



Research article

Effects of Chitin Nanofiber on Growth and Yield of Brinjal (*Solanum melongena* L.)Meghna Khatun¹, Refa Tashnia Hossain Roti¹, Md. Yamin Kabir^{1*}, Md. Yasin Ali¹ and Md. Iftekhar Shams²¹Agrotechnology Discipline, Khulna University, Khulna-9208, Bangladesh²Forestry and Wood Technology Discipline, Khulna University, Khulna-9208, Bangladesh**ABSTRACT**

Brinjal requires the judicious application of fertilizers, particularly nitrogenous fertilizers for its satisfactory yield. A pot (earthen) experiment was conducted at the Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna, to investigate the effect of chitin nanofiber (CNF) on the growth and yield of 'Pritam F1 Hybrid' brinjal during summer in 2024. The experiment consisted of five treatments: control (water), urea (recommended dose), 0.005% CNF, 0.01% CNF, and 0.02% CNF, and replicated five times using a completely randomized design. The highest leaf chlorophyll content index (93.93), number of secondary branches (14.80), fruit length (8.07 cm), and fruit shape index (2.98) were measured for 0.02% CNF. The highest (69.00 cm) plant height was measured from 0.01% CNF, and the maximum (68.20) leaf number was counted from 0.005% CNF. The maximum (9.20) primary branches were recorded for the urea application. Among the treatments, 0.01% CNF resulted in statistically similar plant height, leaf chlorophyll content index, flower cluster with urea. The suboptimal growth and yield of brinjal during the study may have been partly associated with the prevailing unfavorable weather conditions, particularly extreme temperature (35–45 °C) and excessive rainfall (>50 mm). These environmental stresses may have reduced the effectiveness of the urea and CNF, thereby contributing to the suboptimal growth and yield observed in the present study. Further investigations under control and diverse environmental conditions are warranted to elucidate the influence of CNF application on the agronomic potential of brinjal production.

Introduction

Brinjal (*Solanum melongena* L.), a member of Solanaceae, is a popular and key winter vegetable in Bangladesh. With over 100 cultivars, it can be produced in practically every agroclimatic zone of the country (Chatterjee et al., 2021). Brinjal covers more than 19,920.30 hectares of land in Bangladesh in 2022–2023 and produces 235421.40 metric tons of fruits. Khulna produces 62525.70 metric tons from an area of 5,136.40 ha in 2022–2023 (BBS, 2023). Brinjal is mostly farmed for vegetables and rich in nutrients (Naeem et al., 2019).

Brinjal needs nitrogenous fertilizer to grow, develop, and yield (Keya et al., 2020). Cow dung or compost, urea (a nitrogenous fertilizer), TSP, MoP, gypsum, and boric acid are all necessary for brinjal cultivation. Nitrogen (N) is a crucial element for plant growth and development. Every part of a plant cell — cell wall, plasma membrane,

cytosol, chloroplast, mitochondria, nucleus, vacuole — requires N. The application of nitrogen increases plant height, fruit size, and fruit yield (Zainub et al., 2016). Plants that lack N exhibit chlorosis, stunted growth, low yield, and poor productivity. Our farmers use urea fertilizer to supply N (Bremner, 1995). However, urea is costly, and the price is increasing. The Government of Bangladesh provides subsidies for urea. The amount of urea subsidies in the fiscal years 2020–21 and 2021–22 were Tk. 7,717 crore and Tk. 28,000 crore, respectively (The Business Standard, 2022). Therefore, the government increased the price of per kg urea from Tk. 16 to Tk. 22 on August 1, 2022. Moreover, urea has certain drawbacks, being prone to loss by leaching, percolation, runoff, and volatilization (Jadon et al., 2018). Excessive or inefficient use of urea can contribute to environmental pollution, particularly through nitrogen losses and eutrophication,

