International Journal of Multiphysics
Volume 18, No. 2, 2024
ISSN: 1750-9548

Effect of Selected Bio-stimulants and Organic Fertilizers on the Flowering, Yield, and Quality of White-Fleshed Dragon Fruit Plants (Hylocereus undatus) under Sandy Soil Conditions

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Abstract

This study was conducted over two consecutive growing seasons (2023 and 2024) in a private orchard located in Belbis City, Alsharqia Governorate, Egypt. The primary objective was to evaluate the physiological and physiochemical responses of two-year-old white-fleshed dragon fruit (*Hylocereus undatus*) plants to five organic and biological treatments: seaweed extract (5 cm/L), Spirulina extract (3 cm/L), chitosan extract (4 cm/L), tea compost (150 ml/L), and humic acid (1.5 gm/L), alongside an untreated control group. The treatments were applied three times per season (March, May, and July) to plants grown under drip irrigation in sandy soil. The experimental results revealed significant variations in growth, reproductive dynamics, and fruit quality traits. Spirulina extract demonstrated superior consistency in enhancing fruit biochemical properties, achieving the highest total phenolic content across both seasons, maximizing total soluble solids (TSS, °Brix), and producing the thinnest peels. However, antioxidant activity showed high seasonal fluctuation, with Spirulina dominating the first season and seaweed extract dominating the second. Structurally, humic acid exerted the most stable and superior influence on vegetative growth, significantly optimizing plant height, stem diameter, and the fruit shape index (Height/Diameter ratio) over the two-year period. Regarding reproductive biology, all evaluated bio-stimulants significantly enhanced flower numbers and fruit set percentages compared to the control group. However, a distinct physiological trade-off emerged between reproductive success and final tree productivity. Due to resource depletion caused by heavy, induced flowering, most biostimulants (particularly seaweed and tea compost) resulted in a significant reduction in overall yield. The untreated control group maintained the highest final tree productivity. Notably, chitosan extract emerged as the optimum and most balanced treatment. Chitosan successfully broke the negative correlation by significantly boosting flowering and fruit set while maintaining a high yield that was statistically equal to the control group. Furthermore, chitosan was highly effective in increasing edible pulp weight and maximizing initial fruit firmness. In conclusion, the strategic application of specific biostimulants particularly chitosan and Spirulina presents a highly effective, sustainable approach to improving dragon fruit quality and commercial viability in semi-arid, light-soil regions.

Keywords: Dragon fruit; Yield; Quality; seaweed extract; Spirulina extract; Sustainable chitosan extract; tea compost and humic acid.

1. Introduction

The cactus genus Hylocereus and Selenicereus (of the Cactaceae family), collectively known as dragon fruit (Pitahaya), comprises species of climbing cacti native to the tropical and subtropical regions of the Americas. In recent decades, this exotic fruit has gained significant global attention, transforming from a local wild crop into a highly valued commercial fruit widely grown in Southeast Asia, Australia, and parts of the Middle East. Among the cultivated varieties, Hylocereus undatus (white-fleshed), Hylocereus monacanthus (red-fleshed), and Selenicereus megalanthus (yellow pittahaya) are among the most economically important. The growing agricultural interest in dragon fruit is primarily due to its remarkable ability to adapt to semi-arid environments, where it utilizes crassolase acid metabolism (CAM) to achieve high water use efficiency and withstand prolonged drought stress.

Besides its agricultural versatility, dragon fruit has emerged as a major subject in functional food research and pharmacology. Dragon fruit is a rich source of bioactive compounds, including betalains, polyphenols, flavonoids, and essential vitamins, which have strong antioxidant, antimicrobial, and anti-inflammatory properties. Furthermore, the presence of bioavailable oligosaccharides in its pulp and seeds underscores its potential to promote digestive health. In light of the challenges facing global agriculture as a result of climate change and changing food needs, understanding the physiological, genetic and phytochemical characteristics of dragon fruit is crucial for improving its productivity, extending its post-harvest life and developing its industrial applications.

Dragon fruit (*Hylocereus spp.*) is the most cultivated cactus fruit crop in the world **(Mizrahi *et al.*, 1997).** It is known by various common names such as Red Pitaya, Pithaya, Strawberry Pear, Night Blooming Cereus, Belle of the Night, and Conderella Plant **(IPGRI 2006).** Fruit is named as pitaya because of the bracts or scales on the fruit skin and hence the name of pitaya meaning the scaly fruit. It is native to Central Americas but now grown all over the world especially in the tropical countries. Being a crassulacean acid metabolism (CAM) plant with xerophytes characters, it has got ability to grow in a wide range of agro– climates including areas of high temperature and water scarcity regions. The dragon fruit can be cultivated commercially up to altitude of 1700 m with rainfall ranging from 500–1500 mm. Water requirement of dragon fruit is very minimal and can survive well in desert condition. It can also grow well in degraded and light soil. Therefore, in recent two decades, dragon fruit has gained wide popularity in tropical Asian countries, which initiated its commercial cultivation around the world **(Sanoamuang 2019**). It has been considered as a super fruit of tropics with huge nutraceutical value. It contains several health benefits along with a delicately sweet taste. It is rich in nutrient content specially vitamin C, phosphorus, calcium as well as its antioxidant properties **(Morton 1987).** It is low in calories and rich in vitamins, minerals and other nutrients. It helps to control chronic illness and boost the immunity. It is helpful in weight loss, reduces the cholesterol level and control diabetes.

It is a nutritious fruit with a variety of uses as pulp, which constitute 70-80^{o}% of the ripe fruit. Dragon fruit is mainly available in three variants viz., red skin with white pulp (*Hylocereus undatus*), red skin with red pulp (*Hylocereus monacanthus* previously known as H. polyrhizus) and yellow skin with white pulp (*Hylocereus megalanthus* previously known as Selenicereus megalanthus). It is rich in vitamin C, phosphorus and calcium. The flavour of the fruit resembles to kiwi fruit. Fruits are low in fat and rich in minerals with the optimum Brix value of 15-18% (**Nangare *et al.*, 2020).**

Morphologically dragon fruit is an incomplete plant. It does not have true leaves. It is perennial in nature, fast growing climber with triangular or rarely four or five ridged stems. It is a hardy plant and having spines all over the stem. Stem size, pattern and distribution of thorns on stems are different from species to species. Spines are situated on the edge of the stem and branch **(Setyowati, 2008).** It is shallow rooted plant and has aerial roots which can absorb the moisture and nutrients from the atmosphere and helps to climb and keep the plant erect. Waxy coating on stem reduces rate of transpiration **(Emil, 2011).** As for reproductive biology of dragon fruit concerned, most studies reported that pitaya has large, hermaphroditic nocturnal flowers with natural flowering and production during warmer months. It is a long day plant with beautiful night blooming flower that is nicknamed as “Nobel Women” or “Queen of Night” **(Umayah, 2007).** This crop normally starts yielding after

18-24 months from plantation. It fruits in 5 to 8 waves during one season depending upon growing conditions. Harvesting of fruit can start from June to September. Each fruit weighs about 200 to 800 grams. One pole normally yields approx 15 to 25 kg of fruits. One of the obstacles to increasing the profitable commercial cultivation of pitaya is the lack of information about its nutritional management **(Costa *et al.,* 2015)**.

