

Original Research Paper

Effects of formulations on growth, yield and fruit quality of red dragon fruit (*Selenicereus costaricensis*) under sodic soil

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ABSTRACT

Natural farming relies on local organic inputs and fermented bioformulations to offer a sustainable nutrient management strategy for constrained soils. The present study was carried out to assess the seven natural farming combinations to determine their influence on the flowering, yield, and quality of red dragon fruit grown in sodic soil, laid out in randomized block design with three replications, during 2023-24 and 2024-25. The treatments paired either farmyard manure or vermicompost with *Panchagavya*, *Amritpani*, or *Jeevamrit* alongside an untreated control. The vermicompost + *Panchagavya* combination emerged as the top performer, consistently producing the highest number of flowers per plant (46.77), yield per pole (6.47 kg), total soluble solids (14.68 °Brix), vitamin C (14.09 mg 100 g⁻¹), and reducing sugars (9.75%). As the year × treatment interaction was non-significant, treatment trends remained stable over both seasons. These findings demonstrate that combining vermicompost with *Panchagavya* enhances red dragon fruit productivity and fruit quality in sodic soils, though multi-year research tracking soil physicochemical and biological shifts is required to uncover the underlying mechanisms.

Keywords: Dragon fruit, farmyard manure, natural farming, *panchagavya*, sodic soil, vermicompost

INTRODUCTION

Dragon fruit (*Selenicereus* spp.), a climbing cactus native to tropical America, has developed from a niche exotic fruit into a high-value horticultural crop in tropical and subtropical regions (Mercado-Silva 2018). Its attractive appearance and nutritionally important constituents, including betalains, vitamin C, and polyphenols, have contributed to increasing consumer interest (Kakade et al., 2020). Dragon fruit is also emerging as a promising high-value crop in India. The crop is adapted to seasonally dry tropical environments and has comparatively low water requirements, making it potentially suitable for diversification in water-limited production systems.

Conventional fruit production systems frequently depend on readily soluble mineral fertilizers to sustain yield and fruit quality. On the other hand, applying organic amendments helps build soil organic matter, retains crucial nutrients, and stimulates underground

biological activity. For dragon fruit cultivation specifically, research indicates that using vermicompost and combined organic nutrient programs can significantly boost growth and final harvest yields (Verma et al., 2019; Laldusangi & Mandal, 2021; Dey et al., 2022; Chauhan et al., 2024). Furthermore, evidence suggests that natural farming practices can enhance overall soil conditions and output depending on the local environment (Duddigan et al., 2023).

Natural farming approaches in India commonly use fermented bio-inputs such as *Jeevamrit* and *Panchagavya* together with organic manures, mulching, and soil-moisture management. *Jeevamrit* is prepared from cow dung, cow urine, pulse flour, jaggery, and soil, whereas *Panchagavya* is a fermented preparation based on cow-derived ingredients. These inputs are intended to supplement organic carbon, nutrients, and biologically active components in the rhizosphere. Vermicompost and FYM provide



additional organic matter and plant nutrients and may improve soil aggregation and water-holding capacity (Saharan et al., 2023).

Although organic and integrated nutrient-management practices have been evaluated in dragon fruit, information on combinations of vermicompost or FYM with fermented natural-farming formulations under sodic soil conditions remains limited. The present study was therefore undertaken to evaluate the effects of FYM and vermicompost in combination with *Panchagavya*, *Amritpani*, and *Jeevamrit* on flowering, fruiting, yield, and fruit biochemical quality of red dragon fruit under sodic soil conditions of the middle Gangetic plains.

MATERIALS AND METHODS

The experiment was conducted at the Main Experimental Station, Department of Fruit Science, College of Horticulture and Forestry, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India (26°47'00" N latitude and 82°12'00" E longitude; altitude 113 m above mean sea level) during 2023-24 and 2024-25. The region falls under the semi-arid to sub-humid climatic zone with annual rainfall of approximately 1050 mm, mostly received during June–September. The experimental soil was sodic in nature characterized by a pH>8.5, electrical conductivity (0.67 dS m⁻¹), exchangeable sodium (15%) and organic carbon content (1.24%). The experiment was laid out in randomized block design with seven treatments and three replications. Each experimental unit consisted of one cement pole supporting four dragon fruit plants, which were trained vertically using circular support rings (diameter approximately 61 cm). The plants were established at a spacing of 2 m × 3 m. Each treatment was represented by one pole (four plants) in each

replication, with three replications. Thus, each treatment comprised three poles and 12 plants, resulting in a total of 21 poles in the experiment. Treatments comprised: T₁: control, T₂: FYM + *Panchagavya*, T₃: FYM + *Amritpani*, T₄: FYM + *Jeevamrit*, T₅: vermicompost + *Panchagavya*, T₆: vermicompost + *Amritpani* and T₇: vermicompost + *Jeevamrit*.

