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COMPARATIVE EFFICACY OF UREA AND NANO UREA ON STEM ARCHITECTURE, CHLOROPHYLL CONTENT AND NUTRIENT STATUS OF DRAGON FRUIT (*Hylocereus costaricensis* WEB. BRITTON AND ROSE)

Neha[1*], Sutanu Maji[1], Kaustubh Y. Deshmukh[2], Krishna Jat[1], Nisha Kumari[3], Sarjesh Kumar Meena[1] and Tendul Chouhan[1]

[1]Department of Horticulture, Babasaheb Bhimrao Ambedkar University (A Central University), Vidya-Vihar, Raebareli Road, Lucknow- 226025 (U.P.), India.

[2]Department of Fruit Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola- 444104 (M.H.), India.

[3]*Division of Vegetable Science, ICAR-Indian Agricultural Research Institute*, New Delhi- 110012, India

*Corresponding author E-mail: nehakajla6@gmail.com

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ABSTRACT

Dragon fruit (*Hylocereus costaricensis*) is an emerging superfruit with immense commercial potential in subtropical regions. The present investigation evaluated the comparative effects of conventional urea and nano urea on number of segments per plant, stem circumference, arch height, chlorophyll content and plant nutrient status (N, P and K) of dragon fruit. The experiment comprised ten treatments laid out in Randomized Block Design with three replications carried out during 2022–2023 at Babasaheb Bhimrao Ambedkar University, Lucknow. Findings revealed that combined application of 2% N_2 through urea + 6 ml/L nano urea (T_6) significantly enhanced number of segments per plant (3.33 total increase), stem circumference (0.68 cm), arch height (0.6 mm) and chlorophyll content (4.261 mg/100g total), while RDF (T_1) recorded maximum available nitrogen (1.76%). The study concluded that integrated use of conventional urea with nano urea can substantially improve vegetative growth parameters, recommending nutrient management practice for dragon fruit cultivation.

***Key words*:** Dragon fruit, nano urea, conventional urea, vegetative growth, chlorophyll content

Introduction

Dragon fruit (*Hylocereus* spp.), a member of the Cactaceae family (2n = 22), has emerged as a commercially important crop owing to its nutritional and medicinal properties. Native to Mexico and Central America (Britton and Rose, 1963; Morton, 1987), the crop is now cultivated across tropical and subtropical regions globally. In India, dragon fruit was introduced during the late 1990s, with cultivation expanding from 4 to 400 hectares between 2005 and 2017 (Karunakaran and Arivalgan, 2019).

The Dragon fruit is known for its adaptability to marginal lands, drought tolerance and high nutritional value. The fruit is rich in vitamin C, phosphorus, calcium and antioxidants (Morton, 1987), with red-fleshed varieties containing beneficial betalains and essential fatty acids (Sonawane, 2017). Being a Crassulacean Acid Metabolism (CAM) plant, dragon fruit thrives in areas of high temperature and water scarcity, making it suitable for degraded soils.

Despite its commercial potential, information on nutritional management of dragon fruit remains limited (Costa *et al*., 2015). Judicious fertilizer application is essential for optimal growth and yield (Nangare *et al*., 2020). Nano-fertilizers, defined as nutrients encapsulated in nano-scale particles (<100 nm), offer advantages including enhanced nutrient uptake, controlled release and improved soil health (Rai *et al*., 2012; Tarafdar *et al*., 2014). Nano urea, developed by IFFCO, contains nitrogen particles (20–50 nm) with 10,000 times more surface area

than conventional urea prills, enhancing nutrient use efficiency by over 80% (Anon., 2005).

The present investigation was undertaken to evaluate the comparative effects of conventional urea and nano urea on stem architecture, chlorophyll content and nutrient status of Dragon fruit.

Materials and Methods

The experiment was conducted at the dragon fruit orchard, Department of Horticulture, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, India (26°55' N, 80°54' E; 123 m above MSL) during 2022–2023. The region experiences a subtropical climate with hot summers (Max. 45°C) and cold winters (Min. 2°C), with annual rainfall of approximately 700 mm.