Globally, dragon fruit is produced in Vietnam, China, Indonesia Thailand, Malaysia, Israel, Sri Lanka, Mexico, Central America, Europe, South East Asia, United States and Australia over an area of 1,12,264 ha with the production of 21,00,777 MT **(Wakchaure *et al.,* 2020).** Three major countries *viz*., Vietnam, China and Indonesia contribute more than 93% of dragon fruit production of world. The share of Vietnam alone is more than half (51.1%) of the world production over an area of 55, 419 ha with average productivity of 22–35 MT/ha. China is second largest producer contributing 33.3% of the world production of dragon fruit *i.e.,* producing about 7, 00,000 MT over growing areas of 40,000 ha with average productivity of 17.5 MT/ha. **(Chen and Paull, 2019).** Indonesia is third largest producer of dragon fruit contributing 10.6 % of world production and produces annually about 2.22 lakh MT dragon fruit over an area of 8,491 ha. China is the biggest consumer and importer while Vietnam is the biggest exporter of the fresh dragon fruit (mostly white flesh).

Dragon fruit is cultivation faces numerous obstacles related to abiotic and biotic stresses, particularly in arid and semi-arid regions. These challenges encompass water and temperature stress, self-incompatibility and insufficient pollination, suboptimal canopy management, and the emerging threats posed by new diseases and pests. These factors collectively lead to reduced yield and diminished fruit quality. Furthermore, the scarcity of region-specific cultivation methods and limited research hinder the understanding and management of these issues. To address these challenges, it is crucial to implement sustainable and cost-effective best management practices to boost productivity and quality. These practices involve various aspects such as efficient soil and nursery management, shade and canopy regulation, manual pollination techniques, and key strategies to mitigate biotic and abiotic stresses. Proper implementation of these methods has the potential to significantly increase dragon fruit production, enhance its nutritional content, and ultimately improve farmers' income.

But the organic cultivation of fruits has yet not received the priority it deserves; as a result, soil physical, chemical and microbiologic health have deteriorated irrecoverably **(Ghosh, 2000)**.

There are various benefits for compost, poultry manure, vermicompost, farm yard manure, humic acid and biochar applications in fruits orchards include; Enhancing soil penetrability, improving economic benefits for citrus growers, stimulating tree growth as well as increasing tree productivity and fruit yields) **(Trinchera *et al.* 2015 and Hameed *et al.,* 2018).**

Therefore, it is essential to conduct studies to determine the amount of nutrients dragon fruit requires throughout its life cycle and to identify the stage at which these nutrients are most critical. Accordingly, the main objective of present study is to determine the influence of bio-fertilizers as well as organic fertilizers on dragon growth, flowering, yield and fruit quality in order to obtained safety and healthy production.

Materials and Methods

The present investigation will be conducted in a private orchard located at Belbis city, ALsharqia Gov. Egypt. The physicochemical properties of soil (top soil and sub-soil) of the experimental site was analyzed, some physical and chemical properties of the investigated soil shown in Table (1). The experiment was carried out on two-year-old white-fleshed genotype of dragon fruit. The plants were trained on single post system spaced at 2m (plant to plant) × 3m (row to row), accommodating 27 posts in a faddan. Each post (hill) comprised of 4 plants. The experimental plot was installed with drip irrigation system, with the provision of mulching. The crops in the experiment field received a uniform package of practice. Healthy, uniformly growing plants of white-fleshed dragon fruit was randomly chosen for experimentation.

Table 1. Some physical and chemical properties of the investigated soil

Characteristics	**Value**
Textural class	Sandy
Saturation point, %	20.2
Field capacity (FC),%	10.1
$CaCO_3$, (%)	8.5
Organic matter,(%)	0.12
pH*	8.18
EC,(dSm^{-1}) **	1.6
CEC, $cmol_c$/kg soil	9.5
ESP,%	3.6
Soluble cations and anions, (mmolc L^{-1})**	
Ca^{++}	5.4
Mg^{++}	5.7
Na^{+}	4.2
K^{+}	0.70
$CO_3^{=}$	0.00
HCO_3^{-}	6.7
Cl^{-}	5.8
$SO_4^{=}$	3.5
Available nutrient , (mg kg^{-1}soil)	
N	14.2
P	6.7
K	69.3
Fe	1.98
Zn	0.46
Cu	0.52
Mn	0.33

* Soil-water suspension 1: 2.5 ** Soil water extract 1:1

The experiment was arranged in a randomized complete block design (RCBD) comprising six treatments with three replicates per treatment. Each replicate consisted of four plants, giving a total of 72 experimental plants (6 treatments × 3 replicates × 4 plants). as follows:

1. Control (untreated plants).
2. Humic acid at 1.5 g/ L^{-1} per plant.
3. Seaweed extract at 5 mL/ L^{-1} per plant.
4. Compost tea at 150 mL /L^{-1} per plant.
5. Spirulina extract at 3 mL /L^{-1} per plant
6. Chitosan extract at 4 mL/ L^{-1} per plant.

All treatments were added three times in March, May and July 2023 and 2024 seasons at a rate of 5 liters per replicate. The above mentioned treatments were adapted to the same plants in both seasons. The responses of tested plants to the applied treatments were evaluated through the following parameters:

Plant yield

At the commercial harvesting date of each season, the remained fruits on each Plant will be picked out and weighted. The average yield per tree (kg/tree) and the average number of fruits / tree will be registered.

- Yield (Number/plant)

The number of flowers, the percentage of nodes and the productivity of the tree were evaluated as an average at the end of the whole season.

