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Effect of NPK fertilizer application on growth and yield of dragon fruit in Kerala

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Abstract

A field experiment was conducted to evaluate the impact of four fertilizer treatments on the growth, flowering, yield, and fruit quality of dragon fruit (*Hylocereus* spp.). The treatments included three levels of NPK fertilization—T₁ (N 337.5 g: P₂O₅ 262.5 g: K₂O 225 g per pole), T₂ (N 225 g: P₂O₅ 175 g: K₂O 150 g per pole), T₃ (N 112.5 g: P₂O₅ 87.5 g: K₂O 75 g per pole) and a control (T₄) with no fertilizer application. Results revealed significant differences among the treatments in all evaluated parameters. T₁ and T₃ consistently outperformed the other treatments, with T₁ excelling in fruit weight, pulp weight, shelf life, and number of flushes, while T₃ showed superior flower production, monthly flower and fruit count, and anthocyanin and sugar content. Although T₂ promoted early flowering and higher chlorophyll and carotenoid levels, it underperformed in yield and fruit quality. The control treatment (T₄) recorded the highest TSS and seed count, likely due to reduced fruit size and moisture content. Sensory evaluation favoured T₃ and T₄, with T₃ offering the best combination of yield and sensory quality. Season 2 outyielded Season 1, likely due to more effective nutrient uptake from timely split fertilizer applications. Overall, T₁ is recommended for maximizing yield and postharvest quality, while T₃ is suitable for enhancing flowering and fruit biochemical traits.

Keywords: *Hylocereus*, dragon fruit, nutrient management, fertilizer application

Introduction

Dragon fruit (*Hylocereus* spp.) is a perennial climbing vine from the Cactaceae family. In some countries, it is commonly referred to as pitaya or pitahaya (Britton and Rose, 1920) ^[1]. Presently, dragon fruit is regarded as one of the potential future fruit crops of Kerala owing to the increasing health consciousness of Keralites. Even though the cultivation of dragon fruit has gained momentum, scientific production technologies are lacking and farmers are adopting their own management practices. Proper production technology for crops is essential for increasing productivity, conserving resources, improving quality, mitigating risks, promoting sustainability, adapting to climate change, and fostering economic development.

Turcios and Miranda (1998) ^[2] examined the impact of nitrogen and phosphorus dosages on the cultivation of *Hylocereus undatus*. The application of nitrogen at 40 kg ha⁻¹ and 80 kg ha⁻¹ significantly increased fruit count per plant and total yield over three consecutive years. Meanwhile, phosphorus at 20 and 40 kg ha⁻¹ influenced the first and second harvests. The study also assessed the effects of potassium (10 kg ha⁻¹) and micronutrients (5 kg B, 10 kg Cu, 10 kg Zn, and 5 kg Mn per hectare), which became evident from third year onward.

Under Vietnamese conditions, Tri *et al.* (2000) ^[3] recommended applying 540 g of nitrogen, 720 g of phosphorus, 300 g of potassium, and 20 kg of manure per plant annually, as four splits for three-year-old plants. Zee *et al.* (2004) ^[4] suggested a fertilizer regime in Taiwan that involved applying 9 pounds of well-composted steer manure per plant every four months, beginning from April, supplemented with 3.5 ounces per plant of a commercial 13-13-13 fertilizer. Bellec *et al.* (2006) ^[5] reported that dragon fruit possesses a shallow root system capable of absorbing even small quantities of nutrients and hence, combining mineral nutrients with organic inputs was found to be advantageous. To enhance fruit production, Rahim *et al.* (2009) ^[6] recommended application of 40 kg of cow dung, along with 50 g of urea, 100 g of TSP (triple superphosphate),

100 g of MoP (muriate of potash), 100 g of gypsum, and 10 g of borax per planting pit.

Thohirah *et al.* (2009) ^[7] investigated the impact of application of potassium on yield improvement in dragon fruit and proposed an application rate of 71.4 g of potassium per plant per year. Liaotrakoon (2013) ^[8] highlighted that the nutritional composition of dragon fruit varied based on species, origin, and time of harvest. In a fertilizer trial conducted in Bangladesh, it was observed that the application of NPK fertilizers at the rate of N 540 g, P₂O₅ 310 g, and K₂O 250 g per plant enhanced fruit length, width, fruit weight, and yield (Chakma *et al.*, 2014) ^[9]. Karunakaran *et al.* (2014) ^[10] observed that applying 100 g of NPK (19-19-19) every three to four months, along with organic manure, produced beneficial results. Tran *et al.* (2015) ^[11] detailed a fertilizer schedule in Vietnam wherein a basal dose of 10-20 kg decomposed manure, 0.5 kg superphosphate, and 0.2-0.5 kg lime was applied around each support post. During the first year, 200 g of NPK (20-20-15 or 16-16-8) and 200 g of urea were used to promote vegetative growth. As shoots expanded, additional phosphatic fertilizers were applied to strengthen root systems. During fruiting, the recommended nutrient application was 500 g each of N, P₂O₅, and K₂O, supplemented with 20-30 kg of decomposed manure. Approximately 30-35% of total fertilizers were applied during the fruiting stage, with extra decomposed manure further boosting yield in intensive cultivation.

