



Foliar Chitosan Application Enhances Growth and Seed Yield of Sesame (*Sesamum indicum* L.)

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ABSTRACT

Sesame (*Sesamum indicum* L.) is a valuable oilseed crop renowned for its high-grade edible oil, nutritional value, and resilience under challenging climates. However, sesame productivity in Bangladesh remains relatively low due to poor crop management practices and limited adoption of sustainable growth-promoting technologies. Therefore, a field experiment was carried out to assess the impact of foliar-applied chitosan on the growth and yield performance of sesame varieties. The study comprised two sesame varieties (BARI Til-4 and BARI Til-6) and five chitosan levels (0, 50, 100, 150, and 200 ppm), arranged in a randomized complete block design (RCBD) with three replications. Varietal differences were relatively less pronounced during the early growth stages but became more evident at harvest. Among the chitosan treatments, 150 ppm consistently exhibited superior performance in enhancing growth and yield related traits. BARI Til-6 treated with 150 ppm chitosan produced the highest plant height (96.89 cm), branches/plant (8.00), pods/plant (59.67), filled pods/plant (34.89), seeds/pod (77), 1000-seed weight (3.35 g), seed yield (1.39 t ha⁻¹), stover yield (3.27 t ha⁻¹), biological yield (4.15 t ha⁻¹), and harvest index (34.92%) whereas the control chitosan (0 ppm) produced the lowest values for most yield-related traits regardless of variety. Correlation and heat map analyses further confirmed strong positive associations among major yield-contributing traits and seed yield under chitosan application. The results suggest that foliar application of 150 ppm chitosan with BARI Til-6 can effectively improve sesame productivity under the Old Brahmaputra Floodplain conditions of Bangladesh.

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1. Introduction

Sesame (*Sesamum indicum* L.), a member of the Pedaliaceae family, is considered one of the oldest domesticated oilseed crops cultivated worldwide. Owing to its remarkable adaptability to water limited environments, it is extensively grown in arid and semi-arid regions where other oilseed crops often perform poorly. Sesame seeds are distinguished by their exceptionally high oil content, which may reach up to 63%, exceeding that of several major oilseed crops, including peanut, rapeseed, sunflower, and soybean (Teklu *et al.*, 2021). In addition to their high oil concentration, sesame seeds are an excellent source of proteins, essential fatty acids, vitamins, and minerals, making them valuable for both nutritional and therapeutic purposes. Furthermore, the exceptional oxidative stability of sesame oil is primarily attributed to the presence of naturally occurring lignan antioxidants, such as sesamin, sesamol, and sesamol,

which contribute to its prolonged shelf life and health-promoting properties (Dossou *et al.*, 2023). Sesame is grown across Bangladesh with major production concentrated in the districts of Pabna, Faridpur, Rajshahi, Khulna, Dhaka, Jessore, and Mymensingh. Its acreage and output have declined significantly in recent years owing to strong competition with other economically important crops (Paul *et al.*, 2019; Dey *et al.*, 2023). In Bangladesh, sesame is the second most widely produced oil crop, following rapeseed and mustard. Although approximately 75946.35 acres of land are currently under sesame cultivation with a productivity of 29996.83 metric tons (BBS, 2024), land area under sesame cultivation and its total production are declining gradually (Malek *et al.*, 2021). The average yield of is low compared to other sesame-producing countries. This low productivity is mainly because of poor soil fertility, scarcity of high-yielding improved varieties, and inadequate crop

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management practices (BBS, 2019). In addition, environmental stresses including drought and salinity, markedly reduce sesame growth and yield. Drought stress, in particular, reduces photosynthesis, disrupts metabolic activities, and ultimately decreases yield components such as capsule number and seed weight (Reddy *et al.*, 2004). In recent years, more attention has been dedicated to the use of eco-friendly and sustainable growth promoters to improve crop productivity.

Chitosan, a biopolymer made from chitin, has emerged as an effective environmentally friendly biostimulant with proven roles in enhancing plant growth, physiological efficiency, stress tolerance, and defense responses (Hadwiger, 2013; Nguyen *et al.*, 2013). Chitosan has been reported to stimulate photosynthesis, nutrient uptake, endogenous phytohormone activity, and antioxidant defense mechanisms (Pongprayoon *et al.*, 2013). The application of chitosan increases crop yields by enhancing the activity of plant defense enzymes and protecting against microbial threats. Plants receiving chitosan treatments produce more branches and demonstrate better growth relative to untreated plants (Sultana *et al.*, 2020). Increased chitin within the plant further strengthens its disease resistance. In addition, chitosan works with beneficial soil microbes to optimize nutrient uptake and activates plant defenses against various stresses, resulting in notable gains in plant health and productivity (Rahman *et al.*, 2025).

Bangladesh's shrimp-processing industry provides an abundant and low-cost source of chitin, making chitosan production economically viable and environmentally sustainable for agricultural use (Khan, 2020). Studies to date have indicated that chitosan possesses considerable potential to progress both the growth and productivity of a variety of crops, including apple, rice, wheat, maize and several legumes (Ray *et al.*, 2016; Rahman *et al.*, 2025). In sesame, chitosan application has shown promising results in improving growth and yield attributes. Chitosan application to the foliage has been shown to improve plant height, leaf area, branch number, and biomass accumulation. It also enhances yield-contributing attributes including capsules/plant, seeds/capsule, and 1000-seed weight, ultimately leading to increased seed yield (Farouk *et al.*, 2011). El Hadrami *et al.* (2010) reported that chitosan-based formulations improve plant resistance against pathogens and enhance overall plant performance.