- Fruit set (%)
- Tree productivity (kg)
- Number flowers

Fruit characteristics: After fruit harvest, 20 fruits will be randomly collected from each replicate to determine the following fruit characteristics:

- Fruit height (H)(mm) and fruit diameter (D) (mm) and the Height –to-Diameter ratio (H/D)(mm).
- Fruit weight (g) The average weight of fruits was calculated by means of a digital balance
- Edible pulp weight (g)
- Shell weight(g)
- Shell thickness(mm)
- fruit firmness (g/m^2): The pulp firmness was estimated by a digital fruit firmness tester (Lutron, FR 5120) using a 3-mm tip and represented as Newton/mm (N/mm).
- TSS (°Brix): The soluble solids were measured with hand refractometer**.**

The fruit were chemically analyzed in both seasons and evaluated as an average at the end of whole season:

The total phenols (mg GAE/g): was determined by using Folin-Ciocalteu (FC) reagent and total flavonoid was quantified by aluminium chloride method **(Chang *et al.*, 3).**

The total phenolic content was determined according to the Folin-Ciocalteu procedure (**Zilic *et al.*, 2012**). Briefly, the extract (100 µL) was transferred into a test tube and the volume adjusted to 3.5 mL with distilled water and oxidized with the addition of 250 µL of Folin-Ciocalteau reagent. After 5 min, the mixture was neutralized with 1.25 mL of 20% aqueous sodium carbonate (Na_2CO_3) solution. After 40 min, the absorbance was measured at 725 nm against the solvent blank. The total phenolic content was determined by means of a calibration curve prepared with gallic acid (Fig. 1), and expressed as mg of gallic acid equivalent (mg GAE) per g of sample.

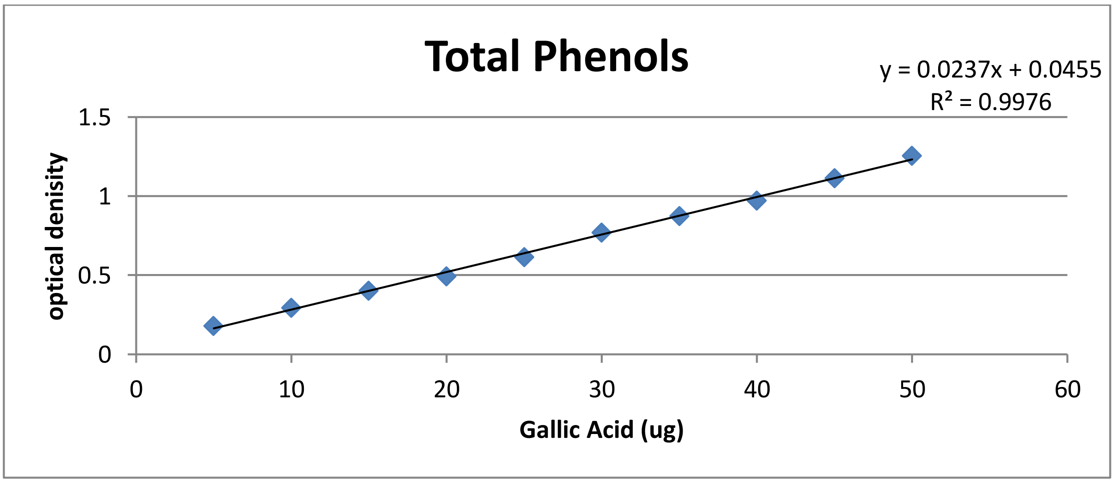

Fig. (1)

Antioxidant activity (mg TE/g)

Radical DPPH scavenging activity

Free radical scavenging capacity was determined using the stable 1,1-Diphenyl-2-picryl-hydrazyl (DPPH•). The final concentration was 50 µM for DPPH• and the final reaction volume was 4.0 mL. The absorbance at 517 nm (A) was measured against a blank of pure methanol at 60 min. Percent inhibition of the DPPH free radical was calculated by the following equation:

$$\text{Inhibition (\%)} = 100 \times (A_{control} - A_{sample})/A_{control}$$

Also, the antioxidant activity was determined by means of a calibration curve prepared with Trolox acid (Fig. 2), and expressed as mg of Trolox equivalent (TE) per gram of sample.

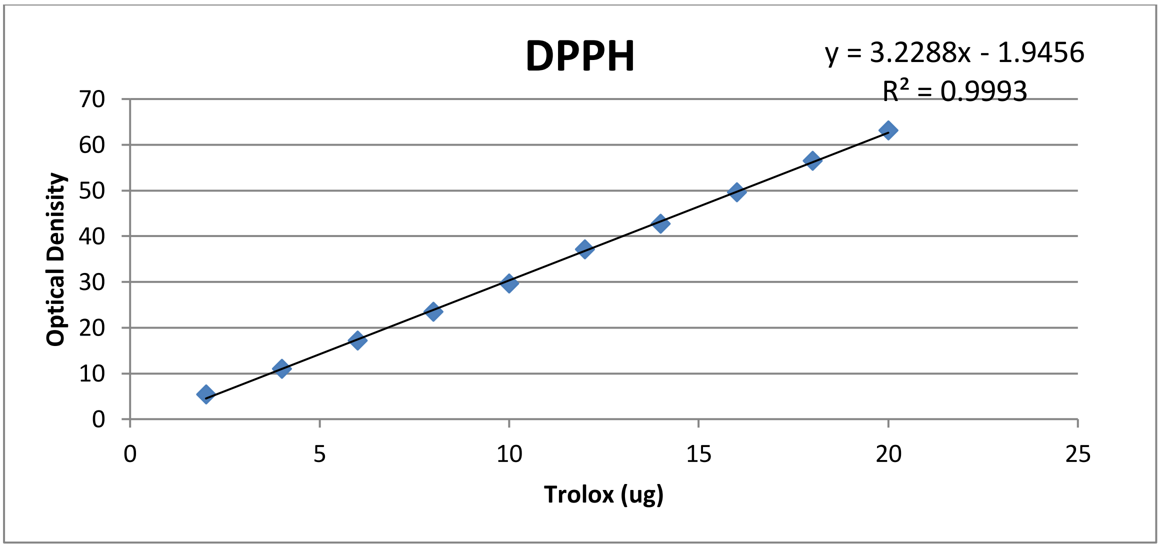

Fig. (2)

Total Carbohydrate (%)

The total carbohydrate content was determined using the phenol-sulfuric acid procedure (BeMiller, 2010). Aliquot of sample (0.25 g) were hydrolyzed using 10 ml of sulfuric acid (72%) in a boiling water bath for 2 hours. Samples were left to cool, filtered and diluted to 50 ml by distilled water. 0.25 mL of each sample solution was transferred into a test tube and the volume adjusted to 1.0 mL with distilled water. Added 1.0 mL of 6% phenol solution, then quickly added 5.0 mL of concentrated sulfuric acid, mixed well in time, and leaved at room temperature for 20 min. Distilled water was used as blank control. The absorbance was measured using spectrophotometer at a wavelength of 490 nm. The total carbohydrate content was determined by means of a calibration curve prepared with glucose (Fig. 3) and expressed as percentage.