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while also posing other ecological concerns. Consequently, increasing attention has been directed toward more sustainable nutrient-management strategies, including the use of organic fertilizers, which are being evaluated as alternative nutrient sources for vegetable crops such as tomato and knolkhol (Islam et al., 2020; Saha et al., 2019). Therefore, looking for an alternate source of urea is of great importance. Shrimp, crab, squid, and marine crustacean bone plates are composed of chitin — a natural source of nitrogen. Chitin contains about 6.89% nitrogen by mass (Janssen et al., 2017). Chitin appears to be the most cost-effective to increase the quality and production of plants, particularly high-value horticultural crops (Shahrajabian et al., 2021). Due to its intriguing qualities, particularly those pertaining to its use in biological applications, chitin has attracted a lot of attention (Pereira et al., 2017). Though chitin is insoluble in water, nanofibrillation makes it water-soluble. Chitin nanofiber (CNF) is a fiber with an aspect ratio greater than 100 and diameter in nanometer-scale (Li and Xia, 2004). It exhibits a good dispersing ability in water and a very homogeneous structure with a thickness of 10–20 nm (Egusa et al., 2020). CNF demonstrates comparable growth and yield outcomes to urea fertilizers in crops such as rice and coriander (Afroj et al., 2025; Biswas et al., 2025; Bagchi et al., 2025; Shams et al., 2025) and has shown promising applications in postharvest preservation of fruits like mangoes, bananas, papayas, dragon fruits, and cucumbers (Hossain et al., 2025; Kabir et al., 2026; Munira et al., 2025a, 2025b; Parvin et al., 2025; Tanpichai et al., 2023). Owing to their biocompatible, biodegradable, and non-toxic nature, CNF materials promote ecological sustainability by minimizing carbon emissions, utilizing agricultural waste, and extending food shelf life (Munoz-Nunez et al., 2022). Chitin nanofibers (CNF) stimulate plant growth by pacing soil nitrogen availability and maximizing root nutrient uptake efficiency. Because of an inherently high nitrogen content (3.6%–6.8%) and a low carbon-to-nitrogen (C/N) ratio, these biopolymers function as effective agronomic enhancers and soil conditioners (Egusa et al., 2019; Janssen et al., 2017). Moreover, it enhances plant growth by improving root development, nutrient uptake, and stress tolerance while also removing heavy metals, serving as biodegradable mulch, and exhibiting antifungal and antibacterial properties that protect crops from pathogens (Egusa et al., 2019; Shahrajabian et al., 2021; Yanat & Schroën, 2023). When applied as seed coatings or foliar sprays, CNF effectively stimulates plant growth and productivity across various horticultural systems (Shahrajabian et al., 2021). Although chitin nanofiber (CNF) has been studied for its beneficial effects on plant growth, yield, stress tolerance, nutrient uptake, and postharvest preservation in several crops, including rice, coriander, leafy vegetables, mango, banana, papaya, dragon fruit, and cucumber, there is limited or no specific research on its application in brinjal (*Solanum melongena* L.). Previous studies have mainly focused on cereals, leafy vegetables, and fruit crops, leaving a significant knowledge gap regarding the effects of CNF on solanaceous vegetables. In particular, the influence of CNF on the vegetative growth and yield performance of brinjal, as well as its potential to serve as a sustainable alternative to conventional urea fertilizer, remains poorly understood.

Since brinjal is a high-value and nutrient-rich crop that is sensitive to soil nutrient dynamics and biotic stress, investigating the effects of CNF on its vegetative growth and yield components could provide valuable insights into sustainable fertilizer alternatives and bio-stimulant technologies for vegetable production in Bangladesh and other tropical regions. Therefore, the current study assesses the performance of CNF for growth and yield of brinjal as a substitute for urea.

Materials and Methods

Pot preparation, Planting material, Treatments, and Experimental design

It is a pot experiment, and the earthen pots (16" diameter) were prepared at the Field Laboratory of Agrotechnology Discipline, Khulna University, Khulna. The soil was collected from Nijkhamar, Khulna, and spread over the floor for two days. About 405 kg of soil was weighed with a digital balance and mixed thoroughly with 2 kg cow dung, 50 g TSP, 40 MoP, 20 g gypsum, and 2 g boric acid. Each pot was filled with 12 kg of soil. About 30-day-old seedlings of brinjal, Pritam F1 hybrid, were transplanted into the pot on 4th April 2024. Pritam is a high-yielding, year-round, and disease-resistant hybrid variety. The experiment was conducted using a Completely Randomized Design (CRD) with five treatments: control (water), the recommended dose of urea, and three concentrations of chitin nanofiber (CNF) solution (0.005%, 0.01%, and 0.02%). Each treatment was randomly assigned and replicated five times.