The experimental soil was sandy loam, slightly alkaline (pH 8.1), with available N (188.3 kg/ha), P_2O_5 (32.8 kg/ha), K_2O (491.7 kg/ha), and organic carbon (0.12%).

There were 30 poles each having 4 plants planted at 4 m × 2 m spacing. The base area of 1m radius was cleaned for fertilizer and irrigation management. Plants along with new growth are tied up with pole regularly for better support.

The experimental site accommodated 30 dragon fruit poles, each planted with four plants at a spacing of 4 m × 2 m. A 1 m radius apart trench of 30 cm depth was excavated around each pole to facilitate fertilizer application and irrigation. Regular tying of plants and new growth to the supporting poles was carried out to ensure proper support and canopy management.

The experiment was laid out in a Randomized Block Design (RBD) with three replications and ten treatments *viz.*, T_0: Control (water spray), T_1: RDF (Recommended dose of fertilizers), T_2: 2% N_2 through urea as foliar spray, T_3: 1.5% N_2 through urea as foliar spray, T_4: 6 ml/L nano urea as foliar spray, T_5: 4 ml/L nano urea as foliar spray, T_6: 2% N_2 through urea + 6 ml/L nano urea, T_7: 2% N_2 through urea + 4 ml/L nano urea, T_8: 1.5% N_2 through urea + 6 ml/L nano urea and T_9: 1.5% N_2 through urea + 4 ml/L nano urea

RDF (200 g N, 225 g P_2O_5, 137.5 g K_2O per pole) along with well-rotted FYM @ 16 kg/pole and Vermicompost @ 8 kg/pole was applied as soil application, while urea and nano urea were applied twice as foliar sprays. Observations were recorded at 30, 45, 60, 75 and 90 days after treatment (DAT).

Observations of vegetative growth parameters were recorded *viz.*, number of segments per plant, stem circumference (cm), Arch height (mm) each at intervals of 30, 45, 60, 75 and 90 DAT. Chlorophyll content (mg/100g) was estimated using 80% acetone extraction followed by spectrophotometric analysis (Thimmaiah, 2009). Plant nutrient status (N, P and K) was analyzed at Indian Institute of Sugarcane Research (IISR), Lucknow, using Kjeldahl distillation, Olsen's method and flame photometry, respectively. (Jackson, 1973; A.O.A.C., 1980)

Data were analyzed using analysis of variance

Table 1: Effect of Urea and Nano Urea on increase of number of segments per plant at different growth stages of Dragon fruit.

Treatments	NSPP		NSPP 45 DAT	INSPP 45 DAT from 30 to 45 DAT	NSPP 60 DAT	INSPP 60 DAT from 45 to 60 DAT	NSPP 75 DAT	INSPP 75 DAT from 60 to 75 DAT	NSPP 75 DAT	INSPP 90 DAT from 60 to 90 DAT	TIC from 30 to 90 DAT
	30 DAT	45 DAT									
T_0	3.33	3.33	0.00	3.67	0.34	4.00	0.33	4.33	0.33	1.00	130.00
T_1	4.67	4.67	0.00	5.33	0.67	6.33	1.00	7.00	0.67	2.33	150.00
T_2	5.00	5.67	0.67	6.33	1.33	7.00	0.67	7.00	0.00	2.00	140.00
T_3	4.33	4.67	0.34	4.33	0.00	5.67	1.33	6.33	0.67	2.00	146.15
T_4	5.00	5.00	0.00	5.67	0.67	6.67	1.00	6.67	0.00	1.67	133.40
T_5	5.00	5.00	0.00	5.33	0.33	6.00	0.67	6.00	0.00	1.00	120.00
T_6	4.00	4.33	0.33	4.33	0.33	5.67	1.33	7.33	1.66	3.33	183.25
T_7	5.00	5.33	0.33	5.00	0.00	6.33	1.33	6.67	0.33	1.67	133.33
T_8	4.67	4.67	0.00	5.00	0.33	6.33	1.33	6.67	0.34	2.00	142.93
T_9	5.00	5.00	0.00	5.33	0.33	6.33	1.00	6.67	0.33	1.67	133.33
SE(m)			0.004		0.007		0.012		0.006	0.246	
CD at 5%	-	-	0.011	-	0.020	-	0.037	-	0.019	0.743	-