Cajazeira *et al.* (2018) ^[12] discovered that supplying 125 mg dm⁻³ of potassium enhanced net photosynthesis, while a combination of 250 mg dm⁻³ of potassium and 159 mg dm⁻³ of calcium was found to be optimal for dragon fruit cultivation in Fortaleza-Ceará, Brazil. Their study also found that total soluble solids (TSS) were not significantly affected by fertilizer application, as the highest TSS was observed in fruits grown under native soil fertility. A study at BCKV, Kolkata, indicated that a combination of N 450 g, P₂O₅ 350 g, and K₂O 300 g per plant yielded superior results in terms of productivity and quality. Fertilizers were administered in four split doses: 10% N, 10% P₂O₅, and 30% K₂O before flowering; 20%, 40%, and 25% at fruit set; 30%, 20%, and 30% at harvest; and 40%, 30%, and 15% two months after harvest (Karunakaran *et al.*, 2019) ^[13]. Parween and Hasan (2019) ^[14] found that applying N 450 g, P₂O₅ 350 g, and K₂O 300 g per plant resulted in the highest fruit weight (222.03 g), fruit count (68), and yield (24.15 t ha⁻¹). In India, for two-year-old plants fertilizer application included 500 g of urea, 500 g of phosphorus, and 300 g of potassium annually, while for older plants, application consisted of 800 g of nitrogen, 900 g of phosphorus, and 550 g of potassium.

Nangare *et al.* (2020) ^[15] documented that in Taiwan, at every four month interval farmers applied 540 g of nitrogen, 720 g of phosphorus, and 300 g of potassium per plant per year, along with 20 kg of organic manure and 100 g of an NPK (13-13-13) mixture. Hariyanto *et al.* (2023) ^[16] reported that growth and yield of dragon fruit were significantly influenced by nitrogen and phosphorus fertilizers. The optimal dosage for maximum yield was determined to be 50 g of nitrogen and 75 g of phosphorus per pillar. However, increased nitrogen and phosphorus levels had no significant effect on TSS, and variations in nitrogen levels did not have any significant impact on individual fruit weight. Maurya *et al.* (2023) ^[17] examined the impact of nano urea on *Hylocereus costaricensis* and found that applying 6 mL L⁻¹ of nano urea resulted in the highest vegetative growth compared to conventional urea along with farmyard manure (FYM), and vermicompost. They emphasized that while dragon fruit is not a highly prolific crop, it requires

substantial nutrient inputs due to its shallow root system. Proper fertilizer and manure application were essential for maximizing fruit yield and quality.

Rawat *et al.* (2022) ^[18] demonstrated that combining organic and inorganic fertilizers, such as 75% of the recommended dose of fertilizers (RDF) with 4 kg of FYM per plant, produced vigorous vegetative growth when four plants were supported on a single pole. Similarly, 75% RDF combined with 1 kg of vermicompost also performed well in promoting vegetative growth. Their findings suggested that integrating chemical fertilizers with organic amendments improved plant development, as indicated by enhanced stem length, branch production, segmental length and number, areole spacing, and chlorophyll content. However, some growth parameters showed no significant differences under different nutrient management strategies. Satish (2023) ^[19] observed significant variations in growth parameters across different fertilizer treatments. The application of N 450 g, P 350 g, and K 300 g per plant resulted in highest vine length per pole (2.86 m), maximum number of cladodes (67), longest cladodes (102.45 cm), higher number of flowers per pole (78.34), highest fruit count per pole (74.75), largest fruit length (19.23 cm), heaviest fruit 402.67 g, widest fruit (8.00 cm), highest yield per pole (30.10 kg), and greatest pulp weight (316.76 g). Additionally, this treatment led to shortest time to first flowering (219.50 days) and harvest (245.20 days). However, maximum shelf life, minimal physiological weight loss, and least shrivelling were recorded in untreated plants which received no inorganic fertilizers.

Materials and Methods

The research was conducted at the Department of Fruit Science, College of Agriculture, Vellanikkara, Thrissur, Kerala from 2022 to 2024. Vellanikkara is situated at a latitude of 10° 31'N and longitude 76° 17' E in the Thrissur district of Kerala, India. The climatic condition of this region is tropical humid and is at an altitude of 22.25 m above mean sea level. The region received both the South West and North East monsoons.

Healthy and disease-free planting materials (3 ft long rooted cuttings of Cambodian Red dragon fruit) were procured from the nursery and planted in containers of 100 L capacity during October 2022. The experimental setup employed a Completely Randomized Design (CRD).

Potting media consisted of coirpith compost, rocksand, vermicompost, *Trichoderma* enriched goat manure and bonemeal in the ratio 1:1:1:1:1 (on weight basis). At the time of planting, Arbuscular Mycorrhizal Fungi (AMF) was applied at the rate of 0.5 kg. For container planting, before filling the media in the containers, cement poles (6 feet height and 4-inch thickness) were erected and centrally positioned in the containers using iron rods. Baby metal was laid at the bottom of the container for proper drainage. Spacing of 2 m x 2 m was followed between the poles. Irrigation was done as and when required, usually twice a week (when there were no rains), based on moisture levels in the media. Preventive plant protection measures were adopted to reduce the severe incidence of pest and diseases. Manual weeding and application of pre-emergence herbicide like Indaziflam 500 gL⁻¹ (Alion 500 SC) were followed to control weeds in the orchard.

The experiment included four treatments (each with four replications) namely T₁ - N 337.5 g; P₂O₅ 262.5 g; K₂O 225 g (per pole), T₂ - N 225 g; P₂O₅ 175 g; K₂O 150 g (per pole), T₃ - N 112.5 g; P₂O₅ 87.5 g; K₂O 75 g (per pole) and T₄ - Control (no fertilizer application). Fertilizers were applied in four split doses to each pole, i.e., 10, 10 and 30% of total NPK before flowering,

20, 40 and 25% of total NPK at fruit set, 30, 20 and 30% of total NPK at harvest and 40, 30 and 15% of total NPK after two months of harvest. The field images while planting, during first season and second season are showed in fig. 1, fig.2 and fig. 3 respectively.