The CNF concentrations were selected based on previous studies reporting improved growth and yield of rice and coriander with CNF application, particularly at a concentration of 0.01%. Therefore, concentrations below (0.005%) and above (0.02%) were included to evaluate the response across a broader concentration range. Although the CNF treatments did not provide an amount of nitrogen equivalent to that supplied by the recommended urea treatment, the experiment was designed to determine whether any of the tested CNF concentrations could promote crop growth and yield comparable to that achieved with the recommended urea application. The recommended urea rate for brinjal cultivation was 300 kg ha⁻¹, corresponding to 3.6 g per pot containing 12 kg of soil. Urea was applied in five equal splits of 0.72 g at 20, 40, 50, 65, and 80 days after transplanting (DAT). CNF solutions were administered at the same intervals, with each pot receiving a total of 60 ml, 120 ml, and 240 ml of 1% CNF solution for the 0.005%, 0.01%, and 0.02% concentrations, respectively. Thirty-day-old brinjal seedlings were transplanted on 4 April 2024, and fertilizer applications were scheduled on 23 April, 12 May, 21 May, 6 June, and 23 June 2024. CNF solutions were applied with care to ensure effective soil absorption. Meteorological data, including temperature, rainfall, and relative humidity, were collected from the nearby Khulna Meteorological Station, located less than 50 m from the experimental site.

The CNF was extracted from the shells of black tiger shrimp (*Penaeus monodon*) in the lab of Bionanomaterials, Forestry and Wood Technology Discipline, Khulna University. The clean, dry shells were crushed and treated with 7% HCl, 4% NaOH, and 50% ethanol for

demineralization, deproteinization, and depigmentation, respectively (Ifuku et al., 2011). The slurry (1 wt.%) blended and passed through a Super Masscolloider (MKCA6-5J, Japan) to get the CNF, which was collected and stored in a refrigerator for future use. The target concentration was adjusted by adding more distilled water.

Measurement of Growth Attributes

Plant height was measured using the measuring scale from the base to the tip of the leaf of each plant in each pot at 50 days after transplanting (DAT), 60 DAT, 70 DAT, 80 DAT, 90 DAT, and 100 DAT. The stem diameter of each plant was recorded through a digital slide caliper. The diameter was measured at 1 inch above the soil surface of each plant at 50 DAT, 60 DAT, 70 DAT, 80 DAT, 90 DAT, and 100 DAT. The number of leaves from each plant was counted at the same DATs, as mentioned before. The leaf chlorophyll content index (SPAD readings) was recorded through the SPAD 502Plus chlorophyll meter from three leaves of each plant at 50 DAT, 60 DAT, 70 DAT, 80 DAT, 90 DAT, and 100 DAT. The number of primary and secondary branches was also counted at 50 DAT, 60 DAT, 70 DAT, 80 DAT, 90 DAT, and 100 DAT.

Measurement of Yield and Yield Attributes

The number of flower clusters was recorded from each plant at 50 DAT, 60 DAT, 70 DAT, 80 DAT, 90 DAT, and 100 DAT. Fruits were harvested twice (70 DAT and 100 DAT) during the growing season. The number of fruits, fruit weight, length, and diameter were estimated after each harvest. The fruit shape index was calculated by dividing the fruit length by diameter.

Statistical Analysis

The data from the field trial were analyzed using a one-way analysis of variance (ANOVA) following CRD

design. Data sets were processed using Microsoft Excel 2013 and analyzed using IBM SPSS Statistics for Windows (Version 27.0.1.0) [IBM Corp. (2020), Armonk, NY, USA]. The assumptions underlying the ANOVA were assessed prior to statistical analysis. The normality of the residuals was checked to ensure that the data were approximately normally distributed, while homogeneity of variance was assessed to confirm that the variances among the treatment groups were sufficiently similar. These assumptions were found to be satisfactory for conducting ANOVA. Statistical significance was evaluated at a significance level of $\alpha = 0.05$ throughout the analysis. Treatment means were compared using the same software by Tukey's Honestly Significance Difference (HSD) Test at 5% probability.