Despite these established advantages, there is still a lack of comprehensive knowledge regarding the most effective chitosan dosage and its interactions with different sesame varieties grown under the specific agro-ecological and meteorological conditions of Bangladesh. Accordingly, the current research was conducted to optimize foliar application of chitosan concentration for maximizing productivity of sesame.

2. Materials and Methods

2.1. Experimental location and experimentation

The experiment was conducted at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh, Bangladesh, from March to June 2025 to evaluate the influence of chitosan application on the

growth and yield performance of sesame. The experimental site is geographically located at 24°07' N latitude and 90°50' E longitude, approximately 18 m above mean sea level. It belongs to the Old Brahmaputra Floodplain under Agro-Ecological Zone 9 (AEZ-9), where the soil is classified as the Sonatola series of non-calcareous dark grey floodplain soils with a silty loam texture. The study area is characterized by a subtropical climatic condition, with comparatively high temperatures and humidity prevailing throughout the cropping season. Monthly meteorological parameters, including average temperature, rainfall, relative humidity, and sunshine duration observed during the experimental period, are presented in Figure 1.

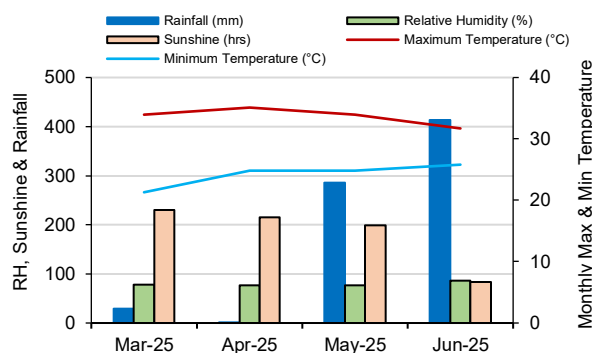


Figure 1. Distribution of monthly rainfall, temperature, sunshine and relative humidity pattern of the experimental site during the crop growth period

2.2. Experimental treatments and design

The experiment involved two sesame varieties, namely BARI Til-4 (V_1) and BARI Til-6 (V_2), and five levels of chitosan: 0 (T_1), 50 (T_2), 100 (T_3), 150 (T_4), and 200 ppm (T_5). The experiment was set up in an RCBD with three replications. Chitosan solutions (50, 100, 150, and 200 ppm; T_2 – T_5) were prepared by dissolving 50, 100, 150, and 200 mg of chitosan per liter of distilled water containing 1% glacial acetic acid, respectively, with continuous magnetic stirring until completely dissolved. The control (T_1 , 0 ppm) consisted of distilled water without chitosan. All solutions were homogenized before foliar application to sesame plants.

2.3. Crop husbandry

Seeds of BARI Til-4 and BARI Til-6 were collected from the Bangladesh Agricultural Research Institute (BARI). The experimental field was prepared through ploughing, cross-ploughing, and laddering to obtain a fine, levelled seedbed. The experiment comprised 30 plots, each measuring 2.5 × 2.0 m (5.0 m²), with 0.5 m spacing between plots and 1.0 m between blocks. Fertilizers were applied following BARC (2018) recommendations at 60, 30, 40, 20, and 5 kg ha⁻¹ of N, P, K, S, and Zn, respectively. Urea, triple superphosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulphate were used as nutrient sources. Full doses of TSP, MoP, gypsum, and zinc sulphate were incorporated during final land preparation, while urea was top-dressed in two equal

splits at 15 and 30 days after sowing (DAS). Seeds were sown on 1 March 2025 by following 30 cm line spacing using continuous sowing (5 kg seed ha⁻¹) with 2-3 cm deep furrows. Chitosan solutions were prepared by dissolving chitosan powder in distilled water containing 1% glacial acetic acid.

Foliar sprays were applied at 40 and 60 DAS according to the treatment schedule using a hand-operated knapsack sprayer, while control plots received distilled water only. Standard intercultural operations, including weeding, thinning (maintain a plant to plant distance 5-7 cm), gap filling, drainage, and pest management, were performed as necessary throughout the growing period.

2.4. Data collection

Data were collected at both the vegetative (at 40 and 60 DAS on plant height, branch count and dry weight/plant) and harvesting stages (on crop characters and yield components) from five randomly selected plants, excluding border rows. The crop was harvested when 75-80% of the capsules had become yellowish brown and reached maturity. Harvested plants were sun-dried, threshed, cleaned, and dried to a consistent weight before seed and stover yields were measured. Biological yield was computed as the total of seed and stover yields, and harvest index (%) was derived using the following formula:

Biological yield = Seed yield + Stover yield.

Harvest Index (%) = (Seed yield/Biological yield) × 100

2.5. Statistical analysis

The collected data were analyzed using analysis of variance (ANOVA) with the MSTAT-C statistical software package. When significant differences among treatments were detected, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the appropriate level of significance, following the procedure described by Gomez and Gomez (1984). Pearson's correlation analysis and heat map analysis were performed to evaluate relationships among growth and yield traits by using R software (version 4.4.2).