NSPP: No. of segments per plant; INSPP: Increase in no. of segments per plant at 45 DAT (from 30 to 45 DAT);
TIC: Total increase over; T_1: RDF (Recommended dose of fertilizers), T_2: 2% N_2 through urea as foliar spray, T_3: 1.5% N_2 through urea as foliar spray, T_4: 6 ml/L nano urea as foliar spray, T_5: 4 ml/L nano urea as foliar spray, T_6: 2% N_2 through urea + 6 ml/L nano urea, T_7: 2% N_2 through urea + 4 ml/L nano urea, T_8: 1.5% N_2 through urea + 6 ml/L nano urea and T_9: 1.5% N_2 through urea + 4 ml/L nano urea

(ANOVA) for RBD as suggested by Fisher (1950). Treatment means were compared using critical difference (CD) at 5% level of significance.

Results and Discussion

Number of Segments per Plant

The number of segments per plant showed non-significant variation at most stages (Table 1). At 45 DAT, T_2 recorded the maximum increase (0.67), while at 60 DAT, T_2 again showed the highest increase (1.33). At 75 DAT, T_3, T_6, T_7 and T_8 recorded equal increases (1.33). At 90 DAT, T_6 showed the maximum increase (1.66).

The overall increase from 30 to 90 DAT was maximum in T_6 (3.33), followed by T_1 (2.33), with minimum in T_0 and T_5 (1.00). The non-significant changes from 60 to 90 DAT suggest that segment number may be governed by genetic makeup and less influenced by nutrient management during later stages. However, the cumulative effect of combined treatment (T_6) indicates that nano urea enhances nutrient availability over an extended period, supporting segment development. These findings align with Kumar *et al.*, (2021), who reported yield increases of 6.87% in wheat, 9.38% in maize and 9.34% in barley with nano-N application.

The superiority of T_6 for total segment increase (3.33) compared to control (1.00) demonstrates the potential of integrated nutrient management for enhancing this parameter. The non-significant nature of the results, however, indicates that segment number is predominantly governed by genetic factors, with nutrient treatments having a modulating influence rather than a determining role.

Stem Circumference

Stem circumference showed significant variation across treatments as depicted in Table 2. At 45 DAT, T_2 and T_7 recorded the maximum increase (0.14 cm), followed by T_4 (0.11 cm). At 60 DAT, T_7 showed the highest increase (0.17 cm), while at 75 DAT, T_4 recorded the maximum increase (0.34 cm). At 90 DAT, T_4 again showed the highest increase (0.34 cm).

The overall increase from 30 to 90 DAT was maximum in T_4 (0.68 cm), followed by T_2 (0.55 cm), compared to the control (0.09 cm). The superior performance of T_4 (6 ml/L nano urea) at later stages (75 and 90 DAT) suggests that nano urea provides sustained nitrogen release, supporting continuous stem expansion. The highest rate of increase at 90 DAT coincides with rising temperatures, indicating temperature-dependent nutrient uptake.

The maximum stem circumference at 90 DAT (12.64 cm) was recorded in T_2, while T_4 (6 ml/L nano urea) showed the greatest overall increase (0.68 cm) from 30 to 90 DAT which also showed the greatest overall increase. These results corroborate the findings of Ibrahim *et al.*, (2022), who reported significant effects of NPK fertilizer on stem girth. The significant increase in stem circumference with nano urea treatments (T_4, T_5) and combined treatments (T_6, T_7) can be ascribed to improved nitrogen assimilation and carbohydrate accumulation, as nano urea enhances root growth and shoot establishment

Table 2: Effect of Urea and Nano Urea on increase of stem circumference (cm) at different growth stages of Dragon fruit.

