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Impact of plant growth modulators on morpho-physiological characteristics of *Kharif* groundnut variety GJG-31

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Abstract
In the *kharif* season of 2018, a field trial was carried out at Cotton Research Station, Junagadh Agricultural University, Junagadh, to explore the influence of diverse plant growth regulators on the morphological and physiological characteristics of *kharif* groundnut variety GJG-31. The experiment was designed using a randomized block setup with three replications. It involved the foliar application of varying concentrations of growth regulators—PBZ, TRIA, BR, and SA—along with a control treated with water spray, administered at specific growth phases. Results indicated that TRIA, BR, and SA treatments led to increased plant height and salicylic acid (SA) treatment at 50 ppm notably resulted in the highest plant height. Additionally, SA treatment positively influenced the number of leaves per plant. Leaf area index (LAI) exhibited an initial increase up to 90 days after sowing (DAS), followed by a decline due to leaf senescence. SA treatment at 50 ppm displayed the highest LAI. Specific leaf weight (SLW) increased until pod filling, with SA at 50 ppm showing the highest SLW, relative growth rate (RGR), and crop growth rate (CGR).

Keywords: Plant growth regulators, morphological parameters, physiological parameters, kharif groundnut, salicylic acid, leaf area index, specific leaf weight, relative growth rate, crop growth rate

Introduction
Groundnut, with its high-quality edible oil and protein content, plays a crucial role in global agriculture (Arnarson, 2015) [2]. Its adaptability to diverse regions has contributed to its wide cultivation across tropical and subtropical zones. Groundnut cultivation spans approximately 26.4 million hectares worldwide, producing around 37.1 million metric tonnes with an average productivity of 1.4 metric t/ha (Anon., 2018) [1].

Plant growth and performance are influenced by both environmental conditions and internal metabolic processes. The role of endogenous growth substances in regulating plant metabolism has been recognized, prompting efforts to enhance crop growth and productivity through exogenous application of growth regulators.

Various growth regulators, such as paclobutrazol (PBZ), triacontanol (TRIA), brassinosteroids (BR), and salicylic acid (SA), have distinct effects on plant growth. PBZ inhibits gibberellin biosynthesis, effectively reducing shoot length. TRIA, a growth enhancer, enhances plant growth and accumulation of biomass. BR, a newer group of phytohormones, influences diverse physiological processes (Clouse and Sasse, 1998) [6]. SA's role as a plant growth regulator has gained recognition relatively recently (Raskin, 1992) [16].

This study aims to assess the impact of different growth regulators on various morphological and physiological parameters affecting yield.

Materials and Methods
The investigation took place at Cotton Research Station, JAU, Junagadh, in the kharif season of 2018. The experimental site consisted of clayey soil with moderate pH and EC levels. The experimental design involved ten treatment combinations, arranged in a randomized block configuration, and replicated three times. Growth regulators (PBZ, TRIA, BR, SA) were applied foliarly at specific growth stages, while a water spray served as the control. The crop received uniform doses of NPK fertilizers.

Morphological traits
The evaluation encompassed plant height, count of primary branches, and leaf number per plant, conducted on five chosen plants within each treatment, spanning all replications at 50, 70, 90 DAS, and upon harvest.

Physiological traits
LAI)
The leaf area index was computed by dividing the complete leaf area by the corresponding ground area, following the methodology proposed by Watson (1952) [18], at 50, 70, 90 DAS, and at harvesting.

$$LAI = \frac{\text{Total leaf area of the plant}}{\text{Ground area covered by the plant}}$$

Specific leaf weight (SLW, g cm^{-2}): Specific leaf weight is a measure of leaf weight per unit leaf area. Hence, it is a ratio expressed as g cm^{-2}. SLW was calculated at 50, 70, 90 DAS and at harvesting as suggested by Pearce *et al*. (1968) [14].