3. Results

3.1. Plant characters

Plant height, branches plant⁻¹, and dry weight plant⁻¹ of sesame were significantly influenced by chitosan application and its interaction with variety, whereas varietal effects were generally non-significant during the vegetative stages (Table 1). At harvest, plant height was significantly affected by both variety and chitosan (Table 2). BARI Til-6 produced taller plants (81.27 cm) than BARI Til-4 (74.76 cm). Among the treatments, 150 ppm chitosan (T₄) produced the tallest plants (92.39 cm), statistically comparable to 200 ppm (T₅), whereas the control (T₁) produced the shortest plants (61.61 cm). The interaction effect was significant, with BARI Til-6 receiving 150 ppm chitosan (V₂T₄) recording the tallest plant (96.89 cm) and BARI Til-4 without chitosan (V₁T₁) the shortest one (61.33 cm). A similar trend was observed for branches plant⁻¹.

Although varietal differences were non-significant, BARI Til-6 produced numerically more branches (5.13) than BARI Til-4 (4.62) (Table 2).

Chitosan significantly increased branch number, with the highest value (7.44) at 150 ppm (T₄) and the lowest one (3.00) in the control. The interaction was significant, with V₂T₄ producing the highest number of branches (8.00) and V₁T₁ the lowest one (2.66). Dry weight accumulation was significantly affected by chitosan at both 40 and 60 DAS, whereas varietal effects remained non-significant (Table 1). Nevertheless, BARI Til-6 produced numerically higher dry weight (4.59 and 6.82 g) than BARI Til-4 (3.72 and 5.80 g) at 40 and 60 DAS, respectively. The highest dry weight was obtained with 150 ppm chitosan (T₄; 6.80 and 9.48 g), statistically similar to 200 ppm (T₅), while the control recorded the lowest values (2.00 and 3.34 g). The interaction was significant, with V₂T₄ producing the highest dry weight (7.08 and 10.17 g) and V₁T₁ the lowest (1.90 and 3.21 g) at 40 and 60 DAS, respectively. Overall, BARI Til-6 treated with 150 ppm chitosan consistently showed superior growth, indicating greater responsiveness to chitosan-mediated growth enhancement.

3.2. Pod and seed production

Yield-contributing traits of sesame were significantly influenced by chitosan application, whereas varietal effects were generally non-significant except for unfilled pods plant⁻¹ (Table 3). Although differences in pods plant⁻¹ between varieties were not significant, BARI Til-6 produced more pods (41.24) than BARI Til-4 (36.61). Chitosan markedly increased pod number, with the highest value (57.09) was recorded at 150 ppm (T₄), statistically similar to 200 ppm (T₅), while the control (T₁) produced the fewest pods (22.06). The interaction effect was significant, with BARI Til-6 treated with 150 ppm chitosan (V₂T₄) producing the maximum pods plant⁻¹ (59.67) and BARI Til-4 without chitosan (V₁T₁) the minimum (19.33). A similar pattern was observed for filled pods plant⁻¹. BARI Til-6 produced slightly more filled pods (31.09) than BARI Til-4 (29.49), although the difference was not significant. The highest number of filled pods (33.61) was obtained with 150 ppm chitosan (T₄), statistically comparable to 100 ppm (T₃), whereas the control recorded the lowest value (25.56). Likewise, V₂T₄ produced the highest filled pods (34.89) and V₁T₁ the lowest one (25.45). In contrast, unfilled pods plant⁻¹ were significantly affected by both variety and chitosan. BARI Til-4 produced more unfilled pods (1.53) than BARI Til-6 (1.19). Chitosan reduced unfilled pods from 1.94 in the control to 1.00 under 150 ppm (T₄). The interaction was also significant, with the highest value in V₁T₁ (2.11) and the lowest in V₂T₄ (0.89) (Table 2). Seeds pod⁻¹ followed a similar trend. Although varietal differences were non-significant, BARI Til-6 produced slightly more seeds (65.93) than BARI Til-4 (64.93). Chitosan significantly increased seeds pod⁻¹, reaching the highest value (76.67) at 150 ppm and the lowest (52.83) in the control. The maximum number of seeds (77.00) was obtained from V₂T₄, whereas V₁T₁ produced the minimum (52.67) (Table 4).

Table 1. Analysis of variance of data of vegetative characters of sesame

Source of variation	df	Plant height (cm)		No. branches plant ⁻¹		Dry weight (g)	
		40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS
Replication	2	18.162	4.21	1.2074	4.9343	2.5283	0.092
Variety (V)	1	5.923NS	83.03NS	0.947NS	0.6078NS	5.7116NS	7.854NS
Chitosan level (T)	4	241.661**	494.67**	7.2185**	8.2173**	24.6494**	47.92**
V × T	4	0.391*	4.1*	0.1436*	0.0475*	1.1276*	0.61*
Error	18	16.987	24.72	0.4097	0.9442	2.0446	2.389

** = Significant at 1% level of probability, * = Significant at 5% level of probability and NS = Non-significant.

Table 2. Effect of variety, chitosan and their interactions on the growth parameters of sesame at different days after sowing