Statistical analysis

All experiments were conducted with three replications. The 5th and 95th percentiles used calculated using Microsoft Excel 2010. The first time of symptom, conidia and number of conidia was analyzed for one-way ANOVA with Duncan multiple range test by using Statistix9 Program. For the correlation of time and fungal colonies, it was also calculated using the same program.

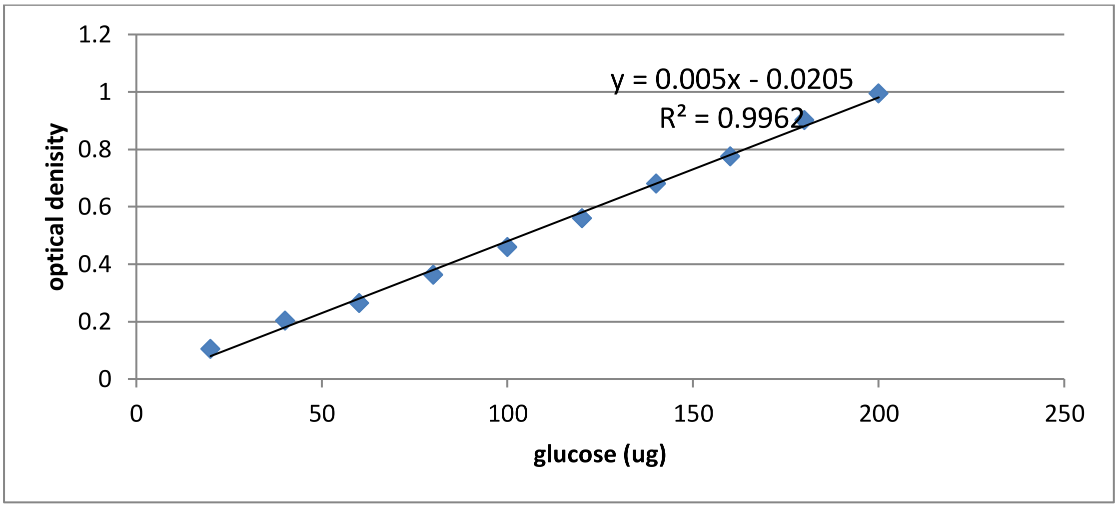

Fig. (3)

3. Results and Discussion

Total phenols, antioxidant activity and total carbohydrate

Fruit plants as influenced by various bio-materials over two consecutive growing seasons (2023 and 2024). The data focuses on three key quality indicators: Total Phenols Content, Antioxidant Activity, and Total Carbohydrate Percentage. The primary objective of this data presentation is to evaluate the efficacy of organic and biological treatments namely Humic Acid, Seaweed, Tea Compost, Spirulina, and Chitosan relative to a non-treated Control group. These parameters were measured to determine the impact of each treatment on the accumulation of secondary metabolites and the overall nutritional value of the fruits across different environmental cycle (Table 2).

Season 2023: Data shows that the Spirulina treatment achieved a significant advantage, followed by the tea fertilizer. The other treatments, including the control group, were at a much lower level, with humic acid recording the lowest value. Season 2024: Although the values were generally lower compared to the first season, Spirulina maintained its results. However, chitosan was observed to increase significantly, while seaweed extract fell to its lowest level.

Similar trends were reported by **Satish (2023) and Sahu *et al.* (2023)** in dragon fruit (*Selenicereus monacanthus*), where the application of organic and bio-organic fertilizers significantly increased the total phenolic content.

2023 Season: A statistically significant difference was observed between the treatments; Spirulina showed the highest activity, followed by the control group and then tea fertilizer. In contrast, humic acid and chitosan ranked lowest in antioxidant capacity. 2024 Season: The ranking changed completely; seaweed moved from an intermediate ranking in the first season to the highest statistically significant value. In contrast, Spirulina dropped sharply from first place in 2023 to the lowest statistically significant ranking in 2024. Tea fertilizer remained stable in second place. Similar trends were reported by **Rebecca *et al.* (2010)** in red dragon fruit (*Hylocereus polyrhizus*). **Sahu *et al.* (2023)** in dragon fruit (*Selenicereus monacanthu*) where the application of organic and bio-organic fertilizers significantly increased the antioxidant content.

Season 2023: The highest significant percentages were concentrated in the Spirulina and tea compost treatments. The humic acid treatment showed the least carbohydrate accumulation during this cycle. Season 2024: A clear reversal occurred; the control treatment outperformed all organic and biological treatments, registering the highest percentage. Among the treated plants, Spirulina remained the most effective, while humic acid, seaweed, and chitosan registered the lowest values, with no significant difference between them. Similarly, trends were reported by **Sahu *et al.* (2023)** in dragon fruit (*Selenicereus monacanthu*) where the application of organic and bio-organic fertilizers significantly increased total carbohydrate content.

The statistical results reveal that Spirulina was the most consistent treatment in enhancing phenolic content across both seasons. However, antioxidant activity showed a high degree of seasonal fluctuation, with Spirulina dominating the first season and Seaweed dominating the second. Regarding carbohydrate accumulation, the superiority shifted from the bio-stimulated treatments (Spirulina and Tea Compost) in the first year to the Control treatment in the second year.