Results and Discussion

Plant Height (cm)

The plant height of brinjal varied significantly at 70 and 100 DATs due to the effects of treatments (Table 1). At 100 DAT, the highest plant height (69.00 cm) was obtained from 0.01% CNF, which was statistically similar to 0.02% CNF, urea, and 0.005% CNF, and the lowest plant height (57.20 cm) was recorded from the control. Though reports regarding the effect of CNF on plant height are rare, several studies evaluated the effect of chitosan, a chitin derivative, on the height of plants as the foliar application of chitosan @ 100 mg L⁻¹ increased tomato plant height under water stress (Hassnain et al., 2020); 50 and 100 ppm chitosan resulted in higher mungbean plant height (Mondal et al., 2013); and chitosan spray increased the plant height of the 'Super Hot' chili peppers (Kramchote et al., 2022), suggesting that N in chitin may contribute plant height increase in brinjal.

Table 1: Effect of Chitin Nanofiber (CNF) on Plant Height of Brinjal at Different Days After Transplanting (DAT)

Treatment	Plant Height (cm)					
	50DAT	60DAT	70DAT	80DAT	90DAT	100DAT
Control	30.40	38.80	40.80ab	47.00	52.20	57.20b
Urea	34.00	38.00	46.20a	55.40	59.80	65.60ab
0.005% CNF	31.40	40.40	43.80ab	49.00	56.60	63.00ab
0.01% CNF	28.20	39.00	42.60ab	53.40	61.60	69.00a
0.02% CNF	27.40	34.80	39.60b	52.80	60.00	67.60ab
p	0.121	0.543	0.048	0.086	0.062	0.040
CV	8.69	5.46	6.05	6.65	6.34	7.21

CV = Coefficient of variation. In a column, values having similar letters did not differ at 5% probability according to Tukey's HSD Test.

Stem Diameter (mm)

Though the stem diameter of brinjal did not differ at any stage of growth due to the application of CNF, it increased as the age of the plant increased (Table 2). However, the stem diameter (mm) for control, urea, 0.005% CNF, 0.01%

CNF, and 0.02% CNF were 13.77, 13.66, 13.30, 13.22, and 12.47 mm, respectively, at 100 DAT. Similarly, chitosan also did not affect the stem diameter of the tomato (Waewthongrak et al., 2020).

Table 2: Effect of Chitin Nanofiber (CNF) on Stem Diameter of Brinjal at Different Days After Transplanting (DAT)

Treatment	Stem Diameter (mm)					
	50DAT	60DAT	70DAT	80DAT	90DAT	100DAT
Control	8.42	9.66	10.86	12.20	12.69	13.77
Urea	9.21	11.27	11.99	11.92	12.53	13.66
0.005% CNF	8.12	9.97	11.58	11.86	12.48	13.30
0.01% CNF	8.07	9.77	10.31	11.50	12.32	13.22
0.02% CNF	7.62	9.87	10.30	11.29	11.72	12.47
p	0.399	0.328	0.096	0.421	0.298	0.148
CV	7.11	6.52	6.89	3.60	3.03	3.84

CV = Coefficient of variation.

Leaf Number

The leaf number of brinjal did not vary among the treatments except at 70 DAT (Table 3). The highest number of leaves (45.20) was counted from 0.005% CNF,

which was statistically similar to control, urea, and 0.01% CNF at 70 DAT. However, the lowest number of leaves (36.80) was counted for 0.02% CNF. Chitosan increased leaf number in tomato and strawberry than control (El-Miniawy et al., 2013; Waewthongrak et al., 2020).

Table 3: Effect of Chitin Nanofiber (CNF) on Leaf Number of Brinjal at Different Days After Transplanting (DAT)

Treatment	Leaf Number					
	50DAT	60DAT	70DAT	80DAT	90DAT	100DAT
Control	32.20	48.20	39.60ab	45.80	55.80	60.60
Urea	32.80	51.80	41.20ab	48.60	54.60	58.60
0.005% CNF	32.20	50.40	45.20a	50.80	57.20	68.20
0.01% CNF	30.60	46.60	42.00ab	50.40	59.60	67.60
0.02% CNF	26.80	39.80	36.80b	46.40	53.80	63.40
p	0.662	0.123	0.027	0.394	0.763	0.378
CV	7.90	9.86	7.55	4.68	4.80	6.62

CV = Coefficient of variation. In a column, values having similar letters did not differ at 5% probability according to Tukey's HSD Test.