Treatment	Plant height (cm)		No. branches plant ⁻¹		Dry weight (g)	
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS
Variety (V)						
V ₁	38.87	57.32	2.51	4.42	3.72	5.80
V ₂	39.75	60.64	2.86	4.70	4.59	6.82
Sig. level	NS	NS	NS	NS	NS	NS
Chitosan level (T)						
T ₁	31.95c	47.18b	1.44c	3.17c	2.00b	3.34c
T ₂	34.17c	51.56b	1.72c	3.83bc	2.69b	3.95bc
T ₃	43.72ab	63.67a	2.78b	4.66b	3.60b	5.81b
T ₄	47.11a	68.22a	3.94a	6.26a	6.80a	9.48a
T ₅	39.61b	64.28a	3.55a	4.89b	5.69a	8.99a
Sig. level	**	**	**	**	**	**
Interactions (V × T)						
V ₁ T ₁	31.56e	44.92d	1.33e	2.89c	1.90d	3.21d
V ₁ T ₂	33.78c-e	49.22cd	1.67de	3.66bc	2.00d	3.73d
V ₁ T ₃	43.44ab	63.11a	2.66cd	4.55bc	3.57cd	4.97cd
V ₁ T ₄	46.22ab	67.22a	3.77ab	6.22a	6.51ab	8.80ab
V ₁ T ₅	39.33b-d	62.11ab	3.11a-c	4.77ab	4.63bc	8.30ab
V ₂ T ₁	32.33de	49.44cd	1.55e	3.44bc	2.11d	3.47d
V ₂ T ₂	34.55c-e	53.89bc	1.78de	4.00bc	3.39cd	4.16cd
V ₂ T ₃	44.00ab	64.22a	2.89bc	4.78ab	3.64cd	6.65bc
V ₂ T ₄	48.00a	69.22a	4.11a	6.30a	7.08a	10.17a
V ₂ T ₅	39.89bc	66.44a	4.00a	5.00ab	6.75ab	9.68a
Sig. level	*	*	*	*	*	*
CV (%)	10.48	8.42	13.82	11.30	14.39	14.30

Means followed by the same letter(s) within a column are not significantly different according to the applied statistical test. ** and * indicate significance at the 1% and 5% probability levels, respectively, while NS denotes a non-significant effect.

Table 3. Analysis of variance of data of yield parameters and yield of sesame

SoV	df	PH	BP	PP	FP	UFP	SP	100-WTS	SY	STY	BY	HI
Replication	2	54.08	1.4	67.03	407.29	0.25	12.13	0.029	0.001	0.009	0.036	1.60
Variety (V)	1	318*	1.9NS	160.7NS	19.2NS	0.88**	7.5NS	0.05NS	0.010**	0.252*	0.588**	4.17**
Chitosan(T)	4	955**	16.5**	1574.1**	56.83*	0.74**	476**	0.325**	0.148**	0.841**	1.763**	88.82**
V × T	4	19.*	0.27*	5.55*	2.9*	0.02*	0.92*	0.007*	0.000*	0.012*	0.073*	0.10*
Error	18	51.94	0.506	43.33	15.06	0.082	12.36	0.022	0.000	0.036	0.050	0.282

** = Significant at 1% level of probability, * = Significant at 5% level of probability and NS = Non-significant. Here, PH= Plant height (cm), BP= Branches plant⁻¹ (no.), PP= Pods plant⁻¹ (no.), FP= Filled pods plant⁻¹ (no.), UFP= Unfilled pods plant⁻¹ (no.), SP= Seeds pod⁻¹ (no.), 1000-WTS= 1000-seed weight (g), SY= Seed yield (t ha⁻¹), STY= Stover yield (t ha⁻¹), BY= Biological yield (t ha⁻¹), HI= Harvest index (%)

3.3. Weight of 1000 seeds, seed and stover yields

The 1000-seed weight was not significantly affected by variety, although BARI Til-6 produced slightly heavier seeds (3.11 g) than BARI Til-4 (3.03 g) (Table 4). Chitosan significantly increased 1000-seed weight, with the highest value (3.34 g) obtained at 150 ppm (T₄), statistically similar to 100 ppm (T₃) and 200 ppm (T₅), while the control

(T₁) recorded the lowest value (2.77 g). The interaction effect was significant, with BARI Til-6 treated with 150 ppm chitosan (V₂T₄) producing the highest 1000-seed weight (3.35 g) and BARI Til-4 without chitosan (V₁T₁) the lowest (2.67 g) (Table 4). Seed yield (SY) was significantly influenced by both variety and chitosan application. BARI Til-6 produced a higher yield (1.22 t ha⁻¹) than BARI Til-4 (1.18 t ha⁻¹) (Figure 2A). The highest SY (1.36 t ha⁻¹) was

recorded with 150 ppm chitosan (T_4), whereas the control produced the lowest yield (0.96 t ha^{-1}) (Figure 2B). The interaction was also significant, with V_2T_4 producing the highest SY (1.39 t ha^{-1}) and V_1T_1 the lowest one (0.94 t ha^{-1}) (Figure 2C). Similarly, stover yield (STY) was significantly affected by variety and chitosan. BARI Til-6 produced higher STY (2.81 t ha^{-1}) than BARI Til-4 (2.62 t ha^{-1}), while 150 ppm chitosan (T_4) produced the maximum STY (3.18 t ha^{-1}) compared with 2.26 t ha^{-1} in the control (Figures 2A and 2B). The highest STY (3.27 t ha^{-1}) was obtained from V_2T_4 , whereas V_1T_1 recorded the lowest (2.15 t ha^{-1}) (Figure 2C).

3.4. Biological yield and harvest index

Biological yield (BY) was significantly influenced by both variety and chitosan application. BARI Til-6 produced a higher BY (3.53 t ha^{-1}) than BARI Til-4 (3.25 t ha^{-1}) (Table 4). Chitosan markedly increased BY, with the highest yield (4.11 t ha^{-1}) recorded at 150 ppm (T_4) and the lowest (2.63 t ha^{-1}) in the control (T_1). The interaction effect was also significant, with BARI Til-6 treated with 150 ppm chitosan (V_2T_4) producing the highest BY (4.15 t ha^{-1}), whereas BARI Til-4 without chitosan (V_1T_1) recorded the lowest (2.40 t ha^{-1}). Harvest index (HI) was also significantly affected by variety and chitosan (Table 4). BARI Til-6 recorded a higher HI (30.20%) than BARI Til-4 (29.45%). The highest HI (34.58%) was obtained with 150 ppm chitosan (T_4), while the control produced the lowest value (24.53%). The interaction was significant, with V_2T_4 achieving the highest HI (34.92%) and V_1T_1 the lowest (24.14%).