Table 2. Effect of some Bio materials on total phenols, antioxidant activity and total carbohydrate of Dragon fruit plants

Treatment	Total phenols (mg GAE/g)		Antioxidant activity (mg TE/g)		Total carbohydrate (%)	
	2023	2024	2023	2024	2023	2024
Control	15.77 c	13.52 e	23.05 b	17.79 e	12.69 c	15.94 a
Humic acid	12.28 c	15.45 d	13.33 d	20.45 c	10.86 d	12.57 e
Sea weed	13.38 c	12.60 f	16.65 cd	24.86 a	12.63 c	12.63 d
Tea Compost	21.31 b	16.36 c	22.40 bc	22.80 b	14.00 ab	14.10 c
Spirulina	30.52 a	18.05 a	33.25 a	16.14 f	14.23 a	14.93 b
Chitosan	14.49 c	17.89 b	15.37 d	19.45 d	13.26 bc	12.58 e

First round

Fruit firmness, fruit weight and shell weight

Table 3 illustrates the comparative effects of various biomaterials specifically humic acid, seaweed extract, tea fertilizer, spirulina, and chitosan on the physical quality parameters of dragon fruit plants. The evaluation covers two consecutive growing seasons (2023 and 2024), focusing on three key physical indicators: fruit firmness (g/m²), total fruit weight (g), and shell weight (g). These parameters are essential for determining the product's durability and post-harvest marketability.

Based on the data in Table 3, the bio-treatments significantly affected fruit firmness during both seasons. In 2023, seaweed recorded the highest firmness value, followed by humic acid, both of which showed statistical superiority over the spirulina and chitosan treatments. By the 2024 season, humic acid had the highest firmness value, while the lowest value was recorded for the chitosan treatment, which was significantly lower than the control group and most of the other treatments. Similarly, trends were reported by **Satish (2023)** on dragon fruit, **Elazazi *et al*. (2024)** on orange tree (*Citrus sinensis*) and **Sahu *et al.* (2023)** in dragon fruit (*Selenicereus monacanthu*) that using organic and bio organic increase where the application of organic and bio-organic fertilizers significantly increased the fruit firmness content.

Fruit weight responses varied between treatments and the control group. In the first season (2023), the control and chitosan groups achieved the highest numerical weights. In contrast, the seaweed and tea fertilizer treatments resulted in the lowest fruit weights. In the 2024 season, although chitosan maintained the highest numerical value, statistical analysis showed no statistically significant differences between all treatments. Similarly, trends were reported by **Satish (2023)** in dragon fruit, **Elazazi *et al.* (2024)** on orange tree (*Citrus sinensis*). where the application of organic and bio-organic fertilizers significantly increased fruit weight content.

Regarding shell weight, humic acid showed a clear trend in 2023, rising significantly to reach its highest shell weight in 2024. In contrast, tea fertilizer consistently produced the lowest shell weights in both seasons. The control group maintained a relatively high and stable shell weight compared to the seaweed and spirulina treatments, which showed a significant decrease in shell mass during the second season. Similarly, trends were reported by **Satish (2023)** in dragon fruit, **Elazazi *et al.* (2024)** on orange tree (*Citrus sinensis*). where the application of organic and bio-organic fertilizers significantly increased shell weight content.

The experimental data in Table 3 indicate that the application of bio-materials significantly influenced the physical attributes of Dragon fruit, with Seaweed and Humic acid demonstrating the highest efficacy in improving fruit firmness (g/m^2) across the 2023 and 2024 seasons, respectively. While the Control and Chitosan treatments maintained superior fruit weight (g) compared to other applications, treatments such as Tea Compost and Seaweed resulted in lower fruit mass. Additionally, humic acid led to a notable increase in shell weight by the second season, whereas Tea Compost consistently recorded the lowest shell biomass in both years. Overall, the results highlight a clear trade-off between structural firmness and fruit weight depending on the type of bio-material applied.

Overall, the results suggest that while some bio-materials like humic acid and Seaweed optimize structural quality (firmness), others like Chitosan are more effective in maintaining fruit mass.

Table 3. Effect of some Bio materials on fruit firmness, fruit weight and shell weight of Dragon fruit plants

Treatment	Fruit firmness(g/m^2)		Fruit weight(g)		Shell weight(g)	
	2023	2024	2023	2024	2023	2024
Control	392.33 ab	387.0abc	301.00 a	257.00 a	124.33 a	118.50 ab
Humic acid	410.00 a	432.33 a	227.50bc	234.83 a	94.33 bc	152.50 a
Sea weed	434.83 a	389.3abc	213.50 c	198.50 a	91.00 bc	75.00 bc
Tea Compost	407.33 a	376.00 bc	214.00 c	229.00 a	79.33 c	63.00 c
Spirulina	352.50 b	410.00 ab	279.00 ab	201.50 a	105.3 abc	80.00 bc
Chitosan	355.00 b	343.33 c	298.50 a	275.00 a	112.33 ab	83.00 bc

TSS, shell thickness and edible pulp weight

The data in Table 4 show the significant effect of various biostimulants on the quality parameters of dragon fruit *(Hylocereus undatus*) during the 2023 and 2024 seasons. The measured parameters total soluble solids (Brix), shell thickness, and edible pulp weight - show varying physiological responses to the treatments applied.

Statistical analysis revealed significant differences in total soluble solids (Brix) levels among the treatments applied. In both seasons, Spirulina exhibited the highest sugar content, peaking in 2023 and 2024, followed by the control and seaweed treatments. Conversely, the lowest Brix values were recorded with tea fertilizer in 2023 and remained among the lowest groups in 2024. Humic acid and chitosan showed identical Brix values across both seasons.

Similarly, trends were reported by **Satish (2023)** in dragon fruit, **Sahu *et al.* (2023)** in dragon fruit *(Selenicereus monacanthu)*. where the application of organic and bio-organic fertilizers significantly increased total soluble solids (Brix) content.

Regarding the physical characteristics of the fruit, tea fertilizer consistently produced the thickest peels in 2023 and 2024, significantly outperforming all other treatments. In contrast, the use of Spirulina algae resulted in the lowest peel thickness values. The remaining treatments, including humic acid, seaweed, and chitosan, showed average values throughout the study period. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased shell thickness content.

Data on edible pulp weight showed different trends between the two years: In 2023: No statistically significant differences were observed between most treatments, with the chitosan treatment recording the highest numerical value and the seaweed treatment the lowest.

In 2024: Statistically significant differences emerged between the treatments. The chitosan treatment maintained the highest edible pulp weight, while the spirulina treatment recorded the lowest. The tea fertilizer treatment showed a significant numerical increase in pulp weight from the first to the second season. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased edible pulp weight content.