FYM and vermicompost were applied at a rate of 10 kg pole⁻¹ per application, twice a year, with the first application during the last week of December and the second during the last week of March. *Panchagavya*, *Amritpani*, and *Jeevamrit* were applied individually as 30% (v/v) aqueous solutions through soil drenching at a rate of 10 L plant⁻¹ application⁻¹ at two-month intervals. For preparing 10 L of a 30% (v/v) solution, 3 L of the respective formulation was diluted with water to a final volume of 10 L, following (Saharan et al., 2023). Observations were recorded from all four plants supported by each pole.

Data were subjected to analysis of variance (ANOVA) following Panse & Sukhatme (1985), with experimental year considered Factor A and treatment (T1–T7) Factor B. Treatment means were compared using Fisher's protected least significant difference (LSD) test at $p \leq 0.05$ when the corresponding F-test was significant. The year × treatment interaction was also tested to determine whether treatment responses differed between experimental years. The biochemical traits evaluated were total soluble solids (TSS), vitamin C (VITC), titratable acidity (TTC), reducing sugars (RDS), non-reducing sugars (NRDS), and total sugars (TS).

RESULTS AND DISCUSSION

Natural farming formulations produced significant differences in several flowering, fruiting, yield, and biochemical attributes of red dragon fruit grown under sodic soil conditions. Year-wise comparison showed

Table 1 : Year-wise variation in flowering, fruiting, and yield attributes of red dragon fruit under sodic soil conditions

Year (A)	NF	FL	FW	FTL	FTW	FLWR	FTD	DWBB	NBPF	LEAB	WFBB	YPP
1	30.14	28.25	4.31	9.51	7.71 ^b	1.30	22.37	3.72	36.19	3.09 ^b	2.90	4.70
2	30.23	28.36	4.26	9.72	8.47 ^a	1.31	22.70	3.83	38.81	3.44 ^a	3.15	4.72
F stat	0.07 ^{NS}	0.12 ^{NS}	0.16 ^{NS}	1.26 ^{NS}	7.27 ^{**}	0.21 ^{NS}	1.39 ^{NS}	1.15 ^{NS}	1.14 ^{NS}	5.75 [*]	3.97 ^{NS}	0.05 ^{NS}
p value	0.79	0.73	0.69	0.27	0.01	0.65	0.25	0.29	0.30	0.02	0.06	0.83
LSD ($p \leq 0.05$)	-	-	-	-	0.58	-	-	-	-	0.31	-	-

*significance at 5% level, ** significance at 1% level, NS non-significance

Table 2 : Effect of natural farming formulations on flowering, fruiting, and yield attributes of red dragon fruit under sodic soil conditions