3.5. Correlation analysis

The Pearson's correlation matrix revealed strong relationships among yield and yield-related traits of sesame under different chitosan treatments and varieties (Figure 3). Seed yield (SY) was strongly and positively correlated with seeds pod $^{-1}$ (SP), branches plant $^{-1}$ (BP), and 1000-seed weight (1000-SW), indicating that improvements in these traits contributed directly to higher seed production. Stover yield (STY) also showed strong positive correlations with plant height (PH), and 1000 SW, suggesting that greater vegetative growth enhanced biomass accumulation. Plant height (PH) was positively associated with pods/plant (PP), filled pods plant $^{-1}$ (FPP), STY, HI, and SY, while filled pods/plant (FPP) was positively correlated with PP, PH, SP, BY, and SY, highlighting its importance for seed formation and productivity. Harvest index (HI) exhibited strong positive correlations with SP, BY, and SY, emphasizing its role in efficient assimilate partitioning to seeds. Similarly, biological yield (BY) was positively associated with BP, HI, and SP. In contrast, unfilled pods/plant (UPP) showed significant negative correlations with all major yield-related traits, including FPP, PH, SP, HI, BY, and SY, indicating that a higher number of unfilled pods reduced seed development and overall yield. Overall, the analysis identified seeds/pod, filled pods/plant, harvest index, plant height, and 1000-seed weight as the key traits contributing to seed yield improvement in sesame under different chitosan concentrations and varieties.

Table 4. Effect of variety, chitosan and their interactions on the crop characters, yield attributes and harvest index of sesame at harvest

Treatment	PH	BP	PP	FPP	UPP	SP	100-WTS	BY	HI
Variety (V)									
V_1	74.76b	4.62	36.61	29.49	1.53a	64.93	3.03	3.25b	29.45b
V_2	81.27a	5.13	41.24	31.09	1.19b	65.93	3.11	3.53a	30.20a
Sig. level	*	NS	NS	NS	**	NS	NS	**	**
Chitosan level (T)									
T_1	61.61c	3.00d	22.06c	25.56b	1.94a	52.83d	2.77b	2.63d	24.53e
T_2	69.22c	3.94c	25.95c	30.17ab	1.33b	61.33c	2.89b	3.17c	27.73d
T_3	79.84b	4.89b	34.83b	32.33a	1.22b	67.50b	3.16a	3.50b	30.54c
T_4	92.39a	7.44a	57.09a	33.61a	1.00b	76.67a	3.34a	4.11a	34.58a
T_5	87.00ab	5.11b	54.72a	29.78ab	1.31b	68.83b	3.18a	3.53b	31.75b
Sig. level	**	**	**	*	**	**	**	**	**
Interaction									
V_1T_1	61.33f	2.66d	19.33d	25.45b	2.11a	52.67e	2.67d	2.40f	24.14g
V_1T_2	65.33ef	3.67cd	22.67cd	29.33ab	1.55bc	60.33d	2.87cd	3.04de	27.19f
V_1T_3	77.00c-e	4.89b	32.55bc	30.66ab	1.44b-d	66.67bc	3.12a-c	3.48bc	30.36d
V_1T_4	87.89a-c	6.89a	54.52a	32.33a	1.11c-e	76.33a	3.33a	4.06a	34.24a
V_1T_5	82.22b-d	5.00b	54.00a	29.67ab	1.44b-d	68.67b	3.15ab	3.25cd	31.33bc
V_2T_1	61.89f	3.33cd	24.78cd	25.67b	1.78ab	53.00e	2.87cd	2.85e	24.93g
V_2T_2	73.11d-f	4.22bc	29.22b-d	31.00ab	1.11c-e	62.33cd	2.9bcd	3.30cd	28.27e
V_2T_3	82.67b-d	4.89b	37.11b	34.00a	1.00de	68.33bc	3.21a	3.53bc	30.71cd
V_2T_4	96.89a	8.00a	59.67a	34.89a	0.89e	77.00a	3.35a	4.66a	34.92a
V_2T_5	91.78ab	5.22b	55.44a	29.89ab	1.18c-e	69.00b	3.22a	3.80ab	32.17b
Sig. level	*	*	*	*	*	*	*	*	*
CV (%)	9.23	14.58	16.90	12.81	11.08	5.37	4.87	6.58	1.77

** = Significant at 1% level of probability, * = Significant at 5% level of probability and NS = Non-significant. Here, PH= Plant height (cm), BP= Branches plant $^{-1}$ (no.), PP= Pods plant $^{-1}$ (no.), FP= Filled pods plant $^{-1}$ (no.), UFP= Unfilled pods plant $^{-1}$ (no.), SP= Seeds pod $^{-1}$ (no.), 1000-WTS= 1000-seed weight (g), BY= Biological yield (t ha^{-1}), HI= Harvest index (%)