Treatments	SC (cm)		ISC at 45 DAT (cm) from 30 to 45 DAT	SC at 60 DAT (cm)	ISC at 60 DAT (cm) from 45 to 60 DAT	SC at 75 DAT (cm)	ISC at 75 DAT (cm) from 60 to 75 DAT	SC at 90 DAT (cm)	ISC at 90 DAT (cm) from 75 to 90 DAT	TI (cm) from 30 to 90 DAT	TIO (%)
	30 DAT	45 DAT									
T_0	10.20	10.25	0.05	10.23	0.03	10.24	0.04	10.33	0.09	0.13	101.31
T_1	11.57	11.67	0.10	11.62	0.05	11.72	0.15	11.82	0.10	0.25	102.16
T_2	12.20	12.34	0.14	12.27	0.07	12.39	0.19	12.64	0.25	0.44	103.61
T_3	13.83	13.89	0.05	13.86	0.03	13.94	0.11	14.04	0.10	0.20	101.47
T_4	10.87	10.97	0.11	10.92	0.05	11.21	0.34	11.55	0.34	0.68	106.29
T_5	11.43	11.47	0.03	11.45	0.02	11.51	0.08	11.69	0.18	0.25	102.22
T_6	12.90	13.00	0.10	12.95	0.05	13.02	0.12	13.17	0.15	0.27	102.07
T_7	11.23	11.37	0.14	11.40	0.17	11.51	0.28	11.57	0.06	0.34	103.00
T_8	11.13	11.20	0.07	11.17	0.03	11.26	0.13	11.47	0.21	0.33	102.99
T_9	11.80	11.85	0.05	11.82	0.02	11.96	0.16	12.04	0.08	0.24	102.01
SE(m)			0.001		0.001		0.003		0.002	0.006	
CD at 5%	-	-	0.004	-	0.003	-	0.010	-	0.007	0.018	-

SC: Stem circumference (cm); ISC: Increase in stem circumference; TI: Total increase; TIO: Total increase over; T_1: RDF (Recommended dose of fertilizers), T_2: 2% N_2 through urea as foliar spray, T_3: 1.5% N_2 through urea as foliar spray, T_4: 6 ml/L nano urea as foliar spray, T_5: 4 ml/L nano urea as foliar spray, T_6: 2% N_2 through urea + 6 ml/L nano urea, T_7: 2% N_2 through urea + 4 ml/L nano urea, T_8: 1.5% N_2 through urea + 6 ml/L nano urea and T_9: 1.5% N_2 through urea + 4 ml/L nano urea

Table 3: Effect of Urea and Nano Urea on increase of arch height at different growth stages of Dragon fruit.

Treatments	AH (mm)		IAH at 45 DAT (mm) from 30 to 45 DAT	AH at 60 DAT (mm)	IAH at 60 DAT (mm) from 45 to 60 DAT	AH at 75 DAT (mm)	IAH at 75 DAT (mm) from 60 to 75 DAT	AH at 90 DAT (mm)	IAH at 90 DAT (mm) from 75 to 90 DAT	TI (mm) from 30 to 90 DAT	TIO (%)
	30 DAT	45 DAT									
T_0	3.2	3.3	0.1	3.4	0.2	3.5	0.1	3.5	0.0	0.3	109.38
T_1	4.2	4.2	0.0	4.4	0.2	4.5	0.1	4.5	0.0	0.3	107.14
T_2	5.3	5.4	0.1	5.5	0.2	5.7	0.2	5.8	0.1	0.5	109.43
T_3	4.8	5.0	0.2	5.1	0.3	5.2	0.1	5.2	0.0	0.4	108.33
T_4	2.6	2.8	0.2	2.9	0.3	3.0	0.1	3.0	0.0	0.4	115.38
T_5	3.8	3.9	0.1	4.2	0.4	4.3	0.1	4.3	0.0	0.5	113.16
T_6	4.1	4.1	0.0	4.3	0.2	4.5	0.2	4.7	0.2	0.6	114.63
T_7	2.5	2.6	0.1	2.7	0.2	2.8	0.1	2.8	0.0	0.3	112.00
T_8	2.3	2.4	0.1	2.5	0.2	2.7	0.2	2.7	0.0	0.4	117.39
T_9	3.1	3.1	0.0	3.2	0.1	3.3	0.1	3.3	0.0	0.2	106.45
SE(m)			0.001		0.003		0.001		0.002	0.006	
CD at 5%	-	-	0.004	-	0.008	-	0.003	-	0.005	0.018	-