Observations recorded included phenological parameters, stem characters, yield parameters, fruit characters and quality parameters. The statistical design used was Completely Randomised Design (CRD) for all the five experiments. The data collected were analysed using General R based Analysis Platform Empowered by Statistics (GRAPES) software. The data was subjected to ANOVA, with critical difference values calculated at 5% level of significance at corresponding degrees of freedom (Gopinath *et al.*, 2020) ^[20].



Fig 1: Field before planting



Fig 2: Field during season 1



Fig 3: Field during season 2

Results and Discussion

The performance of dragon fruit under different treatments were evaluated based on observations of phenological parameters, stem characters, yield parameters, fruit characters and quality parameters. Though the study was over a period of two years, the first season did not exactly contribute to the treatment effects since only one split application of the fertilizers (before flowering) was completed before the onset of first season. Hence, for most of the observations, the data during the second season was considered. The results are as mentioned below.

Days to first flowering, fruiting and harvest

All the four treatments did not differ much with respect to duration for first flowering, fruiting and harvest from the day of planting (27.10.2022). Since it was the first season of application, only one split application of the fertilizers (the split before first flowering) was completed. However, minor differences could be observed with respect to duration for first flowering, fruiting and harvest. Out of the four treatments, T₂ exhibited early flowering (235.75 days), fruiting (239.75 days) and harvest (262.25 days). This treatment (T₂) received the same fertilizer dosage, mentioned as the best dosage (combination of N 450: P₂O₅ 350: K₂O 300 for four plants) in an experiment conducted in BCKV, Kolkata (Karunakaran *et al.*, 2019) ^[13]. In the present experiment, as there were only two plants per drum, only half the quantity of the above combination of fertilizers were applied in T₂ and it was found to perform well with regard to yield and quality.

Control (T₄) took the maximum time for first harvest (270. 5 days) than T₁ (268.25 days), T₂ (262.25 days) and T₃ (269 days). The reason why treatment T₁ with the maximum NPK dosage did not contribute to early flowering and harvest compared to T₂ may be because of the higher nitrogen content which might have contributed towards increased vegetative growth. Hariyanto *et al.* (2023) ^[16] opined that increased nitrogen levels beyond 50g per plant did not have any advantage in improving the yield and was found to even cause reduced fruit set in some cases.

Although flowering began in June during the first season, it was observed much earlier in the second season, starting in April.

Flowering and fruiting season

During the first season all the four treatments started flowering from the month of June and the flowering cycles continued till September. Fruiting started from the month of July and the harvest cycles extended till October. During the second season, T₁, T₂ and T₃ had a flowering season that extended from April to September and a fruiting season that extended from May to October, whereas T₄ started flowering a month later, i.e., from May and extended till September and fruiting from June which extended to October.

Experimental results by Satish (2023) ^[19] proved that balanced NPK treatment in dragon fruit promoted early flowering and harvesting with enhanced physiological maturity. Early flowering and harvesting along with higher yield is hastened with the advancement in physiological maturity of the plants which in turn is boosted up by timely application of balanced NPK nutrients.

Total flower production

The total number of flowers produced was significantly influenced by the fertilizer treatments. Both T₃ (45.5) and T₁ (42.5) were on par with the highest number of flowers, indicating that higher NPK application promoted floral development in dragon fruit.

In contrast, the control (T₄), which did not receive any additional NPK fertilizers, produced the lowest number of flowers (28), highlighting the importance of nutrient availability for reproductive growth.

The treatment T₂ (33.5 flowers), though not significantly different from either T₁ or T₄, suggested that a moderate level of fertilizer application is essential to support flower production.

The results imply that adequate and balanced fertilizer application, particularly sufficient nitrogen, phosphorus, and potassium, is crucial for maximizing the flowering potential of dragon fruit.

Number of flowers per month and number of fruits per month

The number of flowers and fruits produced during both the seasons are mentioned in the table 1. The results indicated clear seasonal and treatment-wise variations in flower and fruit production in dragon fruit.

In Season 1 (S₁), flowering and fruiting began in June across all treatments. The highest flower production was observed in T₄ (9.5 flowers) and T₃ (8.5 flowers) during September. The treatment T₁ recorded the highest overall fruit yield, reaching 4.25 fruits in October, indicating better fruit retention and development over time.

In Season 2 (S₂), flowering started earlier, in April, with a significant increase in May, particularly in T₃ (27.5 flowers) and T₁ (19 flowers). The peak fruit set occurred in June and July, with T₃ showing the highest fruit counts—18.5 fruits in June and 9.75 in July. In contrast, the control treatment (T₄) had consistently lower flower and fruit numbers across all months, emphasizing the positive impact of NPK fertilization on reproductive performance.

The treatment T₃ emerged as the most productive treatment, especially in S₂, suggesting its NPK level was optimal for both flowering and fruiting. S₂ showed earlier and more prolific reproductive activity, likely due to increased maturity of the plants and cumulative treatment effects. The control (T₄) showed lower productivity in both seasons, reinforcing the importance of nutrient management in dragon fruit cultivation.

Number of flushes

The number of flowering flushes varied significantly across the treatments and between seasons as it was primarily influenced by improved nutritional conditions. In S₁, the treatments produced fewer and more scattered flushes, with T₄ showing the highest number (4.25), followed by T₂ and T₃ (3.75 each), and T₁ recording the lowest (3.25). However, in S₂, all treatments exhibited a marked increase in the number of flushes, which can be attributed to better nutritional status and advancement in physiological maturity of the plants. Among the treatments, T₁

responded most effectively to the improved nutrition, recording the highest number of flushes (7.00), followed by T₃ (6.50), T₂ (6.25), and T₄ (5.50). This indicated the residual effect of fertilizers applied during S₁ along with the availability of nutrients applied during S₂ which might have played a critical role in enhancing the reproductive potential of the plants, particularly for treatments T₁ and T₃. The observed seasonal variation underscores the importance of nutritional management in optimizing flowering behaviour in dragon fruit. The observations recorded were in line with the findings of Barbeau (1990) ^[21], who identified seven to eight flowering flushes in *H. costaricensis* and five to six flowering flushes in *H. undatus*. An interval of three to four weeks was observed between each flush.