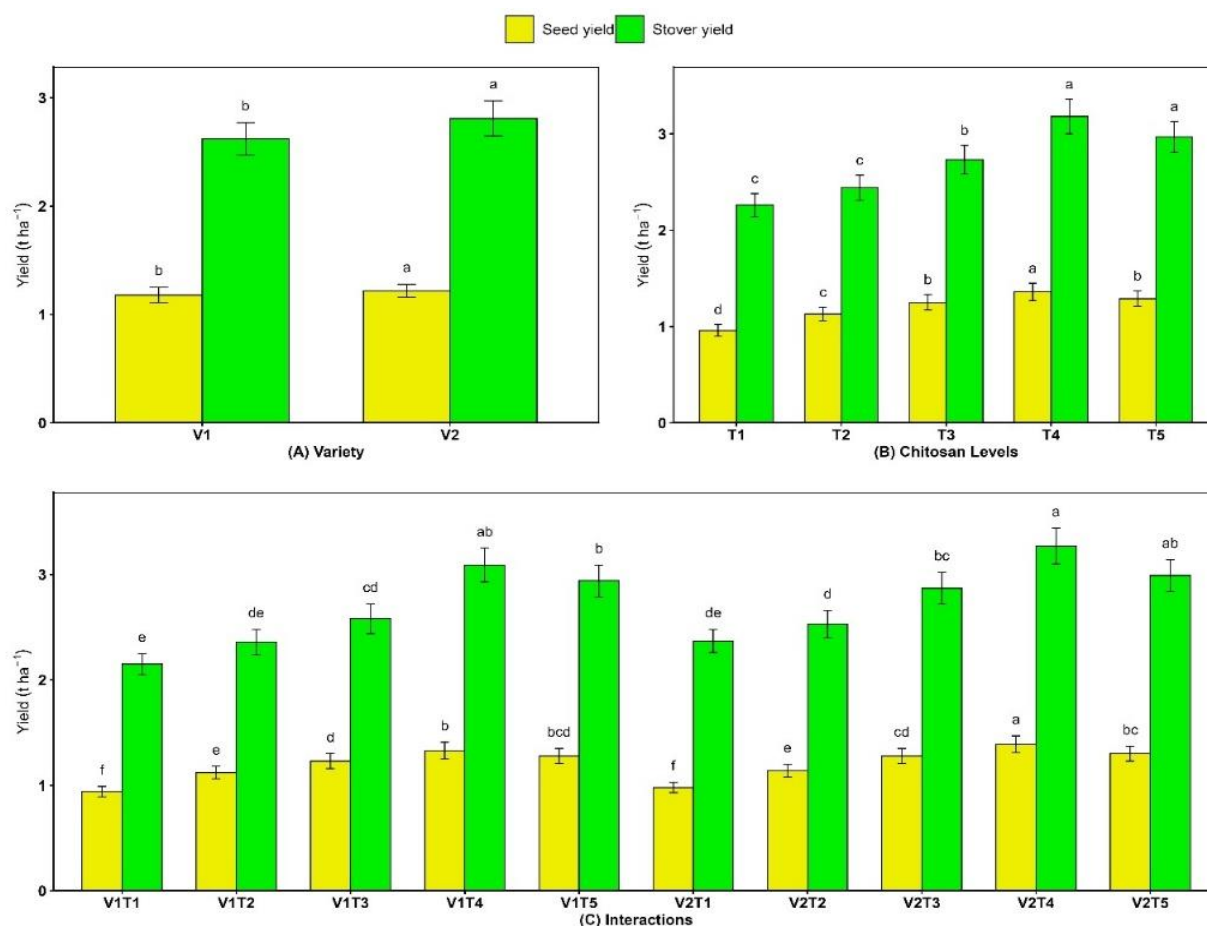


Figure 2. Effects of sesame variety (A), foliar chitosan application (B), and their interactions (C) on seed yield and stover yield. Values are presented as mean $\pm$ standard error

3.6. Heat map analysis

The hierarchical clustered heat map revealed clear differences among chitosan treatments and sesame varieties for yield and yield-related traits (Figure 4). Treatment combinations receiving 150 ppm chitosan (V₁T₄ and V₂T₄) formed a distinct cluster and exhibited the highest positive responses for most traits, including plant height (PH), pods plant⁻¹ (PP), seeds pod⁻¹ (SP), 1000-seed weight, seed yield (SY), stover yield (STY), biological yield (BY), harvest index (HI), and branches plant⁻¹ (BP). The 200 ppm chitosan treatments (V₁T₅ and V₂T₅) also showed favorable responses but were generally less pronounced than those observed at 150 ppm. In contrast, the control treatments (V₁T₁ and V₂T₁) clustered separately and were associated with lower values for most agronomic traits, indicating poor growth and yield performance in the absence of chitosan. The 50 ppm and 100 ppm treatments exhibited intermediate responses. Among the measured traits, SY, BY, HI, SP, and 1000-seed weight showed strong positive associations with higher chitosan concentrations, whereas unfilled pods plant⁻¹ (UPP) showed an opposite trend. These results demonstrate that chitosan application substantially improved sesame productivity, with 150 ppm identified as the most effective concentration across both varieties.

4. Discussion

The results demonstrated a significant positive effect of foliar-applied chitosan on plant growth, yield attributes, and productivity of sesame, although the magnitude of response varied depending on variety and chitosan concentration. The varietal performance revealed clear differences between the two sesame genotypes in terms of growth and yield-contributing traits. Among the tested varieties, BARI Til-6 consistently shown outstanding performance over BARI Til-4 for most agronomic traits. The superior response of BARI Til-6 may be associated with greater genetic potential for assimilate production, improved nutrient-use efficiency, and stronger physiological adaptability under field conditions. Similar varietal variation in sesame growth and yield attributes was also depicted by Teklu *et al.* (2021), who revealed that genotypic variability strongly influences yield ability and stress adaptability in sesame.