$$LAR = \frac{\text{Leaf weight}}{\text{Leaf area}}$$

Crop growth rate (CGR, g m^{-2} day^{-1}): Utilizing the entire plant biomass, the calculation of CGR was performed using the equation provided by Watson (1952) [18] at 50, 70, 90 DAS and at harvesting and expressed in g m^{-2} day^{-1}.

$$CGR = \frac{W_2 - W_1}{(T_2 - T_1)} \times \frac{1}{A}$$

W_1 = Plant biomass (g) at time T_1
W_2 = Plant biomass (g) at time T_2
$T_2 – T_1$ = Time period in days
A = Land area (m^2)

Relative growth rate (RGR, g g^{-1} day^{-1})
This represents the growth rate in terms of the augmented dry weight per existing unit of dry weight, expressed as g g^{-1}day^{-1} (Blackman, 1919). RGR at 50, 70, 90 DAS and at harvesting was calculated as follows

$$NAR = \frac{\log_e W_2 - \log_e W_1}{(T_2 - T_1)}$$

W_1 = Plant biomass (g) at time T_1
W_2 = Plant biomass (g) at time T_2
$T_2 – T_1$ = Time interval in days

Statistical analysis: The data underwent analysis using the method of analysis of variance, as outlined by by Panse and Sukhatme (1984) [15].

Findings and Discussion
Morphological trait
Plant height (cm): The findings outlined in Table 1 illustrate a significant influence of various growth regulator treatments on plant height at 50, 70, and 90 DAS. Notably, treatment T_8 exhibited the highest mean plant height (32.46 cm), followed by T_4 (31.81 cm), T_7 (30.69 cm), T_5 (30.07 cm), T_3 (29.90 cm), and T_6 (29.06 cm). Conversely, treatment T_2 recorded the lowest plant height (23.14 cm). The cumulative experimental data suggests a consistent increase in plant height as the crop ages, culminating in the harvest stage. These observations could potentially be attributed to the role of salicylic acid in enhancing certain physiological and biochemical factors. Additionally, it might contribute to elevated levels of N, P, K, and Ca content, as well as heightened activity in antioxidant enzymes and increased glutathione content (Khan *et al*., 2010) [12].

Count of main branches per individual plant: The data pertaining to the impact of distinct treatments on the count of primary branches per groundnut plant were recorded at 50, 70, 90 DAS, and harvest, and are presented in Table 1. Notably, treatment T_8 exhibited the highest mean count of primary branches (6.05), followed by T_3 (5.73), T_7 (5.59), T_4 (5.34), and T_6 (5.34). In contrast, the control group T_{10} displayed the lowest count of primary branches (3.66). The heightened presence of branches, particularly in higher hormone concentrations during the peak vegetative stage, can be attributed to the influence of salicylic acid on physiological processes like cell division, ion absorption, enzyme activities, photosynthetic efficiency, and source-sink regulation. Similar increases in branch numbers were reported by Kaur *et al*. (2015) [11].

Leaf count per plant: Examination of the data presented in Table 1 highlights the notable impact of distinct growth regulator treatments on the leaf count per groundnut plant at 50, 70, 90 DAS, and harvest stages. The comprehensive experimental outcomes indicate that treatment T_8 exhibited the highest leaf count per plant (159.61), followed by T_6 (157.10), T_7 (148.09), T_3 (154.32), and T_4 (146.66). Conversely, the control group T_{10} displayed the lowest leaf count per plant (3.66). Leaves serve as crucial sources channeling photosynthates to the sink. Throughout the pod-filling phase, leaves contribute photosynthate to the pods, making a higher leaf count conducive to increased pod yield. Tafsira Naz (2006) [17] reported similar findings, indicating increased leaf counts in groundnut due to foliar application of salicylic acid at 500 ppm.