Flower drop

Though the average flower drop data did not indicate notable differences among treatments, there were slight variations in the number of flowers dropped (Table 2). During S₁, the lowest flower drop was observed in T₁ (0.5), followed by T₂ and T₃ (1.5 each), while the control treatment T₄ recorded the highest flower drop (3.0). In S₂, T₂ and T₃ maintained relatively lower flower drops (2.25), whereas both T₁ and T₄ showed slightly higher values (2.75). These results suggested that though the nutrient-treated plants, especially T₁ had better flower retention during S₁, it was observed with an increased flower drop in S₂ which indicated that treatment efficacy can vary seasonally, possibly due to climatic or physiological factors. The control (T₄) consistently showed higher flower drop across both the seasons, underscoring the importance of balanced nutrient management for flower retention in dragon fruit.

Peak flowering month and fruiting month

During the first season, maximum flowers were obtained in all the four treatments during September and maximum fruits were obtained in October whereas in the second season, maximum flowers were obtained during May and maximum fruits during June. The reason for getting maximum flowers and fruits towards the end of the season compared to the initial months during the first season may be because the plants were still in the vegetative growth period and had not attained sufficient maturity required to enter into the reproductive phase. By second year, plants started flowering and fruiting abundantly at the beginning of the season itself, i.e., in May-June as they might have attained the required vegetative growth and sufficient maturity. The study by Davenport (2000) ^[22] had revealed that though the reproductive flushes are confined to periods of stem rest which normally coincides with cool weather and short-day conditions, the vegetative growth flushes occur throughout the growth period during any time of the year.

Table 1: Number of flowers per month and number of fruits per month during 2022-23 (S₁) and 2023-24 (S₂)

Season	Treatment	April		May		June		July		August		September		October	
		Flowers	Fruits	Flowers	Fruits	Flowers	Fruits	Flowers	Fruits	Flowers	Fruits	Flowers	Fruits	Flowers	Fruits
S ₁	T ₁	-	-	-	-	4.5	0	6	3.25	3	3.5	7.75	2.75	0	4.25
S ₁	T ₂	-	-	-	-	4.5	0	2	4.5	1	1.75	5.25	0.5	0	4.5
S ₁	T ₃	-	-	-	-	4.5	0	2.5	4.25	1	1.75	8.5	1	0	7.25
S ₁	T ₄	-	-	-	-	3.5	0	3.5	3	0.5	3	9.5	0.5	0	7.5
S ₂	T ₁	0.25	0	19	2.5	3.5	8.5	2.25	6.5	8.75	1.5	8.25	8.5	0	7.25
S ₂	T ₂	0.25	0	13.25	1.5	3.25	9.75	2	5.5	6	0.5	4.75	5.25	0	4.75
S ₂	T ₃	1.25	0	27.5	2.5	2.75	18.5	1	9.75	10.75	0.25	2.75	10.75	0	2.25
S ₂	T ₄	0	0	15.5	0	2	11.5	0	6	3.5	0	7	2.5	0	5.25

Table 2: Total flower production, flower drop and number of flushes

Treatment	Total flower production	Flower drop		Number of flushes	
		S ₁	S ₂	S ₁	S ₂
T ₁	42.5 ^a	0.5	2.75	3.25	7
T ₂	33.5 ^{ab}	1.5	2.25	3.75	6.25
T ₃	45.5 ^a	1.5	2.25	3.75	6.5
T ₄	28 ^b	3	2.75	4.25	5.5
CD (0.05)	12.92	2.40	1.93	-	-
CV (%)	22.43	-			

Stem segment length (cm), stem segment width (cm), distance between areoles and number of branches per pole

The stem segment length from the top of the pole was measured. Observations were recorded at three months interval. The treatments T₁, T₂ and T₃ were found to be on par with each other with respect to the stem segment length from April 2024 onwards. Control (T₄) recorded the lowest value among all the four treatments. The stem segment lengths during different months are mentioned in the table 3.

Stem segment width and distance between areoles did not vary significantly among the treatments. The number of branches did not differ significantly till August 2023 (Table 3). From September 2023 onwards, the performance of treatments T₁, T₂ and T₃ in terms of branch growth were on par. Control (T₄) produced the lowest number of branches. Each treatment showed a gradual increase in the number of branches per pole over time. The treatment T₁ began with 29.25 branches in September 2023 and reached a maximum of 52.25 branches by April 2024, maintaining this number until the end of the study period in October 2024. Similarly, T₂ started with 25.25 branches and proceeded with a steady increase, reaching upto 48.75 branches by May 2024, where it plateaued. The treatment T₃ also showed comparable growth, beginning with 28.25 branches and reaching 52.5 branches by May 2024, continuing this level throughout the remaining period of the study (Table 4). In contrast, T₄ (control) showed a significantly lower growth trajectory. It started with 18.5 branches and peaked at just 31.25 branches by May 2024, with no further increase observed thereafter. This highlights the importance of fertilizer application in promoting branch development. The result suggested that the application of nutrients for treatments T₁, T₂ and T₃ played a key role in promoting vegetative growth, particularly branch proliferation when compared to the control.