Foliar application of chitosan markedly enhanced vegetative growth and dry matter accumulation, confirming its role as an effective bio-stimulant. Improvements in plant height, branching, dry matter accumulation and pod numbers may be explained by the stimulatory effects of chitosan on cellular metabolism,

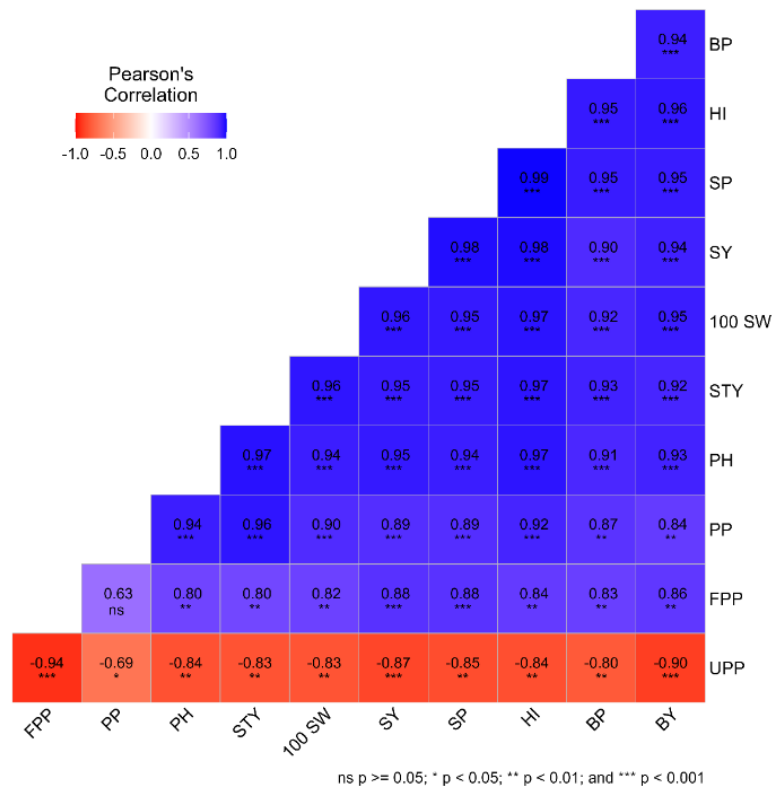


Figure 3. Pearson's correlation matrix showing the pairwise relationship among growth, yield attributes and yield of sesame as influenced by variety and foliar application of chitosan

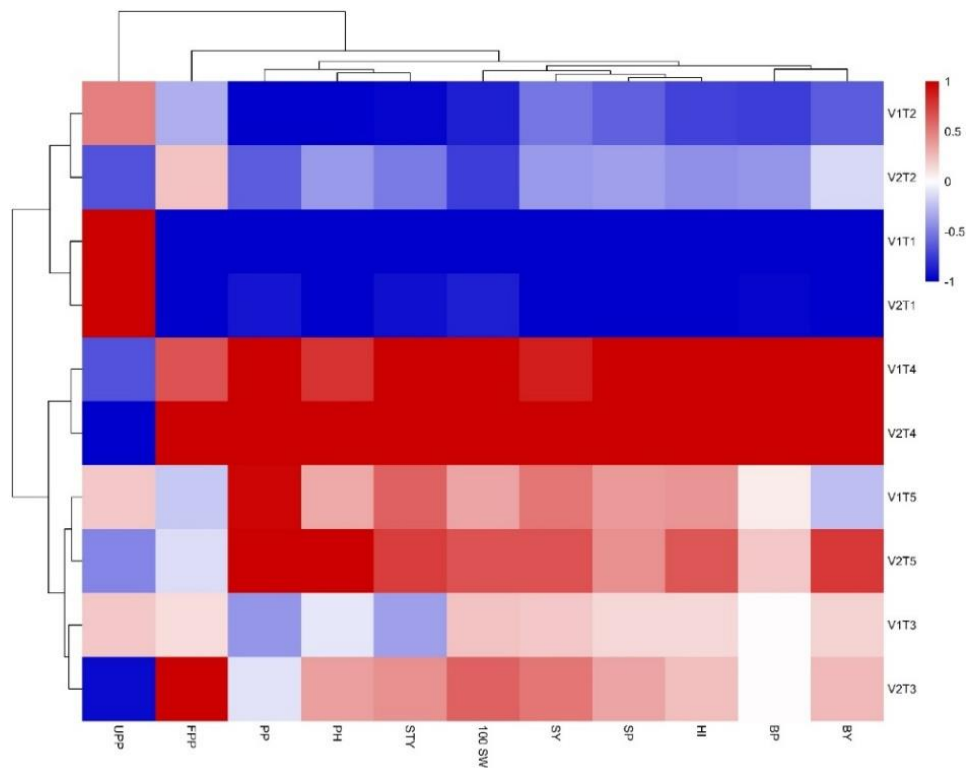


Figure 4. Hierarchical clustering heat map illustrating the relationships among growth, yield attributes and yield of sesame under different interaction treatments. Red and blue colors indicate relatively higher and lower trait values, respectively, with the color scale ranging from -1 to +1.

hormonal regulation, and photosynthetic activity. Chitosan has been reported to enhance endogenous levels of growth-promoting phytohormones such as auxins, gibberellins, and cytokinins, which regulate cell division, cell elongation, and meristematic activity (Reshad *et al.*, 2021). Enhanced hormonal activity likely contributed to improve stem elongation and branch formation observed in the present study. Chitosan, especially in nanoparticle form, is easily absorbed by the leaf epidermis and translocated to other parts of the plant, including the stems and roots (Dawood *et al.*, 2024). Moreover, chitosan may improve chlorophyll synthesis and chloroplast development, thereby increasing photosynthetic efficiency and carbohydrate production, which ultimately promote biomass accumulation and vegetative growth (Seleiman *et al.*, 2021).