Physiological traits
LAI: Examination of the data presented in Table 2 reveals a significant influence of diverse growth regulator treatments on the leaf area index (LAI) at 50, 70, 90 DAS, and the harvest stage. Remarkably, treatment T8 displayed the highest mean LAI (4.45), followed by T_3 (3.59), T_4 (3.51), T_6 (3.58), and T_7 (4.00). Conversely, the control group T_{10} recorded the lowest LAI (2.08). The leaf area serves as a valuable indicator of a plant's photosynthetic capacity. The LAI followed a characteristic sigmoidal pattern, commencing with a gradual increase in leaf area followed by a steep rise. In this study, the leaf area index consistently rose up to 90 DAS. Beyond 90 DAS, a decline in leaf area occurred due to a reduced leaf count, resulting in diminished leaf area and LAI due to leaf senescence with plant age. Similar increases in leaf area index were observed by Mona *et al.* (2012) [13] and Ghai *et al.* (2014) [9].

Specific leaf weight (SLW): An examination of the data in Table 2 revealed significant variation in specific leaf weight due to different growth regulator treatments at 50, 70, 90

DAS, and harvest. Treatment T_8 demonstrated notably higher specific leaf weight (4.66 mg cm-2), followed by T_7 (4.38 mg cm^{-2}), T_6 (4.06 mg cm^{-2}), T_4 (3.69 mg cm^{-2}), and T_3 (3.59 mg cm^{-2}). In contrast, the control group T_{10} exhibited the lowest specific leaf weight (2.33 mg cm^{-2}). The study's findings indicated a continuous increase in groundnut's specific leaf weight until the pod-filling stage, followed by a slight decline at maturity. This pattern suggests that cellular and tissue-level developmental processes within the shoot system are largely completed before flowering. Manipulating the crop's nutrition and hormones during this rapid developmental stage could effectively regulate metabolic processes, enhancing growth and productivity. Notably, specific leaf weight, which quantifies leaf thickness, has been associated with positive correlations to leaf photosynthesis in various crops, as reported by Bowes *et al.* (1972) [5]. Leaves with greater thickness often contain more mesophyll cells with a higher density of chlorophyll, resulting in increased photosynthetic capacity (Craufurd *et al.*, 1999) [7].

Relative growth rate (RGR): Analyzing the data in Table 3 revealed significant impacts of different growth regulator treatments on the relative growth rate during intervals of 30-50, 50-70, 70-90 DAS, and 90 DAS to harvest. Treatment T_8 exhibited the highest relative growth rate (0.040 g g^{-1} day^{-1}), followed by T_1 (0.035 g g^{-1} day^{-1}), T_5 (0.035 g g^{-1} day^{-1}), and T_7 (0.036 g g^{-1} day^{-1}), whereas the control group T^{10} displayed the lowest relative growth rate (0.028 g g^{-1} day^{-1}). Relative growth rate reflects the increase in dry matter per unit of existing dry matter over a unit of time. The elevation of RGR through growth regulator application could be attributed to improved photosynthetic efficiency achieved through increased leaf thickness, enhanced chlorophyll content retention, and efficient translocation of photosynthates. Each treatment exhibited distinct RGR patterns, peaking during the 30-50 DAS interval and decreasing thereafter, notably after 50-70 DAS. All treatments attained their peak relative growth rate (RGR) prior to pod initiation, followed by a subsequent decrease during pod filling. This reduction in RGR during the later growth phase of groundnut was similarly documented by Bharud and Pawar (2005) [3] and Deshamukh (1986) [8].