Leaf Chlorophyll Content Index

Leaf chlorophyll content index differed significantly at 60, 70, and 80 DATs (Table 4). At 60 DAT, the highest chlorophyll content (68.40) was obtained from urea, which was statistically similar to control, 0.01% CNF, 0.02% CNF, and the lowest chlorophyll content (56.61) was recorded from 0.005% CNF. Similarly, the highest chlorophyll content (70.03) was obtained from urea, which was statistically similar to control, 0.01% CNF, 0.02% CNF, and the lowest chlorophyll was recorded from 0.005% CNF at 70DAT. At 80 DAT, the highest chlorophyll content (64.46) was recorded from urea, which was similar to control, 0.01% CNF, 0.02% CNF, and the lowest chlorophyll content (55.59) was recorded from 0.005% CNF. However, the chlorophyll content did not

differ at 90 and 100 DATs (Table 4). Overall, leaf chlorophyll content index showed significant variation at 60, 70, and 80 days after transplanting (DAT), with the highest values consistently observed in the urea treatment, statistically comparable to control, 0.01% CNF, and 0.02% CNF. The lowest chlorophyll levels were recorded in the 0.005% CNF treatment across these intervals, while no significant differences were noted at 90 and 100 DATs. Chitosan solution increased the total leaf chlorophyll content of tomato by 8% - 12% than the control (Waewthongrak et al., 2020). Similarly, topical application of oligo-chitosan raised the overall leaf chlorophyll content of chili by 12% than the control group (Dzung et al., 2017).

Table 4: Effect of Chitin Nanofiber (CNF) on Leaf Chlorophyll Content Index of Brinjal at Different Days After Transplanting (DAT)

Treatment	Leaf Chlorophyll Content Index					
	50DAT	60DAT	70DAT	80DAT	90DAT	100DAT
Control	92.54	65.63ab	61.84ab	59.01ab	54.19	58.64
Urea	78.57	68.40a	70.03a	64.46a	55.74	61.83
0.005% CNF	71.87	56.61b	55.60b	55.59b	56.11	61.56
0.01% CNF	77.23	61.48ab	58.43b	56.89ab	51.80	62.05
0.02% CNF	93.93	62.70ab	62.32ab	58.90ab	51.07	64.93
p	0.632	0.037	0.008	0.052	0.273	0.195
CV	11.87	7.05	8.79	5.58	4.23	3.60

CV = Coefficient of variation. In a column, values having similar letters did not differ at 5% probability according to Tukey's HSD Test.

Primary and Secondary Branches

There were no significant differences in number of primary and secondary branches among the treatments (Tables 5-6). However, the number of primary branches for control, urea, 0.005% CNF, 0.01% CNF, and 0.02% CNF were 7.80, 9.20, 6.80, 7.60, and 7.20, respectively, at 100 DAT (Table 5). Similarly, the number of secondary

branches for control, urea, 0.005% CNF, 0.01% CNF, and 0.02% CNF were 12.60, 14.20, 12.80, 12.60, and 14.80, respectively, at 100 DAT (Table 6). However, foliar application of chitosan at early growth stages increased the number of branches of summer tomatoes (Mondal et al., 2016).

Table 5: Effect of Chitin Nanofiber (CNF) on Number of Primary Branches of Brinjal at Different Days After Transplanting (DAT)

Treatment	Primary Branch (number)				
	60DAT	70DAT	80DAT	90DAT	100DAT
Control	6.40	7.00	7.20	7.80	7.80
Urea	8.40	8.40	8.60	9.00	9.20
0.005% CNF	9.00	6.20	6.40	6.60	6.80
0.01% CNF	8.00	7.20	7.60	7.80	7.60
0.02% CNF	6.60	6.40	7.00	7.20	7.20
<i>p</i>	0.101	0.172	0.219	0.149	0.139
CV	14.8	12.28	11.10	11.58	11.81

CV = Coefficient of variation.

