing valuable insights into sustainable cultivation practices using 11 treatments, viz. T_1, Control; T_2, Vermicompost (0.5 kg/plant); T_3, *Azotobacter* (50 g/plant); T_4, *Azospirillum* (50 g/plant); T_5, Phosphate solubilizing bacteria (50 g); T_6, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant); T_7, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant); T_8, Vermicompost (0.5 kg/plant) + Phosphate solubilizing bacteria (50 g/plant); T_9, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + *Azospirillum* (50 g/plant); T_{10}, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant) and T_{11}, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant). The experiment was laid out in randomized block design (RBD) with three replications. The significant differences in physico-chemical attributes of dragon fruit (*Hylocereus costaricensis* L.), were observed as influenced by vermicompost and biofertilizers application. The maximum length of fruit (8.96 cm), diameter (7.55 cm), weight (205.90 g), volume (162.33 cc), specific gravity (1.27), pulp weight (160.55 g) and peel weight (41.59 g), pulp: peel ratio (3.86), thickness of fruit pulp (6.84 cm), thickness of fruit peel (0.59 cm) and number of bracts/fruit (30.99) and in biochemical parameters, total soluble solids contents (14.80 °Brix), titratable acidity (0.39%), ascorbic acid content (9.42 mg/100 g), total sugars (9.40%), reducing sugar (5.23%) and non-reducing sugar (4.17%) were found elevated with the use of vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant).

Keywords: Biofertilizers, Vermicompost, Dragon fruit, Physical parameters biochemical

Dragon fruit (*Hylocereus costaricensis* L.), a herbaceous perennial climbing cactus from the family Cactaceae, is commonly known as Kamalam in India. Native to the tropical and subtropical forests of Mexico and Central and South America, it has gained prominence as an exotic crop in India due to its adaptability and commercial potential. The plant is a fast-growing, perennial climber that requires vertical support, with succulent, segmented stems. The fruit, characterized by red or yellow skin with green scales, contains either white or red flesh embedded with small, edible black seeds (Perween and Hasan 2019). In India, Gujarat, Karnataka and Maharashtra are the leading producers, contributing about 70% of the country's dragon fruit production.

Dragon fruit is highly valued for its applications in healthcare, food processing, nutraceutical and cosmeceutical industries. It possesses significant health benefits, including immunity enhancement, increased blood cell production and potential therapeutic effects for respiratory diseases, wound healing and digestive health (Stephen *et al.* 2023). The red-fleshed species, dragon fruit, is particularly rich in betalains, which have strong antioxidant properties and serve as natural food colorants, aligning with the growing demand for functional foods (Vinod *et al.* 2021).

Despite its economic and nutritional significance, sustainable production of dragon fruit faces challenges due to soil degradation and excessive reliance on chemical fertilizers. While the crop is relatively easy to cultivate and thrives under diverse environmental conditions, indiscriminate use of synthetic inputs has led to soil infertility, reduced productivity and environmental concerns. The integration of organic amendments, such as vermicompost and biofertilizers (*Azotobacter*, *Azospirillum* and phosphate-solubilizing bacteria), offers a sustainable alternative by enhancing soil fertility, promoting nutrient absorption and stimulating plant growth through phytohormone production (Sahu *et al.* 2022). Vermicompost, in particular, is gaining traction as an eco-friendly fertilizer that supplies essential nutrients while improving soil structure and microbial activity (Anagha *et al.* 2024).

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However, scientific research on organic nutrient management for dragon fruit remains scarce, particularly in the context of its cultivation in the northern plains of India. Understanding the effects of organic amendments on the fruit's physico-chemical attributes is crucial for optimizing its quality and commercial value. This study, therefore, aims to evaluate the impact of vermicompost and biofertilizers on the physical and chemical characteristics of dragon fruit, providing valuable insights into sustainable cultivation practices.