Crop growth rate (CGR): A review of the data in Table 3 unveiled the significant effects of different growth regulator treatments on crop growth rates within intervals of 30-50, 50-70, 70-90 DAS, and 90 DAS to harvest. Treatment T_8 displayed a notably higher crop growth rate (17.39 g m^{-2} day^{-1}), followed by T_7 (16.32 g m^{-2} day^{-1}) and T_6 (16.02 g m^{-2} day^{-1}), while the control group T_{10} recorded the lowest crop growth rate (12.19 g m^{-2} day^{-1}). Crop growth rate (CGR) functions as a metric for gauging the productive efficiency of crop populations, influenced by variables like leaf area index, photosynthetic rate, and leaf orientation. It offers an indicator of light absorption. Crop growth rate demonstrated an increase during the peak period at 70 DAS, followed by a relatively stable growth phase attributed to the efficient transport of photosynthates toward pods during the pod development phase, as pod maturity ensued. Jadhav and Bhamburdekar (2012) [10] reported a significant increase in CGR compared to the control group in groundnut through the foliar application of SA at 50 ppm.

Table 1: Influence of growth regulators on plant height, number of main branches, and the leaf count per groundnut plant

Treatments		Plant height (cm)					Number of main branches per plant					Leaf count per plant				
		50 DAS	70 DAS	90 DAS	At Harvest	Mean	50 DAS	70 DAS	90 DAS	At Harvest	Mean	50 DAS	70 DAS	90 DAS	At Harvest	Mean
T_1	PBZ @ 200 ppm	19.87	24.65	26.15	26.68	24.34	4.39	5.33	5.66	5.66	5.26	64.77	120.83	155.12	146.87	121.90
T_2	PBZ @ 250 ppm	18.34	22.74	25.45	26.03	23.14	4.35	5.33	5.66	5.66	5.25	64.80	139.62	168.20	153.91	131.63
T_3	TRIA @ 5 ppm	23.70	28.95	32.89	33.07	29.90	3.82	5.60	6.65	6.85	5.73	68.69	155.02	210.62	185.94	154.32
T_4	TRIA @ 10 ppm	24.03	30.22	34.08	34.89	31.81	4.38	5.66	5.66	5.67	5.34	64.99	148.98	189.56	183.12	146.66
T_5	BR @ 20 ppm	22.70	29.73	33.72	34.11	30.07	4.39	4.66	5.33	5.67	5.01	62.79	132.85	179.31	171.36	136.58
T_6	BR @ 40 ppm	23.03	28.81	31.89	32.52	29.06	4.69	5.33	5.66	5.66	5.34	68.36	156.00	217.66	186.36	157.10
T_7	SA @ 25 ppm	25.41	29.05	32.81	35.49	30.69	4.68	5.66	6.00	6.01	5.59	72.45	136.75	199.35	183.80	148.09
T_8	SA @ 50 ppm	28.70	30.52	34.50	36.15	32.46	5.66	6.01	6.06	6.13	6.05	72.76	157.29	219.26	189.14	159.61
T_9	Water spray	21.52	26.39	29.34	32.04	27.57	3.66	4.00	4.33	4.33	4.08	55.83	92.28	135.75	124.24	102.03
T_{10}	Control	21.13	26.03	28.93	30.35	26.76	3.34	3.66	3.66	4.00	3.66	53.08	87.08	128.13	112.18	95.12
S.Em.±		1.12	1.29	1.26	1.26	1.23	0.16	0.23	0.32	0.25	0.24	3.91	6.44	9.74	8.76	7.21
C.D. at 5%		3.34	3.83	3.74	3.74	3.67	0.49	0.67	0.95	0.73	0.71	11.61	19.13	28.95	26.03	21.43
C.V. %		8.53	8.03	7.03	6.79	7.60	6.57	7.66	9.94	7.56	7.93	10.44	8.43	9.36	9.22	9.36

Table 2: Effect of growth regulators on leaf area index, specific leaf weight of groundnut