The results indicated that the use of various bio-based materials significantly impacted the quality of dragon fruit during the 2023 and 2024 seasons. Spirulina treatment resulted in the highest total soluble solids (Brix) levels in both years, while simultaneously producing the thinnest peels. In contrast, tea fertilizer produced the thickest peel in the second season, although it registered lower sweetness values. Furthermore, chitosan was the most effective treatment for increasing edible pulp weight, while the other bio-based materials showed varying degrees of influence on the physicochemical properties of the fruit compared to the control group.

Table 4. Effect of some Bio materials on TSS, Shell thickness and Edible pulp weight of Dragon fruit plants

Treatment	TSS (Brix)		Shell thickness (mm)		Edible pulp weight(g)	
	2023	2024	2023	2024	2023	2024
Control	9.93 ab	10.73 bc	7.07 ab	7.20 ab	176.50 a	138.50 ab
Humic acid	9.00 b	11.50 b	5.67 bc	5.63 bc	133.00 a	149.00 ab
Sea weed	10.00 ab	10.00 c	5.42 bcd	5.81 bc	124.00 a	123.50 ab
Tea Compost	7.50 c	10.00 c	7.81 a	9.01 a	134.50 a	166.00 ab
Spirulina	10.93 a	13.73 a	3.55 d	2.58 d	140.17 a	121.50 b
Chitosan	9.00 b	11.50 b	4.62 cd	4.72 c	186.00 a	192.00 a

Fruit height, fruit diameter and height/diameter

Table 5 presents the comparative effects of various bio-material treatments specifically Humic Acid, Seaweed, Tea Compost, Spirulina, and Chitosan on the vegetative growth parameters of Dragon fruit plants. The evaluation focuses on fruit Height (H), fruit Diameter (D), and the Height/Diameter (H/D) ratio over two consecutive growing seasons (2023 and 2024). The data includes statistical significance markers, where mean values followed by different letters indicate significant differences at (LSD at 0.05).

According to the data in Table 5, significant differences were found between the treatments with respect to plant height. The humic acid treatment achieved the highest values in both seasons, representing a significant increase compared to the control group, which recorded the lowest height. The other treatments, including seaweed, tea fertilizer, Spirulina, and chitosan, showed intermediate values, indicating no significant differences between them and either the highest-performing treatment or the control group. Similarly, trends were reported by **Satish (2023)** dragon fruit. where the application of organic and bio-organic fertilizers significantly increased fruit height content.

Similarly, trends were reported by **Elazazi *et al.* (2024)** on orange tree *(Citrus sinensis)*. where the application of organic and bio-organic fertilizers significantly un increase fruit height content.

Stem diameter response showed a fluctuating trend between the two study years: in the 2023 season, the chitosan and control groups recorded the highest diameter values, while humic acid and seaweed recorded the lowest. In the 2024 season, a shift occurred, with humic acid significantly outperforming the other treatments, reaching a peak value. Conversely, Spirulina recorded the lowest diameter in the second season.

Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased fruit Diameter (D) content.

The height-to-diameter ratio, which reflects the relationship between vertical and radial growth, showed the following: Humic acid had the highest significant ratio in 2023. In 2024, the highest ratio was observed in the Spirulina treatment, while the control and chitosan treatments consistently maintained the lowest ratios. Overall, all biomaterial treatments resulted in a higher height-to-diameter ratio compared to the control treatment, indicating a greater relative increase in height compared to diameter. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased height/diameter content.

Statistical analysis showed that humic acid had the most stable and superior effect on plant parameters measured over two years. While other substances, such as tea fertilizer and seaweed, showed positive trends, their effects were often statistically similar to both the control group and the best-performing treatments.

Table 5. Effect of some Bio materials on fruit height, fruit diameter and height/diameter of Dragon fruit plants.

Treatment	Fruit height(H)(mm)		Fruit diameter (D)(mm)		Height/Diameter (H/D)(mm)	
	2023	2024	2023	2024	2023	2024
Control	90.56 b	90.56 b	76.78 a	75.09 ab	1.176 b	1.20 b
Humic acid	112.45 a	112.45 a	68.88 b	80.11 a	1.64 a	1.40 ab
Sea weed	92.57 ab	92.57 ab	69.42 b	66.16 ab	1.33 b	1.40 ab
Tea Compost	100.68 ab	100.68 ab	73.06 ab	74.73 ab	1.38 b	1.35 ab
Spirulina	98.93 ab	98.93 ab	75.99 a	64.32 b	1.30 b	1.56 a
Chitosan	96.65 ab	96.69 ab	78.87 a	74.84 ab	1.22 b	1.29 b

Second round

Fruit firmness, fruit weight and shell weight

The data presented in Table 6 illustrate the influence of various bio-materials on the physical characteristics of dragon fruit across the 2023 and 2024 growing seasons.

In the 2023 season, significant differences were observed between the treatments. The chitosan treatment achieved the highest firmness, significantly outperforming both the control group and the humic acid treatment. The other treatments, including seaweed, tea fertilizer, and Spirulina, showed intermediate values with no statistically significant differences between them. In contrast, in the 2024 season, no statistically significant differences were observed between any of the treatments. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased fruit firmness content.

Regarding fruit weight in 2023, seaweed recorded the highest weight, followed by the control group, then tea fertilizer, and finally Spirulina, with no statistically significant differences between these four groups. However, the use of humic acid and chitosan resulted in a significant decrease in fruit weight compared to the seaweed treatment. In 2024, the effect of all the biomaterials on fruit weight was not statistically significant, as all treatments were classified within the same statistical group. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased fruit weight content.

Similarly, trends were reported by **Samra *et al.* (2017)** on Washington navel orange (*Citrus sinensis L. Osbeck*). where the application of organic and bio-organic fertilizers significantly unincrease fruit weight content.

Significant differences in shell weight were observed across both seasons. In 2023, spirulina treatment resulted in a significantly higher shell weight compared to all other treatments. Chitosan followed, while the lowest shell weights were recorded for seaweed and humic acid. In the 2024 season, tea fertilizer achieved the highest shell weight, significantly higher than seaweed, while all other treatments showed statistically significant overlapping intermediate results. Similarly, trends were reported by **Satish (2023)** in dragon fruit. where the application of organic and bio-organic fertilizers significantly increased shell weight content.