MATERIALS AND METHODS

An experiment was conducted during 2022 and 2023 at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (25º26' and 26º28' N and 79º31' and 80º34' E, at an elevation of 125.90 m amsl), Uttar Pradesh. The experimental site is situated in the Indo-Gangetic central plains, characterized by a sub-tropical climate and alluvial soil. The region experiences a semi to sub-tropical climate with hot, dry summers and cold winters. The site has an assured irrigation facility by tube well. Four-month-old healthy plants were planted on 22 March 2022 at a distance of 2 m × 2 m around the pole. Each pillar has three plants placed on it 15 cm apart from the pole. The experiment was laid out in a randomized block design (RBD) with 11 treatments of different combination of organic manure and biofertilizer, viz. T_1, Control; T_2, Vermicompost (0.5 kg/plant); T_3, *Azotobacter* (50 g/plant); T_4, *Azospirillum* (50 g/plant); T_5, Phosphate solubilizing bacteria (50 g); T_6, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant); T_7, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant); T_8, Vermicompost (0.5 kg/plant) + Phosphate solubilizing bacteria (50 g/plant); T_9, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) +*Azospirillum* (50 g/plant); T_{10}, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant) and T_{11}, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant) were applied in three equal installments, first imposition was carried out after planting, second before one month of flowering and the last application was done before fruiting of dragon fruit plants. Vermicompost contains 2% N, 1% P_2O_5 and 1.5% K_2O. Bio-fertilizers have 5×107 cell/g microbial counts (CFU/g) (Colony farming unites). Vermicompost procured from Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh. The plant normally fruits after 2nd year of planting. Harvesting started from July and continued till October. Dragon fruit is a non-climacteric fruit, so harvesting was done when dragon fruits turned from green to red colour.

The length, diameter, pulp thickness and peel thickness of the fruits were measured using an electronic digital vernier caliper and the average values were expressed in cm. The fruit weight, along with the weight of the pulp and peel, were individually measured using an electronic balance, with results expressed in g. The volume of the fruits was determined using the water displacement method and the average value was recorded in cubic centimeters (cc). Specific gravity was calculated by dividing the fruit's weight (g) by its volume (cc). The number of bracts/fruit was counted manually through visual inspection. Total soluble solids (TSS) were determined using a handheld refractometer (0–32°Brix) and expressed in °Brix. Titratable acidity was calculated as per AOAC (2006). Ascorbic acid content was estimated using a volumetric method with 2,6-dichlorophenol indophenol dye, following the procedure suggested by Ranganna (1977). Reducing sugar was determined using the titrimetric method of Lane and Eynon, as described by Ranganna (1979). For total sugar estimation, the filtrate obtained during reducing sugar estimation was used, with standardized Fehling's solution A and B and a methyl blue indicator and non-reducing sugar content was calculated by subtracting reducing sugar values from total sugar in the fruit pulp, following the methods outlined by AOAC (1980). Non-linear regression analysis was performed to assess the relationship between the treatments and fruit weight (g) as per Kumar *et al.* (2007). The data recorded for various vegetative, flowering, fruiting, yield and quality characters were statistically analyzed as per the method described by Chandel (1984). The significance of treatments was tested through F-test (variance ratio test) and the significance of the difference between any two means was judged with the critical difference (CD) at 5% level of significance.

RESULTS AND DISCUSSION

Length and diameter of fruit: The study revealed significant differences among the treatments regarding the length and diameter of the fruit (Table 1). The highest measurements of fruit length and diameter were recorded as 8.96 cm and 7.55 cm, respectively, from plants treated with a combination of vermicompost (0.5 kg /plant), *Azospirillum* (50 g/plant) and phosphate solubilizing bacteria (50 g/plant). This was followed by plants treated with vermicompost (0.5 kg/plant), *Azotobacter* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant), which produced fruits measuring 8.62 cm in length and 7.37 cm in diameter whereas, the control plants exhibited the lowest values at 7.21 cm and 6.14 cm, which were statistically similar to treatment T_2. The superior performance of the combined treatments over individual or control treatments may be attributed to enhanced microbial activity, improved nutrient availability and better soil moisture retention facilitated by vermicompost and biofertilizers. This synergy enhanced enzymatic activity (e.g. phosphatase and urease), promoting better nutrient uptake and assimilate transport into the fruit, leading to larger dimensions. The results align with findings by Verma *et al.* (2019), Tripathi *et al.* (2017) in strawberry, Dey *et al.* (2022) in dragon fruit and Singh and Tripathi (2020a) in papaya.