In a fertilizer trial conducted at Bangladesh, fruit length, fruit width, fruit weight, and fruit yield of dragon fruit were found to increase with the application of NPK fertilizers at N 540 g, P₂O₅ 310 g, and K₂O 250 g plant⁻¹ (Chakma *et al.*, 2014) [9]. According to Karunakaran *et al.* (2014) [10], application of NPK (19-19-19) fertilizer at the rate of 100 g per plant at every three to four months interval along with organic manure was found to be beneficial.

A study by Rawat *et al.* (2022) [18] on nutrient management in dragon fruit, clearly demonstrated that integrating chemical fertilizers with organic manures significantly enhanced vegetative traits such as stem length, number of branches, segment length and count, areole spacing, and chlorophyll content in stems. They also noticed that, due to the variation in nutrient management approaches alone some growth traits were not found to differ significantly. Satish (2023) [19] reported that the treatment which received 450 g nitrogen, 350 g phosphorus, and 300 g potassium produced the most favorable results such as longest vine length per pole (2.86 m), highest number of cladodes (67.00) and longest total cladode length (102.45 cm).

Total fruit yield

Treatment-wise yield performance of dragon fruit revealed significant variation among the treatments. The highest mean yield was recorded in T₁ (15.29 kg/plant), which was statistically on par with T₃ (12.75 kg/plant). Treatment T₂ (10.10 kg/plant) showed a moderate response and was statistically comparable to both T₃ and the lowest yielding treatment, T₄ (7.29 kg/plant). The significantly lower yield in T₄ suggested that it was the least effective among all treatments (Table 5).

Fruit weight (g)

Statistical analysis revealed significant differences among the treatments with regard to individual fruit weight. The highest mean fruit weight was recorded in T₁ (491.75 g), which was significantly superior to all the other treatments. This indicated that T₁ had more favourably influenced fruit development and fruit size. Treatments T₃ (380.75 g), T₂ (346.00 g), and T₄ (340.00 g) were found to be statistically on par, showing that no significant difference existed among them, resulting in moderate fruit weights (Table 5). Fruits from different treatments are depicted in fig. 4.

Pulp weight (g)

Significant variation in pulp weight was observed among the treatments. The highest mean pulp weight was recorded in T₁ (365.75 g), which was significantly superior to the other treatments, indicating the effectiveness of the treatment in enhancing the edible portion of the fruit. Treatments T₃ (262.75 g), T₄ (245.75 g), and T₂ (242.25 g) were found to be statistically similar and were grouped together with moderate pulp development (Table 5).

Rind weight (g) and rind thickness (cm)

Rind weight and rind thickness were not significantly influenced by the different treatments. Statistical analysis showed no notable variation among the treatments for these parameters, indicating that the application of treatments had no measurable effect on the structural characteristics of the fruit rind. This suggested that rind development in dragon fruit remained relatively stable, regardless of the treatments applied.

Fruit diameter (cm)

The effect of treatments on fruit diameter showed statistically significant differences. The highest mean fruit diameter was recorded in T₁ (8.75 cm), which was significantly superior to T₄ and statistically on par with T₃. The treatment T₃ (8.43 cm) showed no significant difference with T₁ or T₂, while T₂ (8.23 cm) was statistically similar to both T₃ and T₄. The lowest fruit diameter was recorded in the control T₄ (7.88 cm), which was significantly inferior to T₁. Fruit diameter was found to have a positive relation with fruit weight (Table 5).

Number of seeds per gram of pulp

Significant differences were observed in the number of seeds per

gram of pulp among the treatments. The highest seed density was recorded in T₄ (61.5 seeds/g pulp), which was significantly higher than all other treatments, indicating a coarser pulp texture. The treatment T₃ followed with a significantly lower seed density (50.5) than T₄ but still higher than T₁ and T₂ with T₂ (43.0) statistically similar to T₃ and T₁. The lowest seed count per gram of pulp was observed in T₁ (36.5), which was significantly lower than T₄, indicating a more desirable, smoother pulp. These findings suggest that T₁ is the most favourable treatment for improving pulp quality in terms of low seed density, while T₄ may lead to a coarser texture due to its high seed content. The lower seed density in T₁ may be

correlated to its higher individual fruit weight (Table 5). The findings of Satish (2023) ^[19] highlighted the significant influence of nutrient management on vegetative growth and reproductive performance in dragon fruit. Among the treatments evaluated, the application of 450 g nitrogen, 350 g phosphorus, and 300 g potassium per plant resulted in superior performance across multiple parameters. Fruit characteristics such as size, weight, and pulp content also notably improved under this nutrient regime, culminating in highest yield (30.10 kg per pole). Study results by Lakhanotra *et al.* (2025) ^[23] agrees with the above observation as they found improved fruit weight and yield by combining 75% NPK with vermicompost and biofertilizers.



Fig 4: Fruits from different treatments

Table 3: Stem segment length, width and distance between areoles (cm)

Treatment	Jan 2024			Apr 2024			Jul 2024			Oct 2024		
	Stem segment length	Width	Distance between areoles	Stem segment length	Width	Distance between areoles	Stem segment length	Width	Distance between areoles	Stem segment length	Width	Distance between areoles
T ₁	243.5 ^{ab}	4	3.25	257.5 ^a	4.06	3.5	278.75 ^a	5.06	3.88	296.25 ^a	4.81	3.5
T ₂	261.13 ^a	4.88	3.81	271.0 ^a	4.38	3.81	284.5 ^a	4.81	4.25	296.30 ^a	4.63	3.81
T ₃	258.38 ^a	4.31	3.69	277.8 ^a	4.13	3.75	289.8 ^a	4.56	3.94	296.73 ^a	4.63	3.75
T ₄	199.36 ^b	4.75	3.56	215.5 ^b	4.31	3.31	239.0 ^b	4.31	3.81	266.38 ^b	4.44	3.31
CD (0.05)	44.41	NS	NS	35.86	NS	NS	24.84	NS	NS	13.86	NS	NS
CV (%)	11.98	10.89	15.66	9.11	14.26	14.96	5.91	14.19	5.30	3.11	15.09	14.96