In the 2023 and 2024 seasons, the use of bio-supplements significantly improved dragon fruit quality. Tea fertilizer emerged as the most effective treatment for increasing fruit weight and firmness over time. Chitosan was particularly effective in maximizing fruit firmness during the first season, while seaweed extract achieved the highest initial fruit weight. Notably, Spirulina algae caused a significant and unique increase in shell weight in 2023, while humic acid showed the least effect on overall fruit mass. Although the statistical differences were most pronounced in the first year, the second year showed a trend toward stabilization, with the bio-supplements generally maintaining better physical properties compared to the control group. Similarly, trends were reported by **Satish (2023)** in dragon fruit, where the application of organic and bio-organic fertilizers significantly increased shell weight content.

Table 6. Effect of some Bio materials on fruit firmness, fruit weight and shell weight of Dragon fruit plants

Treatment	Fruit firmness(g/m^2)		Fruit weight(g)		Shell weight(g)	
	2023	2024	2023	2024	2023	2024
Control	398.33 b	420.00 a	330.33ab	271.33 a	105.33 b	84.33 ab
Humic acid	384.17 b	437.00 a	202.33 b	236.00 a	69.00 c	90.00 ab
Sea weed	443.33 ab	403.00 a	357.00 a	337.00 a	64.00 c	77.00 b
Tea Compost	443.33 ab	454.00 a	323.00ab	349.00 a	106.67 b	114.67 a
Spirulina	440.83 ab	447.33 a	328.33ab	297.67 a	328.33 ab	97.67 ab
Chitosan	470.83 a	430.67 a	227.00 b	297.67 a	138.33 a	106.00 ab

TSS, Shell thickness and Edible pulp weight

In the table 7, The effects of various organic and biological treatments on the physicochemical quality attributes of dragon fruit were evaluated over two consecutive seasons (2023 and 2024). The parameters assessed included total soluble solids (Brix), shell thickness, and edible pulp weight. Statistical analysis revealed distinct variations in treatment efficacy during the first season, whereas the second season showed a tendency toward statistical uniformity among the experimental groups.

In the 2023 season, chitosan treatment achieved the highest total soluble solids (Brix) values, demonstrating a significant improvement compared to the other treatments (control group, seaweed, and humic acid). No statistically significant difference was observed between the seaweed, humic acid, compost tea, and Spirulina treatments, while the seaweed treatment showed the smallest statistically significant difference compared to the other treatments. This improvement is attributed to chitosan's role in stimulating secondary plant metabolism and increasing the translocation of photosynthetic products to the fruit. However, during the 2024 season, the differences between all treatments became statistically equal, indicating that the accumulation of total soluble solids became more stable across the various organic treatments. Similarly, trends were reported by **Satish (2023) in** dragon fruit, **Samra *et al.* (2017)** on Washington navel orange (*Citrus sinensis L. Osbeck*). where the application of organic and bio-organic fertilizers significantly increased total soluble solids (Brix) content.

The data indicate Shell thickness that chitosan treatment surpassed other treatments in concentration levels throughout the study. Comparative analysis in the first season revealed that Spirulina, compost tea, and humic acid treatments were statistically comparable to the control. Furthermore, the seaweed treatment did not significantly differ from compost tea. Notably, the second season exhibited a lack of statistical significance across all experimental groups, with chitosan, Spirulina, seaweed, and the remaining treatments performing similarly to the control. Similarly, trends were reported by **Satish (2023) in** dragon fruit, **Samra *et al.* (2017)** on Washington navel orange (*Citrus sinensis L. Osbeck*), where the application of organic and bio-organic fertilizers significantly increased Shell thickness content.

Table 7. Effect of some Bio materials on TSS, shell thickness and edible pulp weight of Dragon fruit plants.

Treatment	TSS(Brix)		Shell thickness (mm)		Edible pulp weight(g)	
	2023	2024	2023	2024	2023	2024
Control	10.00 abc	9.33 a	3.27 c	4.00 ab	225.00 ab	187.00 a
Humic acid	9.16 bc	9.33 a	3.69 c	2.08 b	133.33 b	179.33 a
Sea weed	8.33 c	10.00 a	5.83 b	2.43 b	216.33 ab	260.00 a
Tea Compost	10.66 ab	10.33 a	4.44 bc	3.70 ab	216.33 ab	234.33 a
Spirulina	10.83 ab	10.66 a	3.47 c	3.59 ab	216.33 ab	199.00 a
Chitosan	11.66 a	10.00 a	10.10 a	5.76 a	255.33 a	259.67 a

Regarding the edible pulp weight in 2023, the Chitosan treatment yielded the highest weight, while the humic acid treatment showed the lowest significant value. Interestingly, by the 2024 season, all treatments including the control exhibited non-significant differences. This uniformity in the second season indicates that while certain biostimulants can accelerate pulp development initially, the long-term productivity tends to stabilize across various organic applications. Similarly, trends were reported by **Satish (2023) in** dragon fruit, **Samra *et al.* (2017)** on Washington navel orange (*Citrus sinensis L. Osbeck*) where the application of organic and bio-organic fertilizers significantly increased edible pulp weight content.

The results indicated that chitosan treatment was the most effective in improving fruit quality during the 2023 season, registering the highest values for Brix index and peel thickness. While significant differences were evident in the first year, particularly with humic acid, which showed lower edible pulp weight compared to the other treatments, these differences diminished considerably in the 2024 season. By the second year, all treatments, including the control group, showed statistical equivalence in Brix index and edible pulp weight, suggesting that long-term use of these biostimulants leads to stable fruit quality parameters.

Fruit height, fruit diameter and height/diameter

The vegetative growth parameters, specifically fruit Height (H), fruit Diameter (D), and the Height-to-Diameter ratio (H/D), were evaluated to assess the structural response of the plants to various organic biostimulants. The data, summarized in Table 8, indicate a high degree of statistical homogeneity across the majority of the tested variables.

Regarding the fruit height, Statistical analysis revealed no significant differences between the control group and the other treatments across both growing seasons. Similarly, trends were reported **Satish (2023)** in dragon fruit, where the application of organic and bio-organic fertilizers significantly increased fruit Height content.

Similarly, trends were reported by **Elazazi *et al.* (2024)** on orange tree *(Citrus sinensis)*, where the application of organic and bio-organic fertilizers significantly un increased fruit height content.

Regarding the fruit diameter, the effects of all treatments were comparable to the control in both seasons; however, the humic acid treatment during the first season resulted in a significant reduction relative to the control and other treatments. Similarly, trends were reported by **Satish (2023)** in dragon fruit, where the application of organic and bio-organic fertilizers significantly increased fruit Diameter content.