Weight and volume of fruit: A significant difference was observed among the treatments concerning fruit weight and volume (Table 1). The highest recorded fruit weight and volume were 205.90 g and 162.33 cc, respectively,

Table 1 Effect of different organic manures and bio-fertilizers on fruit length, fruit diameter, fruit weight, fruit volume, and specific gravity of dragon fruit

Treatment	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Fruit volume (cc)	Specific gravity
T_1, Control	7.21	6.14	105.60	127.67	0.83
T_2, Vermicompost (0.5 kg/plant)	7.27	6.41	136.30	138.83	0.98
T_3, *Azotobacter* (50 g/plant)	7.43	6.62	147.50	150.83	0.98
T_4, *Azospirillum* (50 g/plant)	7.56	6.70	163.63	152.33	1.07
T_5, Phosphate solubilizing bacteria (50 g/plant)	7.48	6.50	150.87	149.80	1.00
T_6, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant)	8.00	7.10	171.80	155.00	1.11
T_7, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant)	8.20	7.15	181.03	155.67	1.16
T_8, Vermicompost (0.5 kg/plant) + Phosphate solubilizing bacteria (50 g/plant)	7.86	6.80	166.13	153.30	1.08
T_9, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + *Azospirillum* (50 g/plant)	8.38	7.31	186.73	156.67	1.19
T_{10}, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant)	8.62	7.37	198.80	159.50	1.25
T_{11}, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant)	8.96	7.55	205.90	162.33	1.27
CD (p=0.05)	0.13	0.10	1.74	1.50	0.01
SEM±	0.04	0.03	0.58	0.51	0.004

from plants treated with a combination of Vermicompost (0.5 kg/plant), *Azospirillum* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant followed by plants applied with Vermicompost (0.5 kg/plant), *Azotobacter* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant), which produced fruits weighing 198.80 g and measuring 159.50 cc while, the control group exhibited the lowest values, with a fruit weight of 105.60 g and a volume of 127.67 cc. The enhanced specific gravity can be attributed to improved nutrient assimilation and better soil physico-chemical properties under the combined treatments, fostering superior fruit quality. These findings align with Singh and Tripathi (2020a) in papaya, Yashasvi *et al.* (2021) in strawberry and Bhadauria and Tripathi (2023b) in mango.

Specific gravity of fruit: The maximum specific gravity (1.27) was recorded in the combined treatment of vermicompost (0.5 kg/plant), *Azospirillum* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant), followed by 1.25 in vermicompost, *Azotobacter* and Phosphate solubilizing bacteria (Table 1). The control group showed the lowest specific gravity (0.83). The enhanced specific gravity can be attributed to improved nutrient assimilation and better soil physico-chemical properties under the combined treatments, fostering superior fruit quality. These findings align with Singh and Tripathi (2020a) in papaya and Yashasvi *et al.* (2021) in strawberry.

Pulp and peel weight: The highest pulp weight (160.55 g) and lowest peel weight (29.84 g) were observed in fruits from plants treated with vermicompost, *Azospirillum* and Phosphate solubilizing bacteria, while the control group recorded the lowest pulp weight (83.90 g) and the highest peel weight (41.59 g). The synergistic action of vermicompost and biofertilizers enhanced nutrient uptake and photosynthetic efficiency, resulting in improved physical fruit attributes. This combination outperformed individual treatments, as evidenced by prior studies on dragon fruit (Verma *et al.* 2019), mango (Bhadauria and Tripathi 2023b) and papaya (Singh and Tripathi 2020a).

Pulp-to-peel ratio: The highest pulp-to-peel ratio (5.38) was recorded in the vermicompost, *Azospirillum* and Phosphate solubilizing bacteria treatment, while the control treatment exhibited the lowest ratio (2.02) (Table 2). This improvement was driven by the combined application, which promoted mesocarp cell division and elongation during early fruit development. Furthermore, thicker peels in treated fruits offer better mechanical protection, enhancing shelf life. These findings are supported by Singh and Tripathi (2020a) in papaya and Bhadauria and Tripathi (2023b) in mango.

Pulp and peel thickness: The maximum pulp thickness (6.84 cm) and minimum peel thickness (0.25 cm) were observed in the vermicompost, *Azospirillum* and Phosphate solubilizing bacteria treatment, followed by vermicompost, *Azotobacter* and Phosphate solubilizing bacteria (6.50 cm and 0.27 cm, respectively). The control treatment yielded the lowest pulp thickness (5.22 cm) and highest peel thickness (0.59 cm). The combined treatment enhanced nutrient

Table 2 Effect of different organic manures and bio-fertilizers on pulp weight, peel weight, pulp: peel ratio, pulp thickness, and number of bracts/fruit of dragon fruit