Treatment (B)	NF	FL	FW	FTL	FTW	FLWR	FTD	DWBB	NBPF	LFAB	WFBB	YPP
T ₁ : Control	15.80 ^f	28.19 ^b	4.24	8.84 ^b	7.01	1.35	19.78 ^d	3.65	35.17	2.97	2.75	1.79I ^e
T ₂ : FYM + <i>Panchagavya</i>	25.33 ^d	28.13 ^b	4.47	9.94 ^a	8.37	1.26	22.93 ^{abc}	3.75	37.17	3.16	2.93	3.70H ^d
T ₃ : FYM + <i>Amritpani</i>	18.20 ^e	27.90 ^b	4.17	9.29 ^{ab}	8.31	1.34	23.59 ^{ab}	3.81	35.67	3.10	2.93	3.52H ^d
T ₄ : FYM + <i>Jeevamrit</i>	25.85 ^d	28.25 ^b	4.26	9.72 ^a	8.15	1.28	22.47 ^c	3.65	37.33	3.43	3.34	5.36 ^{ac}
T ₅ : vermicompost + <i>Panchagavya</i>	46.77 ^a	29.70 ^a	4.56	10.00 ^a	8.65	1.35	23.78 ^a	3.92	42.00	3.55	3.25	6.47C ^a
T ₆ : vermicompost + <i>Amritpani</i>	41.15 ^b	27.88 ^b	4.08	9.64 ^a	7.93	1.24	22.50 ^c	3.93	37.67	3.50	3.21	6.17G ^b
T ₇ : vermicompost + <i>Jeevamrit</i>	38.20 ^c	28.10 ^b	4.21	9.88 ^a	8.19	1.33	22.70 ^{bc}	3.74	37.50	3.15	2.80	5.99G ^b
F stat	777.37**	2.48 *	1.08 NS	2.67 *	1.98 NS	2.18 NS	12.86 **	0.75 NS	0.46 NS	1.30 NS	2.05 NS	314.45 **
p value	<0.001	0.05	0.40	0.04	0.10	0.08	<0.001	0.61	0.83	0.29	0.09	<0.001
LSD (p ≤ 0.05)	1.24	1.16	-	0.74	-	-	1.07	-	-	-	-	0.29

*significance at 5% level; ** significance at 1% level; NS non-significance

NF: Number of flowers; FL: Flower length (cm); FW: Flower width (cm); FTL: Fruit length (cm); FTW: Fruit width (cm); FLWR: Fruit length: width ratio; FTD: Fruit circumference (cm); DWBB: Distance between bract to bract (mm); NBPF: Number of bracts per fruit; LFAB: Length of fruit apical bracts (cm); WFBB: Width of fruit basal bracts (cm); YPP: Yield per Pole (kg)

that most flowering, fruiting, and yield attributes remained statistically stable between the two experimental years (Table 1). Fruit width increased significantly from 7.71 in year 1 to 8.47 in year 2, while LFAB increased from 3.09 to 3.44. In contrast, NF, FL, FW, FTL, FLWR, FTD, DWBB, NBPF, WFBB, and YPP did not differ significantly between years. Yield per pole was statistically stable, averaging 4.70 and 4.72 kg pole⁻¹ in years 1 and 2, respectively.

Treatment means revealed a pronounced response of reproductive performance to the natural farming formulations (Table 2). The maximum number of flowers was recorded under T₅ (Vermicompost + *Panchagavya*) with 46.77 flowers plant⁻¹, which was significantly superior to all other treatments, followed by T₆ (41.15) and T₇ (38.20), whereas the control (T₁) produced only 15.80 flowers plant⁻¹. Thus, T₅ produced nearly three times as many flowers as the control. Flower length was also greatest under T₅ (29.70 cm), compared with T₁ 28.19 cm.

The superior flowering response under T₅ may be associated with the complementary effects of vermicompost and *Panchagavya*. Vermicompost provides gradually mineralizable nutrients, humic substances, and a biologically active organic matrix, whereas fermented liquid formulations may provide readily available nutrients and bioactive metabolites. Such conditions may favor nutrient acquisition and

reproductive development. Beneficial effects of liquid organic formulations and integrated organic nutrient management on flowering and plant performance have also been reported by Sreenivasa et al. (2010), Brar et al. (2020) and Verma et al. (2019).

Fruit dimensions also responded to the treatments. Fruit length was highest in T₂ (10.00 cm), followed by T₄ (9.94 cm), T₇ (9.88 cm), T₄ (9.72 cm), and T₆ (9.64 cm), whereas, T₁ recorded the minimum value (8.84 cm). Similarly, the maximum fruit circumference was recorded under T₅ (23.78 cm), which was statistically on par with T₂ and T₅, while, T₁ recorded the lowest fruit circumference (19.78 cm). In contrast, FW, FTW, FLWR, DWBB, NBPF, LFAB, and WFBB showed no significant treatment differences (Table 2). The enhancement of fruit dimensions under organic formulations may be associated with improved nutrient availability throughout fruit development. Organic amendments can enhance soil physical properties and nutrient retention, while their gradual mineralization may provide a sustained nutrient supply during fruit growth. Similar improvements in fruit growth and physical characteristics following organic nutrient management have been reported in dragon fruit (Verma et al., 2019; Dey et al., 2022; Chauhan et al., 2024).