IAH: Increase in arch height at 45 DAT (mm) (from 30 to 45 DAT); AH: Arch height at 60 DAT (mm); TI: Total increase; TIO: Total increase over; T_1: RDF (Recommended dose of fertilizers), T_2: 2% N_2 through urea as foliar spray, T_3: 1.5% N_2 through urea as foliar spray, T_4: 6 ml/L nano urea as foliar spray, T_5: 4 ml/L nano urea as foliar spray, T_6: 2% N_2 through urea + 6 ml/L nano urea, T_7: 2% N_2 through urea + 4 ml/L nano urea, T_8: 1.5% N_2 through urea + 6 ml/L nano urea and T_9: 1.5% N_2 through urea + 4 ml/L nano urea

(Nair *et al.*, 2012).

The 0.68 cm increase in stem circumference under T_4 compared to 0.09 cm in control, suggests the efficacy of nano urea for this parameter. The significant variation across treatments confirms that stem circumference is responsive to nutrient management, unlike some other parameters.

Arch Height

Arch height showed non-significant variation across treatments as presented in Table 3. At 45 DAT, T_3 and T_4 recorded the maximum increase (0.2 mm). At 60 DAT, T_5 showed the highest increase (0.4 mm). At 75 DAT, T_2, T_6 and T_8 recorded the maximum increase (0.20 mm), while at 90 DAT, T_6 showed the highest increase (0.2 mm).

The overall increase from 30 to 90 DAT was maximum in T_6 (0.6 mm), followed by T_3 and T_5 (0.4 mm), with minimum in T_9 (0.2 mm). The non-significant nature of these results, particularly at 90 DAT, suggests that arch height may be governed by genetic makeup. However, the superiority of T_6 indicates that combined nutrient application may have a positive influence on arch height development.

The highest rate of increase at 60 DAT coincides with rising temperatures suggesting temperature-dependent morphological development. The 0.6 mm increase in arch height under T_6 compared to 0.3 mm in control represents a 100% improvement, though the non-significant nature of the results indicates that this parameter is predominantly under genetic control. The results are consistent with the findings of Maurya *et al.*, (2023), who reported vegetative growth promotion with nano urea application.

Chlorophyll Content

Chlorophyll content increased significantly with treatment applications as mentioned in Table 4. Chlorophyll A was maximum in T_6 (2.237 mg/100g), followed by T_2 and T_8 (2.172 mg/100g), compared to the control (0.174 mg/100g). Chlorophyll B was also maximum in T_6 (2.024 mg/100g), followed by T_2 (1.618 mg/100g). Total chlorophyll content was maximum in T_6 (4.261 mg/100g), followed by T_2 (3.694 mg/100g) and T_8 (3.306 mg/100g), compared to the control (0.223 mg/100g).

The significant enhancement in chlorophyll content with T_6 treatment can be attributed to the synergistic effect of conventional urea and nano urea. Nano urea enhances nitrogen availability, which is a key component of chlorophyll molecules. The higher chlorophyll content in T_6 indicates improved photosynthetic efficiency, which translates to enhanced vegetative growth.