Table 6: Effect of Chitin Nanofiber (CNF) on Number of Secondary Branches of Brinjal at Different Days After Transplanting (DAT)

Treatment	Secondary Branch (number)				
	60DAT	70DAT	80DAT	90DAT	100DAT
Control	12.00	10.00	10.40	10.20	12.60
Urea	9.40	11.80	12.20	12.80	14.20
0.005% CNF	12.60	9.00	10.00	10.80	12.80
0.01% CNF	8.40	10.00	10.60	11.20	12.60
0.02% CNF	7.20	10.20	11.20	12.00	14.80
<i>p</i>	0.161	0.399	0.365	0.263	0.156
CV	23.36	9.90	7.86	8.94	7.68

CV = Coefficient of variation.

Flower Cluster

The number of flower clusters did not vary among the treatments at any stage of growth except at 70 DAT. The lowest number (5.80) of flower clusters was counted from 0.005% CNF, and the number of flower clusters for the rest of the treatments (control, urea, 0.01% CNF, and 0.02% CNF) was statistically similar among them, and higher than 0.005% CNF at 70 DAT (Table 7). However, foliar application of chitosan increased the number of effective

flower clusters, flowers per plant, and reproductive efficiency of summer tomatoes (Mondal et al., 2016). Moreover, various chitosan treatment techniques significantly increased the quantity of tomato flower clusters per plant (Parvin et al., 2019). Similarly, chitosan and exogenous GA3 stimulated flowering and increased earliness in the globe artichoke (Elsharkawy et al., 2019).

Table 7: Effect of Chitin Nanofiber (CNF) on Number of Flower Clusters of Brinjal at Different Days After Transplanting (DAT)

Treatment	Flower Cluster (number)				
	60DAT	70DAT	80DAT	90DAT	100DAT
Control	7.60	10.20a	4.60	11.80	11.60
Urea	7.20	9.80a	2.40	7.80	9.80
0.005% CNF	7.80	5.80b	3.40	9.20	10.20
0.01% CNF	8.20	7.00ab	3.80	9.40	10.40
0.02% CNF	7.20	6.80ab	2.60	7.80	8.60
<i>p</i>	0.876	0.011	0.343	0.187	0.349
CV	5.53	2.47	26.75	17.79	10.69

CV = Coefficient of variation. In a column, values having similar letters did not differ at 5% probability according to Tukey's HSD Test.

Yield Attributes of Brinjal

There were no significant differences in fruit number, fruit weight, fruit length, and fruit diameter among the treatments (Table 8). The average fruit number per plant

ranged from 4.60 to 6.20, with a mean of 5.44. The fruit weight (g) for the control, urea, 0.005% CNF, 0.01% CNF, and 0.02% CNF were 151.89, 123.08, 130.16, 120.60, and 147.08, respectively (Table 8). Numerically, larger fruit (8.07cm) and smaller fruit (5.19 cm) were harvested from

0.02% CNF and urea, respectively. Fruits were similar in diameter and ranged from 28.35 mm to 31.87 mm, with an average of 30.30 mm (Table 8). The fruit shape index of brinjal varied significantly among the treatments (Table 8). The highest fruit shape index (2.98) was calculated for 0.02% CNF, which was statistically similar to 0.005% CNF and 0.01% CNF, and the lowest index (1.69) was calculated from urea (Table 8). Overall, there were no significant differences among treatments in fruit number, weight, length, or diameter, although average fruit number ranged from 4.60 to 6.20 per plant. However, the fruit shape index varied significantly, with the highest value

(2.98) observed in the 0.02% CNF treatment and the lowest (1.69) in the urea treatment. However, chitosan boosted the tomato's total fruit weight, on average, by 48% (El Amerany et al., 2022). Similarly, foliar application of chitosan @ 100 mgL⁻¹ under water stress increased the average fruit weight (g) and number of fruits per plant in tomato (Hassnain et al., 2020). Moreover, foliar chitosan spraying enhanced the globe artichoke's head quality (Saif Eldeen et al., 2014). However, foliar spraying of 250 ppm chitosan resulted in a drop in the fruit shape index of Washington navel orange (Ahmed et al., 2016).

Table 8: Effect of Chitin Nanofiber (CNF) on Yield Attributes of Brinjal

Treatment	Yield Attributes				
	Fruit number	Fruit weight (g)	Fruit length (cm)	Fruit diameter (mm)	Fruit shape index
Control	6.20	151.89	5.67	31.87	1.77b
Urea	5.40	123.08	5.19	30.32	1.69b
0.005% CNF	5.20	130.16	5.96	30.04	1.98ab
0.01% CNF	4.60	120.60	6.24	30.94	2.01ab
0.02% CNF	5.80	147.08	8.07	28.35	2.98a
<i>p</i>	0.619	0.191	0.198	0.860	0.027
CV	11.15	10.53	15.80	1.518	24.83

CV = Coefficient of variation. In a column, values having similar letters did not differ at 5% probability according to Tukey's HSD Test.