Table 4: Number of branches per pole

Treatment	Number of branches													
	Sept 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mar 2024	Apr 2024	May 2024	Jun 2024	Jul 2024	Aug 2024	Sept 2024	Oct 2024
T ₁	29.25 ^a	32 ^a	34.5 ^a	37.25 ^a	40.5 ^a	46.25 ^a	49.75 ^a	52.25 ^a	52.25 ^a	52.25 ^a	52.25 ^a	52.25 ^a	52.25 ^a	52.25 ^a
T ₂	25.25 ^a	29 ^a	31.5 ^a	34.5 ^a	38 ^a	44 ^a	44.5 ^a	47.5 ^a	48.75 ^a	48.75 ^a	48.75 ^a	48.75 ^a	48.75 ^a	48.75 ^a
T ₃	28.25 ^a	31 ^a	34 ^a	36.75 ^a	41 ^a	48.75 ^a	50.25 ^a	52 ^a	52.5 ^a	52.5 ^a	52.5 ^a	52.5 ^a	52.5 ^a	52.5 ^a
T ₄	18.50 ^b	19 ^b	20 ^b	21.5 ^b	22.25 ^b	22.75 ^b	26.5 ^b	30.5 ^b	31.25 ^b	31.25 ^b	31.25 ^b	31.25 ^b	31.25 ^b	31.25 ^b
CD (0.05)	5.79	5.42	4.31	4.61	5.62	6.20	7.41	7.69	7.89	7.89	7.89	7.89	7.89	7.89
CV (%)	14.84	12.66	9.33	9.21	10.3	9.95	11.25	10.95	11.08	11.08	11.08	11.08	11.08	11.08

Table 5: Fruit weight, pulp weight, fruit diameter, number of seeds per gram, total yield, TSS

Treatment	S ₂							TSS (°brix)		Titrable acidity
	Fruit weight (g)	Pulp weight (g)	Rind weight (g)	Rind thickness (cm)	Fruit diameter (cm)	Number of seeds per gram of pulp	Total yield (kg)	S ₁	S ₂	
T ₁	491.75 ^a	365.75 ^a	126.00	0.25	8.75 ^a	36.50 ^c	15.29 ^a	13.90 ^{ab}	14.55 ^b	0.13
T ₂	346.00 ^b	242.52 ^b	103.75	0.31	8.23 ^{bc}	43.00 ^{bc}	10.10 ^{bc}	14.70 ^a	15.63 ^a	0.13
T ₃	380.75 ^b	262.75 ^b	118.00	0.29	8.43 ^{ab}	50.50 ^b	12.75 ^{ab}	12.05 ^b	14.50 ^b	0.13
T ₄	340.00 ^b	245.75 ^b	94.25	0.26	7.88 ^c	61.50 ^a	7.29 ^c	15.10 ^a	15.83 ^a	0.13
CD (0.05)	85.69	53.26	NS	NS	0.43	8.88	3.69	1.92	1.06	NS
CV (%)	14.27	12.38	33.62	20.86	3.35	12.04	21.06	8.94	4.54	0

Total soluble solids (TSS) and acidity (%)

The treatments T₄ and T₂ showed the highest value for TSS in both the seasons with mean values of 15.1 and 14.7 respectively in first season and 15.83 and 15.63 respectively in the second season. The treatment T₁ (13.9 and 14.55 for S₁ and S₂ respectively) showed intermediate results whereas T₃ had the lowest TSS in both the seasons (12.05 and 14.5 respectively) as mentioned in Table 5. This observation is in line with the findings of Cajazeira *et al.* (2018) ^[12] as they reported that TSS in dragon fruit was not markedly influenced by fertilizer application, as the highest TSS values were recorded in fruits cultivated under native soil fertility conditions.

The treatments did not significantly influence the titrable acidity. All the fruits collected from the different treatments when analysed were found to have only very low titrable acidity of 0.13%.

Shelf life of fruits at ambient condition (days) and physiological loss in weight after harvest

The fruits belonging to the treatment T₁ recorded the highest average shelf life of 7 days followed by treatments T₂ and T₃ with average shelf life of 6.75 and 6.25 days respectively. Treatment T₄ (control) recorded the lowest average shelf life compared to the other treatments (6 days).

The percentage of physiological loss in weight of the fruits belonging to different treatments during the period of storage (7 days) did not differ significantly. The percentage decrease in fruit weight was less during the initial days of storage and it increased rapidly towards the final days of storage. However, the highest physiological weight loss percentage was recorded by the fruits from the control treatment.

The observations recorded during this experiment differed from the results obtained by Satish (2023) ^[19] where the absolute control (without inorganic fertilizers) demonstrated better post-harvest qualities, including extended shelf life and minimal physiological weight loss and shriveling. But the results were found to be in line with the study by Lakhanotra *et al.* (2025) ^[23] who revealed that combining 75% NPK with vermicompost and biofertilizers (Azotobacter, Phosphate solubilizing bacteria, and Potassium solubilizing bacteria) resulted in improved fruit quality and extended shelf life.