Yield per pole exhibited one of the strongest treatment responses (Table 2). T₅ produced maximum

Table 3 : Year-wise variation in biochemical fruit-quality traits of red dragon fruit under sodic soil conditions

Year (A)	TSS	VITC	TTC	RDS	NRDS	TS
1	14.05	13.05	0.23	9.13	1.77	10.90
2	14.14	13.02	0.26	9.27	1.79	11.05
F stat	0.59 ^{NS}	0.03 ^{NS}	2.05 ^{NS}	1.06 ^{NS}	1.07 ^{NS}	1.17 ^{NS}
p value	0.45	0.86	0.16	0.31	0.31	0.29
LSD ($p \leq 0.05$)	-	-	-	-	-	-

* significance at 5% level; ** significance at 1% level; NS non-significance

Table 4 : Effect of natural farming formulations on biochemical fruit-quality traits of red dragon fruit under sodic soil conditions

Treatment (B)	TSS	VITC	TTC	RDS	NRDS	TS
T ¹ : Control	13.32 ^d	11.38 ^d	0.25	8.46 ^d	1.50 ^e	9.96 ^d
T ² : FYM + <i>Panchagavya</i>	13.79 ^{cd}	13.41 ^{ab}	0.24	9.66 ^{ab}	1.90 ^a	11.56 ^a
T ³ : FYM + <i>Amritpani</i>	14.27 ^{abc}	13.05 ^{bc}	0.25	9.04 ^c	1.78 ^c	10.76 ^c
T ⁴ : FYM + <i>Jeevamrit</i>	14.44 ^{ab}	13.29 ^b	0.24	9.22 ^{bc}	1.81 ^{bc}	11.05 ^{abc}
T ⁵ : vermicompost + <i>Panchagavya</i>	14.68 ^a	14.09 ^a	0.28	9.75 ^a	1.66 ^d	11.40 ^{ab}
T ⁶ : vermicompost + <i>Amritpani</i>	14.17 ^{bc}	13.59 ^{ab}	0.19	8.98 ^c	1.93 ^a	10.92 ^{bc}
T ⁷ : vermicompost + <i>Jeevamrit</i>	14.00 ^{bc}	12.43 ^c	0.24	9.29 ^{abc}	1.89 ^{ab}	11.18 ^{abc}
F stat	7.12 **	10.55**	0.91 ^{NS}	6.26 **	26.01**	8.68 **
p value	<0.001	<0.001	0.50	<0.001	<0.001	<0.001
LSD ($p \leq 0.05$)	0.49	0.79	-	0.51	0.09	0.51

*significance at 5% level, ** significance at 1% level, NS non-significance; TSS: Total soluble solids (%); VITC: Vitamin C (mg 100 g⁻¹); TTC: Titratable acidity (%); RDS: Reducing sugars (%); NRDS: Non-reducing sugars (%); TS: Total sugars (%)

pooled yield (6.47 kg pole⁻¹), followed by T₆ (6.17 kg pole⁻¹) and T₇ (5.99 kg pole⁻¹), while, control (T₁) recorded the minimum yield (1.79 kg pole⁻¹). Thus, T₅ produced approximately 3.6-fold greater yield than the untreated control. The yield advantage of T₅ was accompanied by its exceptionally high flower number and improved fruit dimensions, suggesting that the combined improvement of reproductive attributes contributed to greater productivity. The integration of vermicompost with *Panchagavya* may provide a more synchronized nutrient supply than either the untreated control or FYM-based combinations. Dey et al. (2022) observed beneficial effects of vermicompost on dragon fruit, while, Chauhan et al. (2024) reported improvements in growth, yield, and quality of dragon fruit following the application of organic manures and biofertilizers.

Biochemical fruit-quality response

Biochemical fruit-quality traits also responded markedly to natural farming formulations. ANOVA showed highly significant treatment effects for TSS, vitamin C (VITC), reducing sugars (RDS), non-reducing sugars (NRDS), and total sugars (TS), whereas titratable acidity (TTC) was not significantly influenced by treatment (Table 4). Neither year nor year $\times$ treatment interaction significantly affected any of the biochemical traits.