The 4.261 mg/100g total chlorophyll content in T_6 compared to 0.223 mg/100g in control, demonstrating the profound effect of integrated nutrient management on photosynthetic pigment synthesis. These results are consistent with Abdel Wahab *et al.*, (2019), who reported increased plant growth with nano fertilizer application in red radish. The significant variation across treatments confirms that chlorophyll content is highly responsive to nutrient management, making it a reliable indicator of plant nutritional status.

The maximum chlorophyll A (2.237 mg/100g) and

Table 4: Effect of Urea and Nano urea on increase of chlorophyll content from 30 DAT to 90 DAT different growth stages of Dragon fruit.

Treatments	Chlorophyll A	Chlorophyll B	Total
T_0	0.17	0.05	0.22
T_1	1.26	1.11	2.36
T_2	2.08	1.62	3.69
T_3	1.13	0.18	1.32
T_4	1.12	0.47	1.59
T_5	1.38	0.76	2.14
T_6	2.24	2.02	4.26
T_7	1.30	0.28	1.55
T_8	2.17	1.13	3.31
T_9	1.03	0.12	1.15
SE(m)	0.021	0.015	0.027
CD at 5%	0.064	0.044	0.081

T_1: RDF (Recommended dose of fertilizers), T_2: 2% N_2 through urea as foliar spray, T_3: 1.5% N_2 through urea as foliar spray, T_4: 6 ml/L nano urea as foliar spray, T_5: 4 ml/L nano urea as foliar spray, T_6: 2% N_2 through urea + 6 ml/L nano urea, T_7: 2% N_2 through urea + 4 ml/L nano urea, T_8: 1.5% N_2 through urea + 6 ml/L nano urea and T_9: 1.5% N_2 through urea + 4 ml/L nano urea

chlorophyll B (2.024 mg/100g) in T_6 indicate balanced nitrogen availability, as nitrogen is a critical component of both chlorophyll molecules. The higher chlorophyll content in T_6 also suggests improved light harvesting capacity, which supports carbohydrate production and subsequent vegetative growth.

Plant nutrient status (N, P and K)

The status of N, P, K in a plant sample was analysed, revealed significant treatment effects as illustrated in Table 5. Maximum N (1.76%) was recorded in T_1 (RDF), followed by T_2 (1.50%), while minimum N was in T_3 (0.79%). The highest phosphorus content was in T_9 (0.50%), followed by T_7 (0.42%), with minimum in T_5 (0.13%). Maximum potassium was found in T_2 (0.76%), followed by T_8 (0.72%) and minimum in T_9 (0.24%).

The higher N content in T_1 (1.76%) compared to T_3 (0.79%) highlights the importance of adequate nitrogen supply. The increased P and K levels in T_9 and T_2, respectively, suggest that nano urea may enhance the uptake of other nutrients, possibly through improved root development and nutrient mobilization. These findings are concurrent with results of Nair *et al.*, (2012), who reported enhanced root growth and shoot establishment with carbon nanomaterial-enriched media.

The 1.76% N in T_1 compared to 0.79% in T_3 represents the importance of adequate nitrogen supply for plant nutrition. The 0.50% P in T_9 compared to 0.13% in T_5 that nano urea may enhance phosphorus uptake.

Table 5: Effect of Urea and Nano urea on N, P, and K status of plant sample.

Treat-ment	Treatment details (g/pole)	N %	P %	K %
T_0	Control (water spray)	1.28	0.17	0.57
T_1	RDF (Recommended dose of Fertilizers)	1.76	0.25	0.33
T_2	2 % N_2 through Urea	1.50	0.24	0.76
T_3	1.5 % N_2 through Urea	0.79	0.27	0.66
T_4	6 ml/l Nano Urea	0.95	0.23	0.45
T_5	4 ml/l Nano Urea	0.97	0.14	0.53
T_6	2 % N_2 through Urea + 6 ml/l Nano Urea	1.23	0.20	0.71
T_7	2 % N_2 through Urea + 4 ml/l Nano Urea	0.91	0.42	0.37
T_8	1.5 % N_2 through Urea + 6 ml/l Nano Urea	1.00	0.26	0.72
T_9	1.5 % N_2 through Urea + 4 ml/l Nano Urea	0.88	0.50	0.24
SE(m)		0.016	0.006	0.009
CD at 5%		0.049	0.017	0.026

Similarly, the 0.76% K in T_2 compared to 0.24% in T_9, indicating that conventional urea spray may enhance potassium uptake.