Treatment	Pulp weight (g)	Peel weight of peel (g)	Pulp: peel ratio	Pulp thickness (cm)	Peel thickness (cm)	Number of bracts/ fruit
T_1, Control	83.90	41.59	2.02	5.22	0.59	24.62
T_2, Vermicompost (0.5 kg/plant)	103.78	41.05	2.53	5.41	0.55	25.37
T_3, *Azotobacter* (50 g/plant)	113.45	38.59	2.94	5.50	0.50	25.44
T_4, *Azospirillum* (50 g/plant)	129.17	35.53	3.64	5.70	0.42	26.51
T_5, Phosphate solubilizing bacteria (50 g/plant)	114.77	37.82	3.03	5.43	0.47	26.70
T_6, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant)	135.40	36.78	3.68	5.94	0.45	26.77
T_7,Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant)	142.45	33.58	4.24	6.07	0.30	26.33
T_8, Vermicompost (0.5 kg/plant) + Phosphate solubilizing bacteria (50 g/plant)	131.37	34.73	3.78	5.77	0.38	25.77
T_9,Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) +*Azospirillum* (50 g/plant)	147.44	34.38	4.29	6.24	0.35	27.10
T_{10}, Vermicompost (0.5 kg/plant) + *Azotobacter* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant)	157.41	32.42	4.86	6.50	0.27	28.44
T_{11}, Vermicompost (0.5 kg/plant) + *Azospirillum* (50 g/plant) + Phosphate solubilizing bacteria (50 g/plant)	160.55	29.84	5.38	6.84	0.25	30.99
CD (p=0.05)	1.24	0.22	0.03	0.11	0.010	0.57
SEM±	0.42	0.08	0.01	0.04	0.003	0.19

availability, optimizing soil conditions and promoting better plant growth. Similar findings were reported by Dey *et al.* (2022) in dragon fruit and Singh and Tripathi (2020a) in papaya.

Number of bracts/fruit: The maximum number of bracts (30.99) was recorded in plants treated with vermicompost, *Azospirillum* and Phosphate solubilizing bacteria, followed by vermicompost, *Azotobacter* and Phosphate solubilizing bacteria (28.44), with the control group producing the fewest bracts (24.62) (Table 2). This improvement in bract number demonstrates the role of combined treatments in fostering reproductive growth, consistent with the findings of Dey *et al.* (2022) in dragon fruit.

Total soluble solids and total sugars: The highest TSS (14.80 °Brix) and total sugars (9.40%) were observed in the vermicompost, *Azospirillum* and Phosphate solubilizing bacteria treatment, followed closely by vermicompost, *Azotobacter* and Phosphate solubilizing bacteria with 14.57 °Brix and 9.30%, respectively. The control group recorded the lowest TSS (10.56 °Brix) and total sugars (8.23%) (Fig. 1A, B). This enhancement in biochemical properties may be due to improved carbohydrate metabolism and nutrient translocation resulting from the synergistic action of vermicompost and biofertilizers. These results align with studies by Verma *et al.* (2019) in dragon fruit, Tripathi *et al.* (2017) in strawberry, Mishra and Tripathi (2011) in strawberry and Singh and Tripathi (2020b) in papaya.

Titratable acidity: The highest titratable acidity (0.39%) was observed in fruits treated with the combination of vermicompost (0.5 kg/plant), *Azospirillum* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant), which was statistically similar to the acidity (0.36%) recorded in fruits from vermicompost, *Azotobacter* and Phosphate solubilizing bacteria treatments. In contrast, the control group exhibited the lowest value of 0.22% (Fig. 1C). The combined use of vermicompost and biofertilizers provided a synergistic effect by improving soil microbial activity and nutrient availability, which likely facilitated the efficient conversion of organic acids to sugars via glycolytic and respiratory pathways. This enhanced effect was more pronounced than when either vermicompost or biofertilizers were applied individually, underscoring their complementary roles in improving soil health and plant metabolism. Similar results have been reported by Perween and Hasan (2019) in dragon fruit, Tripathi *et al.* (2017) and Awasthi *et al.* (2021) in strawberry.