The absence of significant year effects was also evident from the year-wise means (Table 3). TSS averaged 14.05 and 14.14 °Brix in years 1 and 2, respectively, while, vitamin C averaged 13.05 and 13.02 mg 100 g⁻¹. Likewise, reducing sugars (9.13 and 9.27%), non-reducing sugars (1.77 and 1.79%), and

total sugars (10.90 and 11.05%) remained statistically comparable between years. This stability indicates that the biochemical quality of the fruits was influenced predominantly by treatment rather than seasonal variation during the experimental period.

Treatment-wise comparison showed substantial differences in fruit quality (Table 4). T_5 recorded the maximum TSS (14.68 °Brix), followed by T_4 (14.44 °Brix), T_6 (14.27 °Brix), and T_6 (14.17 °Brix), whereas the lowest TSS was observed in T_1 (13.32 °Brix). Maximum vitamin recorded under T_5 (14.09 mg 100 g⁻¹), whereas it was recorded minimum in T_1 (11.38 mg 100 g⁻¹). The improvement in TSS and vitamin C under organic formulations may

be related to improved nutritional status and carbon assimilation, which can influence the accumulation of soluble solids and antioxidant metabolites in developing fruits (Sharma et al., 2013; Dey et al., 2022; Chauhan et al., 2024).

Reducing sugars were highest under T_5 (9.75%), statistically on par with T_2 , (9.66%) and T_7 (9.29%), whereas, the control recorded the lowest value (8.46%). A somewhat different pattern was observed for NRDS: T_6 recorded the maximum value (1.93%), statistically on par with T_2 (1.90%) and T_7 (1.89%), while, T_1 had the minimum (1.50%) (Table 4). Importantly, the numerically highest total sugar content was recorded under T_2 (11.56%),

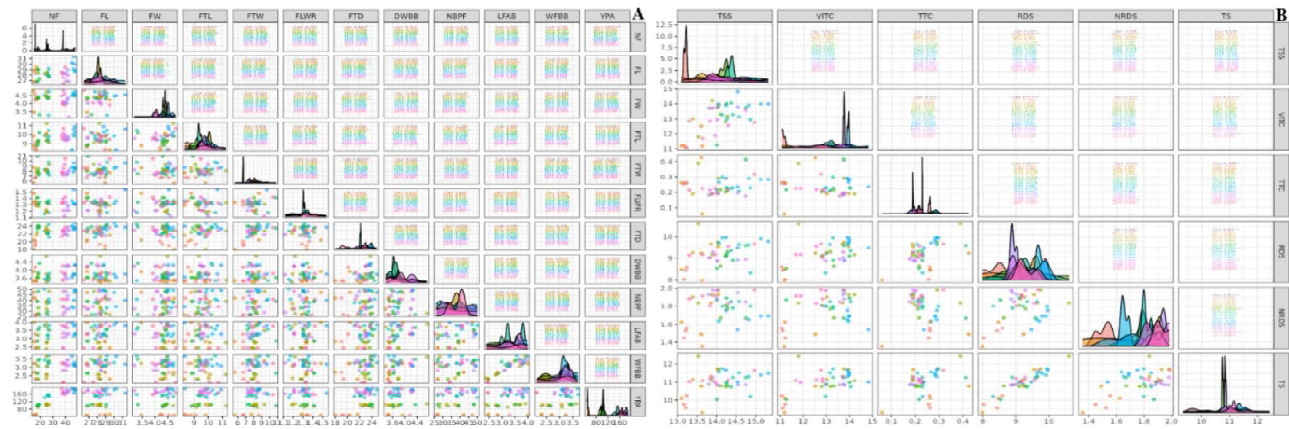


Fig. 1 : Correlation analysis of morphological (A) and biochemical (B) traits in red dragon fruit