Treatments		Leaf area index					Specific leaf weight				
		50 DAS	70 DAS	90 DAS	At Harvest	Mean	50 DAS	70 DAS	90 DAS	At Harvest	Mean
T_1	PBZ @ 200 ppm	1.32	2.79	3.89	3.35	2.84	3.31	3.48	3.67	3.30	3.44
T_2	PBZ @ 250 ppm	1.51	2.73	4.01	3.29	2.89	3.21	3.44	3.61	3.23	3.37
T_3	TRIA @ 5 ppm	1.76	3.32	4.83	4.44	3.59	3.45	3.68	3.81	3.40	3.59
T_4	TRIA @ 10 ppm	1.73	3.73	4.49	4.09	3.51	3.59	3.71	3.83	3.61	3.69
T_5	BR @ 20 ppm	1.75	3.36	4.32	4.12	3.39	3.38	3.53	3.70	3.36	3.49
T_6	BR @ 40 ppm	1.59	3.64	4.63	4.45	3.58	3.86	4.13	4.30	3.95	4.06
T_7	SA @ 25 ppm	1.82	3.91	5.27	5.00	4.00	4.22	4.44	4.61	4.23	4.38
T_8	SA @ 50 ppm	1.93	3.96	5.33	5.13	4.09	4.58	4.61	4.67	4.19	4.36
T_9	Water spray	1.24	2.05	3.01	2.77	2.27	2.44	2.72	2.87	2.43	2.62
T_{10}	Control	1.18	1.94	2.85	2.35	2.08	2.12	2.37	2.59	2.23	2.33

S.Em.±	0.08	0.25	0.28	0.19	0.10	0.28	0.26	0.32	0.22	0.27
C.D. at 5%	0.23	0.74	0.83	0.57	0.31	0.83	0.76	0.94	0.65	0.79
C.V. %	7.92	8.66	11.27	8.42	8.46	13.47	13.98	13.51	7.83	12.20

Table 3: Effect of growth regulators relative growth rate and crop growth rate of groundnut

Treatments		Relative growth rate					Crop growth rate				
		30-50 DAS	50-70 DAS	70-90 DAS	90 DAS -At Harvest	Mean	30-50 DAS	50-70 DAS	70-90 DAS	90 DAS - At Harvest	Mean
T_1	PBZ @ 200 ppm	0.055	0.049	0.020	0.015	0.035	11.67	22.37	17.62	5.93	14.40
T_2	PBZ @ 250 ppm	0.058	0.049	0.016	0.012	0.034	12.23	22.67	17.92	6.62	14.86
T_3	TRIA @ 5 ppm	0.050	0.054	0.018	0.014	0.034	10.66	23.64	18.89	7.42	15.15
T_4	TRIA @ 10 ppm	0.047	0.055	0.019	0.016	0.034	10.07	24.28	19.84	7.11	15.40
T_5	BR @ 20 ppm	0.054	0.054	0.018	0.014	0.035	12.40	23.04	18.29	8.10	15.46
T_6	BR @ 40 ppm	0.057	0.050	0.016	0.012	0.034	12.65	23.67	18.92	8.82	16.02
T_7	SA @ 25 ppm	0.055	0.054	0.019	0.015	0.036	12.36	23.90	19.15	8.10	16.32
T_8	SA @ 50 ppm	0.060	0.059	0.022	0.017	0.041	13.65	24.59	21.53	9.87	17.39
T_9	Water spray	0.046	0.048	0.015	0.011	0.030	8.64	19.13	14.38	7.79	12.49
T_{10}	Control	0.045	0.047	0.013	0.009	0.028	8.66	18.74	13.99	7.36	12.19
S.Em.±		0.003	0.002	0.002	0.001	0.002	0.64	0.38	0.64	0.64	0.58
C.D. at 5%		0.008	0.006	0.005	0.003	0.006	1.91	1.14	1.93	1.91	1.73
C.V. %		10.42	12.20	13.10	11.93	11.91	11.71	9.54	11.45	10.75	10.86

Conclusion

The research highlights the significant impact of distinct growth regulators on the morphological and physiological attributes of kharif groundnut. These findings contribute to our understanding of the intricate relationship between growth regulators and crop performance, aiding efforts to optimize yield and quality in groundnut cultivation.

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