Ascorbic acid: The highest ascorbic acid content (9.42 mg/100 g) was recorded in fruits treated with the combination of vermicompost, *Azospirillum* and Phosphate solubilizing bacteria followed closely by 9.25 mg/100 g in fruits from vermicompost, *Azotobacter* and Phosphate solubilizing bacteria treatments. The lowest value of 8.15

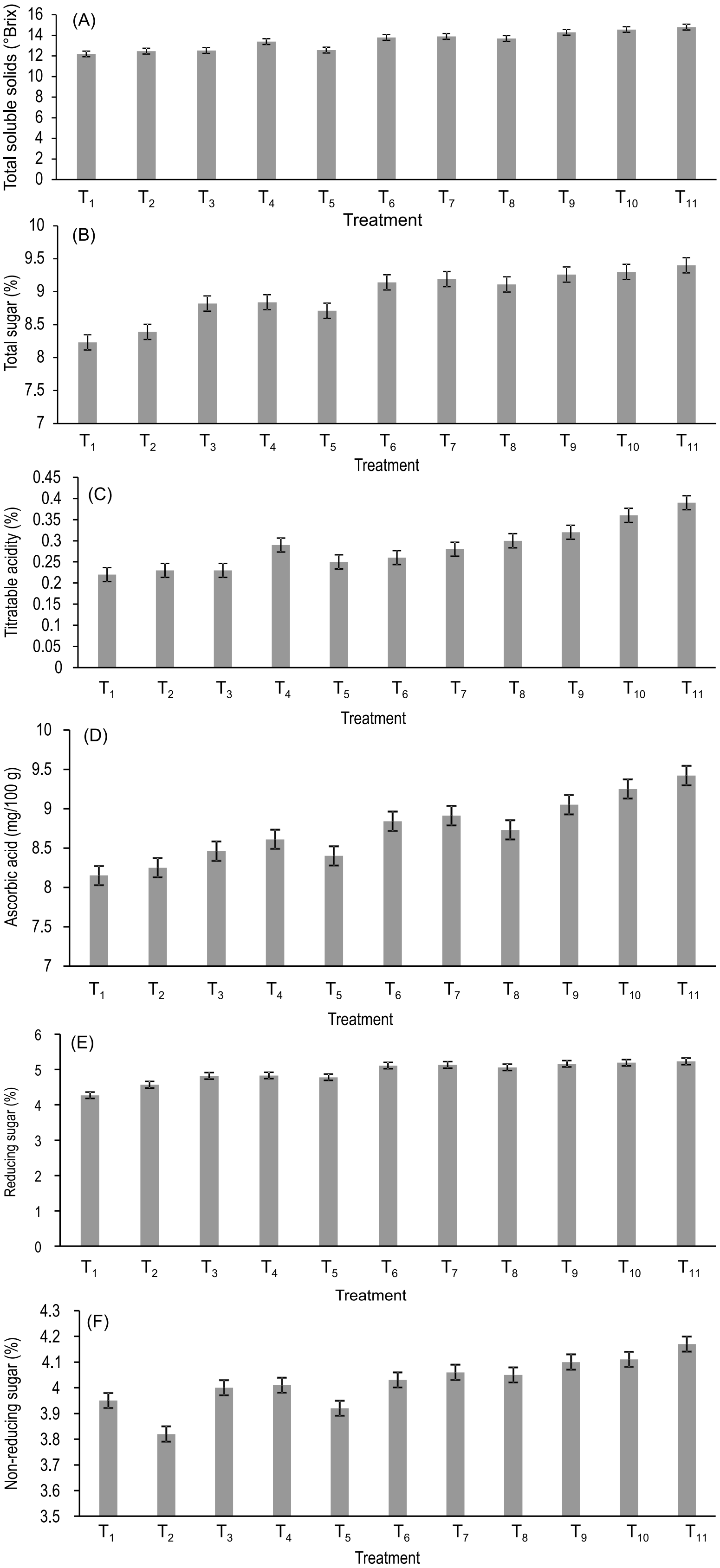

Fig. 1 Effect of various organic manure and biofertilizers on (A) Total soluble solids (°Brix); (B) Total sugar content; (C) Titratable acidity; (D) Ascorbic acid content; (E) Reducing sugar content; (F) Non-reducing sugar content of dragon fruit.
Treatment details are given under Materials and Methods.

mg/100 g was found in the control group (Fig. 1D). The combination of organic and microbial inputs significantly improved nutrient availability in the rhizosphere, thereby enhancing the biosynthesis of ascorbic acid. The joint application also ensured a steady supply of growth-promoting substances and nutrients, leading to superior ascorbic acid accumulation compared to treatments with standalone components. These findings are in agreement with those of Tripathi *et al.* (2015) and Kumar and Tripathi (2020) in strawberry.