Mechanisms Underlying CNF-Mediated Growth and Yield Promotion

The growth-promoting effects of chitin nanofibers (CNF) may be associated with their potential to regulate nitrogen availability in soil and improve nutrient uptake by plants. Owing to their relatively high nitrogen content (3.6–6.8%) and low C/N ratio, CNF can serve not only as a source of nitrogen but also as a soil amendment capable of influencing nutrient dynamics and rhizosphere processes (Egusa et al., 2019; Janssen et al., 2017). The nanoscale structure of CNF may further facilitate interactions with soil and plant roots, potentially enhancing root development and nutrient acquisition. In addition to their nutritional effects, chitin-derived materials have been reported to improve plant tolerance to environmental stresses and contribute to the suppression of soil- and plant-associated pathogens through antifungal and antibacterial activities (Egusa et al., 2019; Shahrajabian et al., 2021; Yanat & Schroën, 2023). Their capacity to interact with and immobilize heavy metals, together with their biodegradability and potential use as mulch or soil conditioners, further highlights the multifunctional agronomic potential of CNF. Collectively, these properties may explain the positive growth responses observed following CNF application; however, the magnitude and consistency of these effects are likely to depend on CNF concentration, soil characteristics, crop species, and

prevailing environmental conditions. Therefore, further field-based studies are required to clarify the relative contribution of nitrogen supply and other CNF-mediated mechanisms to plant growth and nutrient-use efficiency.

Weather Extremes and the Growth and Yield of Brinjal

During the growing season, particularly from April to June 2024, Bangladesh experienced high temperatures during the flowering and fruiting stages of brinjal. During the experimental period, maximum and minimum temperatures ranged from 35–45 °C and 20–33 °C, respectively (Fig. 1). These temperatures were considerably higher than the optimum range for fruit set in brinjal (18–21 °C; Nath et al., 2008). Temperatures above 35 °C have been reported to reduce fruit set through increased flower drop in most brinjal cultivars (Pandit et al., 2010). Similarly, high temperatures can adversely affect growth parameters, including shoot length and dry matter accumulation, thereby reducing yield attributes (Liaquat et al., 2019). Santhiya et al. (2019) also reported that temperatures substantially above the optimum range can negatively affect morphological and yield-related traits in brinjal. Therefore, the prevailing high-temperature conditions during the flowering and fruiting stages may have contributed to poor fruit set, reduced fruit production, and consequently the limited number of harvests observed in the present study.