The significant variation in N, P, K status across treatments reveals that nutrient management significantly influences plant nutrient composition. The higher N content in RDF and urea-treated plants affects the direct supply of nitrogen, while the increased P and K levels in nano urea-treated plants suggest enhanced nutrient mobilization and uptake efficiency.

Discussion

The present investigation demonstrates that combined application of conventional urea and nano urea significantly enhances vegetative growth parameters in dragon fruit. The superior performance of T_6 (2% N_2 through urea + 6 ml/L nano urea) across most parameters can be attributed to the synergistic effect of both nitrogen sources. Conventional urea provides a readily available nitrogen pool for immediate uptake, while nano urea ensures sustained release and enhanced nutrient use efficiency due to its desirable particle size (20–50 nm) and high surface area (Anon., 2005).

Nano urea enhances nitrogen use efficiency (NUE) by up to 45% compared to conventional fertilizers (Rahale, 2010). The increased NUE translates to improved photosynthetic efficiency, as evidenced by higher chlorophyll content in T_6 (4.261 mg/100g). Enhanced photosynthesis supports carbohydrate accumulation, leading to increased stem circumference, segment number and arch height.

The significant increase in stem circumference with T_4 and T_6 treatments aligns with findings of Ibrahim *et al*., (2022), who reported significant effects of NPK fertilizer on stem girth. Similarly, Abdel Wahab *et al*., (2019) reported increased plant growth in red radish with nano fertilizer application. The non-significant results for number of segments per plant and arch height suggest that these parameters may be predominantly governed by genetic makeup. However, the numerical superiority of T_6 in these parameters indicates that nutrient management may have a marginal influence on their expression.

The significant enhancement in chlorophyll content with T_6 treatment is particularly noteworthy, as chlorophyll content is directly related to photosynthetic capacity and subsequent biomass accumulation. The increase in total chlorophyll content in T_6 compared to control represents a substantial improvement in photosynthetic potential, which translates to enhanced vegetative growth.

The elevated P and K levels in T_9 and T_2, respectively, suggest that nano urea may enhance the uptake of other nutrients. This could be due to improved root development and nutrient mobilization, as reported by Nair *et al*., (2012). The enhanced nutrient uptake, in turn, supports vegetative growth and development.

The highest rate of increase in most parameters at 75 DAT coincides with rising temperatures, suggesting temperature-dependent nutrient uptake and metabolic activity. This renders the importance of timing nutrient application to coincide with periods of active growth.

The significant variation in N, P, K status in plant sample across treatments demonstrates that nutrient management significantly influences plant nutrient composition. The higher N content in RDF and urea-treated plants reflects the direct supply of nitrogen, while the elevated P and K levels in nano urea-treated plants suggest enhanced nutrient mobilization and uptake efficiency. These findings have important implications for developing balanced nutrient management strategies for dragon fruit cultivation.

Conclusion

On the basis of results obtained, it can be concluded that application of nano urea is beneficial and resulted very close to RDF. Among the treatments, foliar application of urea @ 2% combined with nano urea @ 6 ml/L (T_6) may be suggested for better growth of dragon fruit in the Lucknow region, having maximum vegetative growth in terms of stem circumference, number of segments, arch height and chlorophyll content. The integrated use of conventional urea and nano urea enhancing nitrogen use efficiency and reducing reliance on conventional fertilizers. However, further studies are needed to evaluate the effect of these treatments on reproductive growth, yield and fruit quality parameters.

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