Reducing sugar: The treatment combining vermicompost, *Azospirillum* and Phosphate solubilizing bacteria recorded the highest reducing sugar content (5.23%), followed by vermicompost with *Azotobacter* and Phosphate solubilizing bacteria (5.19%). The lowest reducing sugar content (4.27%) was observed in the control (Fig. 1E). The synergistic effect of vermicompost and biofertilizers likely enhanced carbohydrate metabolism through improved enzymatic activity and nutrient uptake. The combination proved more effective than individual applications by fostering better moisture retention, microbial diversity and metabolic activity, ultimately contributing to higher sugar content. These results are consistent with those of Perween and Hasan (2019) in dragon fruit.

Non-reducing sugar: The maximum non-reducing sugar (4.17%) was recorded in the treatment involving vermicompost, *Azospirillum* and Phosphate solubilizing bacteria, with comparable values in other biofertilizer combinations, such as vermicompost with *Azotobacter* and Phosphate solubilizing bacteria (4.11%). The control group exhibited the lowest content (3.95%) (Fig. 1F). The combined application enabled better nutrient assimilation and efficient conversion of starches to sugars during fruit ripening, emphasizing the superior efficacy of integrated treatments over individual inputs. These findings align with studies by Bhadauria and Tripathi (2023a) in mango. The integration of vermicompost with biofertilizers like *Azospirillum*, *Azotobacter* and Phosphate solubilizing bacteria significantly outperformed their standalone use due to complementary mechanisms. Vermicompost enriched the soil with organic matter and nutrients while improving its moisture-holding capacity. Biofertilizers enhanced microbial diversity and enzymatic activity, facilitating the uptake of macro- and micronutrients (Srivastava *et al.* 2021). This combination provided a stable

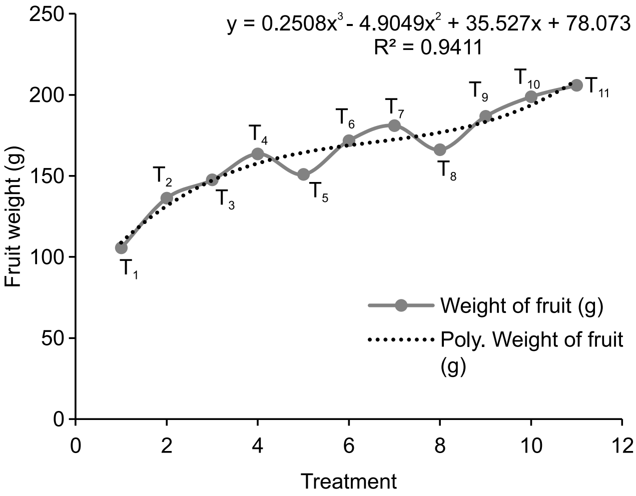

Fig. 2 Relationship between various organic manure and biofertilizers on the fruit weight of dragon fruit. Treatment details are given under Materials and Methods.

supply of growth-promoting substances, leading to improved fruit quality traits such as higher titratable acidity, ascorbic acid and sugar content. The synergistic effects of the treatments underscore the importance of adopting integrated nutrient management practices for sustainable and enhanced crop productivity (Rani *et al.* 2024, Wangchu *et al.* 2024).

Correlation analysis: The non-linear regression analysis between fruit weight and applied treatments revealed a robust determination coefficient ($R^2 = 0.94$) (Fig. 2). This highlights the significant role of combined treatments in enhancing fruit weight and overall quality, as also supported by Kumar *et al.* (2007).

The findings of the present experiment demonstrated that the integrated use of vermicompost and biofertilizers had a profound and positive impact on both the physical and chemical attributes of dragon fruit. Key parameters such as fruit length, diameter, weight, volume, specific gravity, pulp and peel weights, pulp-to-peel ratio, pulp and peel thickness and the number of bracts/fruit were all significantly enhanced. Moreover, chemical characteristics, including total soluble solids, titratable acidity, ascorbic acid content, total sugars, reducing sugars and non-reducing sugars, also showed considerable improvement. The optimal combination of vermicompost (0.5 kg/plant), *Azospirillum* (50 g/plant) and Phosphate solubilizing bacteria (50 g/plant) proved to be highly effective in promoting the overall quality and productivity of dragon fruit cultivated in the Northern Plains of India. This suggests that the integration of organic and biological inputs can play a crucial role in achieving sustainable and enhanced crop production.

Future research should assess the long-term effect of vermicompost and biofertilizers on soil health, subsequent crop cycles and yield sustainability. Studies on scalability, economic feasibility and climate resilience along with testing their efficacy across crops and agro-climatic zone, are essential. Additionally, optimizing nutrient dynamics and plant synchronization will enhance these sustainable practices.

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