Regarding the fruit shape index (H/D) ratio, In the first season, the humic acid treatment was significantly superior to most other treatments, though it did not differ significantly from the Spirulina treatment. Meanwhile, the control group showed statistical parity with seaweed, compost tea, Spirulina, and chitosan treatments. In contrast, during the second season, no significant variations were observed between the control and any of the other experimental treatments. Similarly, trends were reported by **Satish (2023)** in dragon fruit, where the application of organic and bio-organic fertilizers significantly increased height/diameter content.

Experimental results showed a clear divergence between vegetative and reproductive responses to the application of biostimulants. While structural parameters such as height and diameter remained statistically stable across both seasons indicating a consistent growth structure reproductive performance was significantly prioritized. Specifically, tea fertilizer, Spirulina, and chitosan maximized flowering, while humic acid and tea fertilizer improved the conversion rate, leading to peak fruit set, respectively. These results suggest that the organic amendments act as metabolic stimulants, reallocating internal resources toward reproductive sinks rather than plant biomass.

Table 8. Effect of some Bio materials on fruit height, fruit diameter and height/diameter of Dragon fruit plants

Treatment	Fruit height(H)(mm)		Fruit diameter (D)(mm)		Height/Diameter (H/D)(mm)	
	2023	2024	2023	2024	2023	2024
Control	101.75 a	101.75 a	77.75 a	67.17 a	1.31 b	1.52 a
Humic acid	112.04 a	112.04 a	64.35 b	77.59 a	1.75 a	1.45 a
Sea weed	102.95 a	102.95 a	78.52 a	72.79 a	1.31 b	1.45 a
Tea Compost	106.75 a	106.75 a	77.03 a	78.07 a	1.38 b	1.37 a
Spirulina	107.76 a	107.76 a	73.38 a	71.99 a	1.47 ab	1.50 a
Chitosan	106.12 a	103.17 a	78.38 a	71.46 a	1.35 b	1.44 a

Number of flowers, fruit set and productivity

Table 9 provides a comparative analysis of the floral and yield-component responses to different organic treatments during the 2023 and 2024 seasons. The primary variables assessed include the Number of Flowers, representing the dragon fruit reproductive potential, tree productivity and the Fruit Set %, which serves as an indicator of pollination efficiency and fruit retention. These results the physiological impact of biostimulants such as Chitosan and Humic acid on the transition from flowering to fruit development under the experimental conditions.

In the first season, the highest flowering stimulation was observed in dragon fruit plants treated with chitosan, compost tea, and seaweed extract, with no significant differences between them and the humic and Spirulina treatments. The control group showed the lowest significant results, with no significant differences between it and the humic and Spirulina treatments.

In the second season, the flowering response was significantly higher in the organic fertilizer tea, Spirulina, and chitosan treatments, with no significant difference compared to humic acid, representing a notable improvement compared to the previous year. The control group showed significantly lower flowering compared to the other treatments, and no significant differences were found between the humic acid and seaweed treatments. Similarly, trends were reported by **Siddiqua *et al.* (2022)** on dragon fruit, **Satish (2023)** on dragon fruit, **Khatun *et al.* (2023)** on dragon fruit *(Hylocereus undatus Haw.)*, where the application of organic and bio-organic fertilizers significantly increased number of flower content.

In the first season, Chitosan treatment demonstrated superior efficacy, achieving the highest fruit set. This was followed closely by Seaweed, Tea Compost, and Spirulina, which were statistically at par with each other. In contrast, the Control group recorded the lowest reproductive efficiency.

In the second season, the humic acid treatment had a significantly higher percentage compared to the other treatments, while the control treatment had a significantly lower percentage. No statistically significant differences were observed between the control and chitosan treatments, nor between the seaweed and Spirulina treatments. Similarly, no statistically significant difference was observed between the humic acid and compost tea treatments. Similarly, trends were reported by **Satish (2023)** on dragon fruit, **Khatun *et al.* (2023)**, on dragon fruit (Hylocereus undatus Haw.) **Siddiqua *et al*. (2022)** on dragon fruit, where the application of organic and bio-organic fertilizers significantly increased fruit set content.

In contrast to the flowering parameters, tree productivity exhibited an inverse trend. The untreated Control maintained the highest significant productivity in both seasons. Among the biostimulants, Chitosan was the only treatment that remained statistically equal to the control, preserving high productivity. Conversely, treatments like Seaweed and Tea Compost resulted in the lowest productivity values in both years

Major Improvement in Flowering and Fruit Set: All evaluated biostimulants significantly enhanced flower numbers and fruit set percentage compared to the control. Chitosan led the flowering in 2023, while Tea Compost and Spirulina excelled in 2024. The highest fruit set was achieved by Chitosan and Humic acid in 2023 and 2024, respectively. Similarly, trends were reported by **Satish (2023)** in dragon fruit, **Khatun *et al*. (2023)** on dragon fruit *(Hylocereus undatus Haw.)* where the application of organic and bio-organic fertilizers significantly increased tree production content.

The Productivity Trade-off: A clear inverse relationship was detected between reproductive success and final yield. The untreated Control maintained the highest tree productivity, while most biostimulants (particularly Seaweed and Tea Compost) resulted in a significant reduction in productivity due to resource depletion caused by heavy flowering. Chitosan as the Optimum Solution: Chitosan was the most effective and balanced treatment among all tested materials. It successfully broke the inverse trend by significantly boosting flowering and fruit set while maintaining high tree productivity statistically equal to the control group.

Crop yield (2023) =75,77kg/plot

Crop yield (2024) = 89,12kg/plot

Table 9. Effect of some Bio materials on number of flowers, fruit set and productivity of Dragon fruit plants

Treatment	Number of Flowers		Fruit Set %		Tree productivity(kg)	
	2023	2024	2023	2024	2023	2024
Control	26.66 b	24.33 c	50.33 c	49.33 d	301.00 a	301.00 a
Humic acid	40.00 ab	64.00 ab	54.33 bc	73.33 a	227.50 bc	227.50 bc
Sea weed	59.66 a	60.00 b	64.00 ab	63.00 bc	213.50 c	213.50 i
Tea Compost	52.33 a	76.33 a	64.00 ab	66.00 ab	210.67 c	214.00 c
Spirulina	44.00 ab	76.33 a	64.00 ab	60.33 bc	279.00 ab	279.00 ab
Chitosan	60.66 a	76.33 a	68.33 a	56.33 cd	298.50 a	298.50 a

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