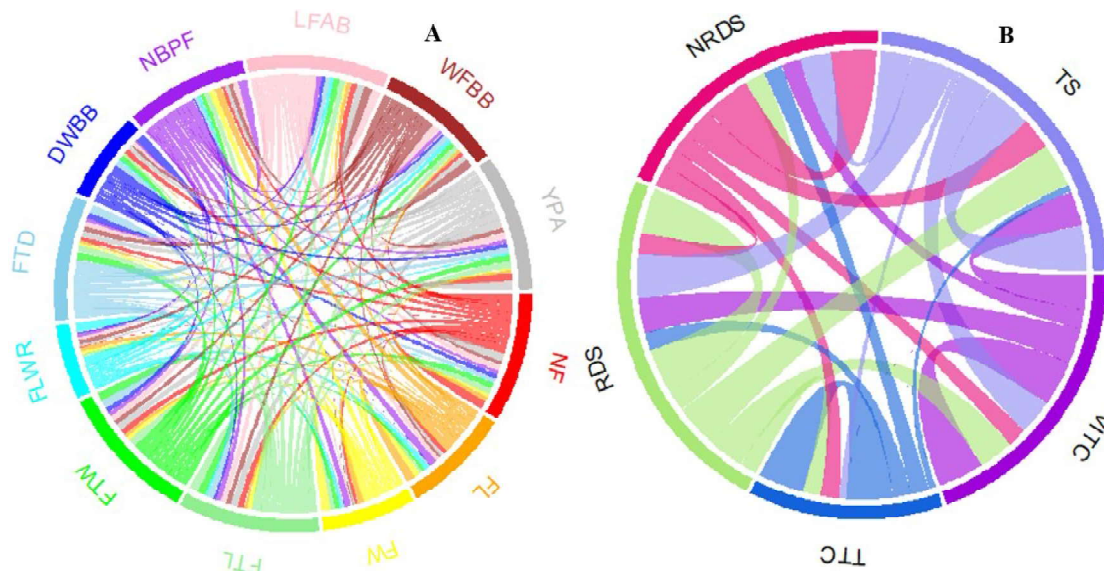


Fig. 2 : Chord diagrams showing inter-trait correlations in red dragon fruit: A. growth and yield attributes and B. fruit quality parameters

Ribbons represent correlations ($|r| \leq 0.60$), with ribbon width indicating the strength of association between traits

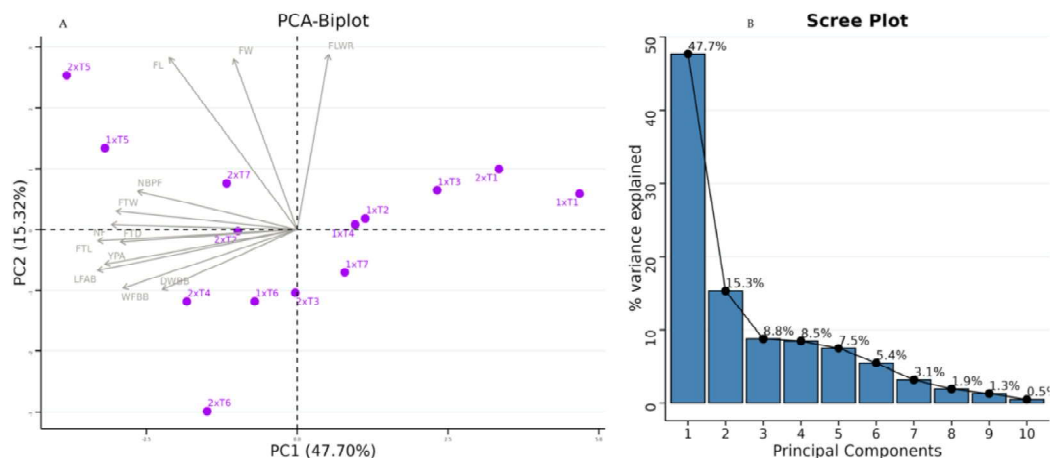


Fig. 3 : Principal component analysis biplot showing multivariate relationships among morphological and yield-related traits of red dragon fruit