Yield components such as pods/plant, filled pods/plant, seeds/pod, and 1000-seed weight were significantly improved by foliar chitosan treatment, particularly at 150 ppm, indicating that moderate application optimizes source-sink relationships, which ultimately ensued yield and other agronomic traits improvement. Moderate chitosan application improves the source-sink relationship and reproductive performance in sesame by increasing leaf photosynthetic activity (source) and promoting the growth of reproductive structures (sink), thereby enhancing the effective translocation of nutrients between them. The enhancement of these reproductive and yield-related traits may be attributed to the stimulatory effects of chitosan on several physiological and biochemical processes. Chitosan has been reported to improve endogenous phytohormone activity, particularly auxins, gibberellins, and cytokinins, which regulate flowering, reproductive development, and assimilate partitioning (Reshad *et al.*, 2021; Reyes-Pérez *et al.*, 2025). Enhanced hormonal regulation may have promoted greater flower retention, improved pollen viability, and more efficient fertilization, leading to increased capsule formation and seed set. In addition, chitosan may enhance chlorophyll synthesis, photosynthetic efficiency, and stomatal conductance, thereby increasing carbohydrate production and translocation of assimilates toward developing reproductive organs (Vishnu *et al.*, 2025). Improved nutrient uptake efficiency and membrane permeability under chitosan application may also have contributed to better seed filling and higher 1000-seed weight. Improved water relations, stomatal conductance, and metabolic activity under chitosan application may have further contributed to enhanced biomass accumulation and yield formation (Abedi *et al.*, 2026). Another important mechanism underlying the positive effects of chitosan is its role in activating antioxidant defense systems. Chitosan stimulates antioxidant enzymes which protect plant tissues from oxidative damage caused. Reduced oxidative stress likely improved reproductive efficiency and minimized flower or pod abortion, thereby contributing to the higher number of filled pods and seeds/pod observed in the present study. Comparable improvements in sesame yield and yield components following chitosan application have also been documented elsewhere (Farouk *et al.*, 2011 and Varamin *et al.*, 2020).

The significant interaction between variety and chitosan concentration further indicated that varietal response depended strongly on physiological compatibility with chitosan application. The highest yield traits and seed yield obtained from BARI Til-6 treated with 150 ppm chitosan suggests that this concentration provided the most favorable physiological environment for growth and reproductive development. The superior response of BARI Til-6 may be associated with greater genetic potential for nutrient-use efficiency, assimilate partitioning, and responsiveness to bio-stimulant mediated physiological enhancement. This finding suggests that improved sesame varieties are more responsive to plant growth-promoting substances such as chitosan. Similar genotype $\times$ management interactions were also noticed by Hussain *et al.* (2025), who told that varietal differences substantially influence crop response to bio-stimulant application. At this moderate concentration, chitosan likely optimized metabolic activity, nutrient assimilation, and photosynthetic performance without causing physiological stress. Although 200 ppm chitosan also improved growth and yield parameters compared with the control treatment, its performance was generally inferior to 150 ppm. This reduction at higher concentration may indicate that excessive chitosan application can disrupt cellular homeostasis, reduce metabolic efficiency, or interfere with gas exchange through partial stomatal restriction and increased solution viscosity on leaf surfaces. Such effects may limit photosynthetic activity and assimilate translocation, thereby reducing the efficiency of reproductive development. Similar concentration-dependent responses were stated by Rojas-Pirela *et al.* (2024), who observed that excessively high chitosan concentrations may induce physiological imbalance and suppress optimal crop performance.

The correlation and heat map analyses further supported the physiological role of chitosan in improving sesame productivity. The correlation analysis clearly demonstrated that faba bean yield is strongly governed by yield-attributing traits such as filled pods/plant, 100-seed weight, BY, and DM. These findings are consistent with those reported by Hiywotu *et al.* (2023) and Youseif *et al.* (2017), who also observed strong interrelationships among growth and yield traits in faba bean. Strong positive associations among seed yield, seeds/pod, harvest index, plant height, and biological yield indicate that enhanced photosynthetic efficiency, nutrient assimilation, and reproductive development collectively contributed to yield improvement under chitosan application. Conversely, the negative association between unfilled pods and yield-related traits suggests that improved reproductive efficiency and reduced physiological stress were important factors in maximizing sesame productivity. Overall, the findings of the present study confirm that chitosan foliar treatment substantially promotes the growth and yield of sesame, with 150 ppm identified as the optimum concentration. BARI Til-6 exhibited superior performance and greater responsiveness to chitosan application, indicating its suitability for achieving higher sesame productivity under the Old Brahmaputra Floodplain conditions of Bangladesh.

5. Conclusion

The findings of this study indicate that foliar application of chitosan significantly enhanced the growth and yield performance of sesame. BARI Til-6 exhibited superior performance over BARI Til-4, while 150 ppm chitosan consistently produced the highest values for growth, yield parameters, and seed yield. The interaction of BARI Til-6 with 150 ppm chitosan resulted in the utmost productivity. Therefore, foliar application of chitosan at 150 ppm may be recommended as an eco-friendly strategy to enhance sesame production in Bangladesh. Further research across locations and growing conditions is needed to confirm these results.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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