Organoleptic scoring

The scoring was based on a 9-point hedonic scale in which nine represented the highest score showing high preference for the fruits and one indicated the least score representing least preference. During the first season, the highest mean score for all the parameters except colour was recorded for T₁ (appearance-8.2, flavour-7.7, texture-7.9, taste-8, after taste-7.4, overall acceptability-7.7). Highest score for colour was recorded by T₂ (7.6). Whereas, towards the end of second season, the highest score for all the parameters except appearance and colour was recorded by the control T₄ (flavour-7.9, texture-7.9, taste-7.7, after taste-7.6, overall acceptability-7.6). Appearance and colour scores were highest for T₃, i.e., 8.2 and 8.6 respectively. The treatments T₃ and T₄ were on par with respect to the mean scores for taste (7.7), after taste (7.6) and overall acceptability (7.6) as stated in table 6. A similar finding was noted by Perween and Hasan (2019) ^[14], who reported higher TSS in the control which received no fertilizer externally.

Reducing, non-reducing and total sugars

Significant variations were observed among the treatments in terms of reducing sugars, non-reducing sugars, and total sugar content (Table 7). The highest reducing sugar content was recorded in T₄ (4.03%), which was significantly superior to all other treatments, followed by T₁ (2.85%), T₃ (2.25%), and the lowest in T₂ (1.63%). In contrary, the trend for non-reducing sugars was that, T₃ (2.00%) recorded the highest value, followed by T₂ (1.34%), T₁ (0.95%), and the lowest in T₄ (0.36%). Regarding total sugar content, T₄ (4.39%) and T₃ (4.25%) were found to be statistically on par and significantly higher than T₁ (3.80%) and T₂ (2.97%). These results suggested that T₄ was the best with regard to the content of reducing and total sugars, while T₃ showed a higher accumulation of non-reducing sugars. The variation in sugar fractions among treatments may be attributed to differences in nutrient availability, metabolic activity, or treatment-specific physiological responses. The findings were comparable with those observed in the studies conducted by Perween and Hasan (2019) ^[14], Sarkar and Rahim (2012) ^[24] and Wrona (2004) ^[25] where, higher fertilizer dosage, especially application of increased quantities of nitrogen fertilizers were reported to be negatively influencing soluble solids and sugar content.

Ascorbic acid and anthocyanin

Significant differences were observed among treatments in terms of ascorbic acid content in dragon fruit. Treatments T₂, T₃, and T₄ recorded the highest and statistically similar ascorbic acid levels (17.91 mg/100g), indicating no significant variation among them (Table 7). Whereas, T₁ showed a significantly lower value (15.82 mg/100g). These results suggested that the treatments T₂, T₃, and T₄ were effective in enhancing or maintaining higher ascorbic acid concentrations compared to T₁, may be due to improved nutrient availability or physiological responses favouring vitamin C synthesis or retention. An imbalance in nutrient supply, particularly elevated nitrogen levels in T₁, could be responsible for the observed reduction in ascorbic acid content. This observation is in line with the findings of Wrona (2004) [25] and Sarkar and Rahim (2012) [24] in apple and mango respectively, who reported a decline in ascorbic acid content with increased fertilizer application.

Significant variation was observed in anthocyanin content among the different treatments. The treatment T₃ recorded the highest anthocyanin concentration (329.93 mg/100g), followed by T₂ (312.01 mg/100g) and T₁ (281.67 mg/100g), while T₄ exhibited the lowest anthocyanin content (225.66 mg/100g) (Table 7). The statistically significant differences among treatments suggested that the nutrient formulation in T₃ was most effective in enhancing anthocyanin synthesis. This can be attributed to optimal nutrient availability that supports the biosynthesis of flavonoid pigments, which play a key role in fruit colouration and antioxidant capacity. Research conducted by Xu *et al.* (2022) [26] in 'Fuji' apples and Delgado *et al.* (2006) [27] in 'Tempranillo' grapes indicated that elevated nitrogen levels led to a reduction in anthocyanin accumulation, while increased potassium application helped to counteract this effect and promoted pigment synthesis.

Table 6: Organoleptic evaluation of dragon fruits from different fertilizer treatments

Treatment	Appearance		Colour		Flavour		Texture		Taste		Aftertaste		Overall acceptability	
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂
T ₁	8.2	8.1	7.5	8.3	7.7	7	7.9	7.7	8	7	7.4	6.9	7.7	7.1
T ₂	7.6	8.2	7.6	8.3	7.2	7.4	7.6	7.6	7.4	7.2	7	7.3	7.2	7.4
T ₃	7.8	8.2	7.4	8.6	6.9	7.6	7.5	7.8	7.2	7.7	6.9	7.6	7.2	7.6
T ₄	7.6	8.1	7.3	8.3	7.3	7.9	7.6	7.9	7.2	7.7	7.3	7.6	7.3	7.6
K W value	0.16	0.01	0.02	0.11	0.18	0.17	0.10	0.04	0.21	0.10	0.10	0.08	0.12	0.10

Table 7: Reducing sugars, non-reducing sugars, total sugars, ascorbic acid and anthocyanin (fruits)

Treatment	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)	Ascorbic acid (mg/100g)	Anthocyanin (mg/100g)
T ₁	2.85 ^b	0.95 ^c	3.80 ^b	15.82 ^b	281.67 ^c
T ₂	1.63 ^d	1.34 ^b	2.97 ^c	17.91 ^a	312.01 ^b
T ₃	2.25 ^c	2.00 ^a	4.25 ^a	17.91 ^a	329.93 ^a
T ₄	4.03 ^a	0.36 ^d	4.39 ^a	17.91 ^a	225.66 ^d
CD (0.05)	0.17	0.32	0.35	0.56	0.83
CV (%)	4.00	17.70	5.88	2.10	0.19

Chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content in cladodes

The analysis of chlorophyll fractions revealed notable differences among the treatments in terms of total chlorophyll and chlorophyll b content, while chlorophyll a remained statistically unaffected (Table 8). Among the treatments, T₂ consistently showed the highest total chlorophyll (0.14 mg/g) and chlorophyll b (0.05 mg/g) levels, indicating a superior influence of this nutrient regime on photosynthetic pigment accumulation. The treatment T₁ followed with moderate values (0.11 mg/g total chlorophyll and 0.03 mg/g chlorophyll b), which were found to be statistically on par with T₂. Meanwhile, T₃ and T₄ recorded significantly lower values for both parameters, suggesting a comparatively low effect on pigment synthesis. The lack of significant variation in chlorophyll a among treatments implied that the observed differences in total chlorophyll are primarily due to the variation in chlorophyll b. The enhanced chlorophyll content in T₂ indicated improved nutrient availability that may support better light-harvesting efficiency and overall physiological performance in dragon fruit. The carotenoid content in the cladode of dragon fruit exhibited significant variation among the treatments. The treatment T₂ recorded the highest carotenoid concentration (0.06 mg/g), which was significantly superior to T₃ and numerically higher than T₄ and T₁. Treatments T₄ (0.05 mg/g) and T₁ (0.05 mg/g) were statistically on par with each other and with T₂. However,

T₃ registered the lowest carotenoid content (0.03 mg/g), indicating a significantly low effect on carotenoid accumulation (Table 8). These results suggested that the nutrient combination in T₂ might have positively influenced carotenoid biosynthesis in the stem, possibly by enhancing antioxidant activity and photo protective functions in the plant.

The superior pigment concentrations observed in the treatment T₂ might have likely resulted from improved nutrient availability, which enhanced photosynthetic efficiency and overall plant health. A study on Ashwagandha (*Withania somnifera*) demonstrated that applying a combination of 50% NPK, farmyard manure (FYM), biofertilizers (*Azotobacter* and phosphate-solubilizing bacteria), and zinc led to the highest recorded levels of chlorophyll a (2.17 mg/g), chlorophyll b (0.48 mg/g), and carotenoids (0.54 mg/g) at 90 days after sowing. This enhancement was attributed to the synergistic effect of organic and inorganic nutrient sources, which improved nutrient uptake and assimilation, thereby promoting pigment biosynthesis (Chaurasia and Singh, 2021) [28]. Similarly, research on *Thymus vulgaris* (garden thyme) indicated that nutrient supplementation positively affected chlorophyll and carotenoid content, further supporting the role of balanced fertilizer application in enhancing photosynthetic pigment accumulation (Sharafzadeh and Alizadeh, 2011) [29]. Rawat *et al.* (2022) [18] reported improved chlorophyll content in stems of dragon fruit with enhanced nutrient management.

Table 8: Chlorophyll and carotenoid pigments in cladode (mg/g)

Treatment	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoids
T ₁	0.08 ^a	0.03 ^{ab}	0.11 ^{ab}	0.05 ^{ab}
T ₂	0.10 ^a	0.05 ^a	0.14 ^a	0.06 ^a
T ₃	0.06 ^a	0.02 ^b	0.08 ^b	0.03 ^b
T ₄	0.07 ^a	0.02 ^b	0.08 ^b	0.05 ^{ab}
CD (0.05)	0.05	0.02	0.06	0.03

Media pH and electrical conductivity

During the second season, the pH of all the four media were recorded after the final harvest (Table 9). The pH of the growing medium showed slight variation among treatments with different NPK levels. The treatment T₁ recorded the highest pH (7.77), followed by T₂ (7.68) and T₃ (7.57), while the control treatment (T₄) exhibited the lowest pH (7.56). The marginal increase in pH with higher NPK application suggested that fertilizer treatments, particularly those involving nitrogen sources like urea may have contributed to slight alkalization of the medium.

Overall, all the treatments maintained a near-neutral to slightly alkaline pH, which generally supports nutrient availability.

The relatively lower pH in the control might be indicating natural acidification in the absence of fertilizer application.

The electrical conductivity (EC) of all the four media were observed towards the end of the second season and the highest EC was recorded in T₃ (0.19 dS m⁻¹) followed by T₁ (0.16 dS m⁻¹) and T₂ (0.15 dS m⁻¹). The least EC was observed in control (0.14 dS m⁻¹) as documented in table 9. The higher EC in the treatments T₃, T₁ and T₂ might be due to the increased release of ions from the fertilizers to the media. The moderate increase in EC due to fertilizer application might have contributed to enhanced nutrient availability, supporting better growth and physiological activity in dragon fruit.

Table 9: Media pH and EC

Treatment	pH	EC (dS m ⁻¹)
T ₁	7.77	0.16
T ₂	7.68	0.15
T ₃	7.57	0.19
T ₄	7.56	0.14

Conclusion

The overall performance was the best for T₁ (N 337.5 g; P₂O₅ 262.5 g; K₂O 225 g per pole) and T₃ (N 112.5 g; P₂O₅ 87.5 g; K₂O 75 g per pole). The treatment T₁ excelled in fruit weight, pulp weight, shelf life, and number of flushes, while T₃ recorded the highest flower production, monthly flower and fruit count, anthocyanin and sugar content. T₂ (N 225 g; P₂O₅ 175 g; K₂O 150 g per pole) showed early flowering and highest chlorophyll and carotenoid content in stems but lagged behind in fruit yield and quality. Both T₁ and T₃ recorded comparable total fruit yields, with T₁ being superior in postharvest behaviour and biochemical composition, making it the most balanced treatment.

Season 2 outperformed Season 1 in terms of earliness, number of flushes, and fruit yield, may be due to better nutrient availability as it received all the split doses of fertilizers. Based on the findings, Treatment 1 can be recommended for optimal yield and postharvest performance, while Treatment 3 for enhancing flowering, fruit count and biochemical quality.

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