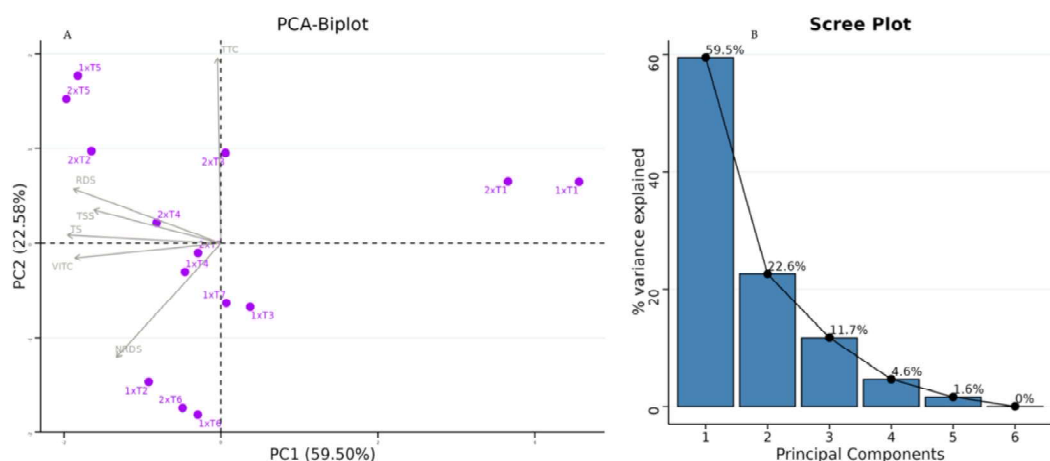


Fig. 4 : Principal component analysis for biochemical fruit-quality traits of red dragon fruit

rather than T_7 . However, T_2 was statistically on par with T_5 (11.40%), T_7 (11.18%) and T_4 (11.05%). This indicates that *Panchagavya* combined with either FYM or vermicompost favored sugar accumulation, although vermicompost + *Panchagavya* produced a more consistent overall advantage across TSS, vitamin C and reducing sugars.

Titrateable acidity ranged from 0.19 to 0.28% but did not differ significantly among treatments. Numerically, T_6 recorded the lowest acidity (0.19%), whereas, T_5 recorded the highest value (0.28%). Therefore, the improvement in sweetness-related quality attributes was associated primarily with greater soluble solids and sugar accumulation rather than a statistically significant reduction in fruit acidity. The improvement in biochemical quality following organic amendments may reflect more favorable nutrient availability and carbon allocation to developing fruits. Fermented

organic formulations and vermicompost have been reported to influence soil biological activity and nutrient mineralization (Sreenivasa et al., 2010; Saharan et al., 2023; Duddigan et al., 2023). Such effects could indirectly favor carbohydrate accumulation and antioxidant metabolism.

Correlation and multivariate analysis

Correlation analysis revealed distinct associations among morphological, yield, and biochemical traits of red dragon fruit (Fig. 1), indicating coordinated variation among fruit-development and quality attributes. Similar relationships among fruit traits have been reported in pitahaya germplasm (Grimaldo-Juarez et al., 2007; Santos-Pelaez et al., 2024). The chord diagrams further highlighted the strongest inter-trait relationships ($|r| \geq 0.60$) among morphological and biochemical variables (Fig. 2), supporting the interconnected nature of fruit development and quality.

Principal component analysis (PCA) effectively summarized treatment-related multivariate variation. The morphological PCA differentiated treatments based on their association with reproductive and yield-related traits (Fig. 3), consistent with previous multivariate characterization of pitahaya germplasm (Grimaldo-Juarez et al., 2007; Santos-Pelaez et al. 2024). Similarly, biochemical PCA separated treatments according to their overall fruit-quality profiles (Fig. 4). Comparable PCA-based differentiation involving sugars and other biochemical attributes has been reported in pitahaya (Attar et al., 2022; Huang et al., 2026).

CONCLUSION

The present study demonstrated that natural farming formulations significantly improved the productivity and fruit quality of red dragon fruit under sodic soil conditions. Among the evaluated treatments, T⁵ (vermicompost + *Panchagavya*) exhibited the most consistent overall performance, recording the highest number of flowers (46.77 plant⁻¹), yield (6.47 kg pole⁻¹), total soluble solids (14.68 °Brix), vitamin C (14.09 mg 100 g⁻¹), and reducing sugars (9.75%), with yield approximately 3.6-fold higher than the untreated control. The non-significant year × treatment interactions indicated that treatment responses were generally consistent across the two experimental years. Overall, the findings suggest that the combined application of vermicompost and *Panchagavya* is a promising natural farming strategy for enhancing dragon fruit productivity and fruit quality under the tested sodic-soil conditions.

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