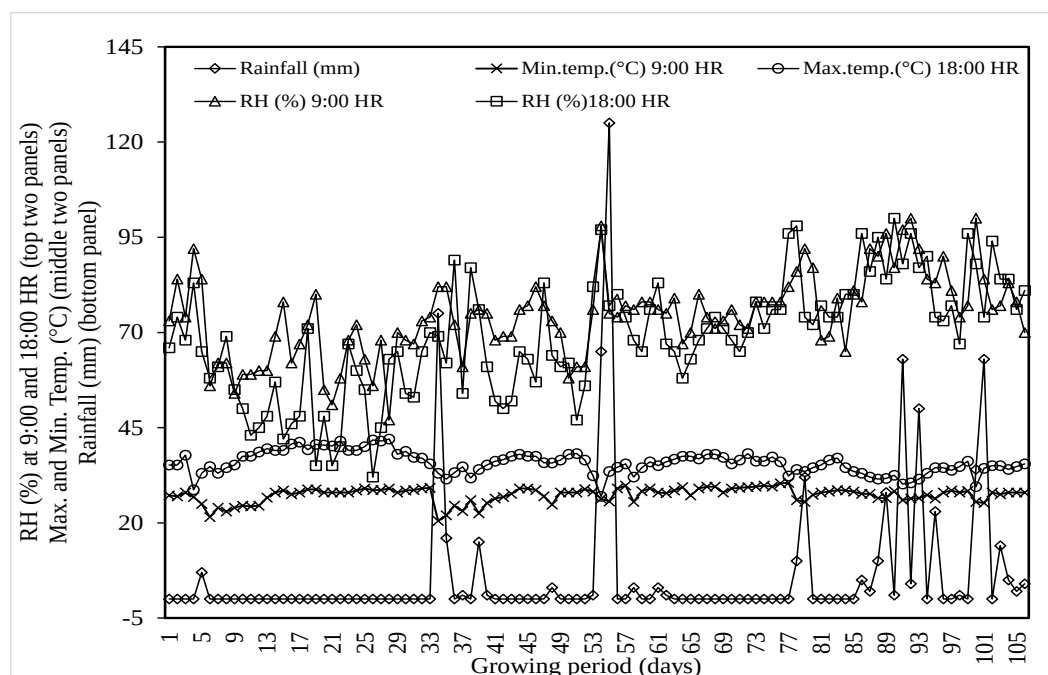


Figure 1: Weather [relative humidity (RH, %, top panel), maximal air temperature (Tmax, °C, upper middle panel), minimal air temperature (Tmin, °C, lower middle panel), and rainfall (mm, bottom panel)] of the study location during the growing season (4th April 2024 to 14th July 2024, total growing period 103 days). Data were gathered from Khulna Meteorological Station, which is within 50 m of the experimental field.

Though summer-rainy brinjal has high demand due to premium price, high temperature, low humidity, and strong desiccating winds have a marked effect on fruit set (Singh and Kalda, 2000). Similarly, drought stress resulted in poor fruit set and reduced fruit weight in brinjal due to decreased photosynthesis and metabolic activities (Abd El-Al et al., 2008; Aujla et al., 2007; Zayova et al., 2017). The eggplant size decreased under drought conditions due to reduced vegetative growth and photosynthesis (Bsoul et al., 2016; Lovelli et al., 2007). Moreover, high temperatures during flowering and fruiting can affect the fruit weight of capsicum (Dahal et al., 2006).

The low growth and yield of brinjal in the present study can largely be attributed to unfavorable weather conditions, including extreme heat and excessive rainfall, which created a challenging environment for brinjal growth and yield (Table 8). It rained a lot at 34-35 DATs, 54-55 DATs, and at the last three weeks of growing season. Under extreme heat and excessive rainfall, the effects of fertilizers (urea and CNF solutions) may have been jeopardized. High temperatures can increase evapotranspiration, leading to nutrient imbalances, while excessive rainfall can leach nutrients like nitrogen from the soil, reducing the effectiveness of urea fertilization (Zhou et al., 2023). Moreover, the effect of chitin and chitosan can vary due to concentration, application method, and environmental conditions. In the study, poor results of the treatment might be due to extreme environmental conditions or suboptimal application rates or methods that overshadowed any potential benefits (Endo et al., 2023).

Limitations of the Study

Despite the observed positive responses to chitin nanofiber (CNF), the findings should be interpreted with caution because the evidence supporting CNF as an alternative nitrogen source to urea remains limited. A substantial

proportion of the treatment effects were non-significant, indicating that the responses of growth and yield-related traits to CNF were not consistently different from those obtained with urea or the control treatment. Therefore, the present results provide preliminary evidence of the potential of CNF as a nitrogen source rather than conclusive evidence of its equivalence or superiority to urea. Furthermore, the study was conducted as a pot experiment, which may not fully represent the complex soil, root, and environmental interactions occurring under field conditions. Moreover, the soil of the experiment was not analyzed. The relatively restricted root volume and controlled experimental setting may also have influenced nutrient availability, root development, and plant responses to CNF. In addition, the experiment was conducted during a single growing season, limiting the ability to account for year-to-year variation in temperature, rainfall, and other environmental factors. Importantly, the study period was characterized by extreme environmental conditions, which may have imposed additional stress on plant growth and reproductive development and potentially masked or modified the effects of CNF treatments. Consequently, the observed responses may reflect an interaction between CNF application and the prevailing environmental conditions rather than the effects of CNF alone. Multi-season field experiments conducted under diverse agroecological conditions, with appropriate nitrogen-rate comparisons and assessment of nitrogen-use efficiency, are therefore necessary to validate the effectiveness and consistency of CNF as a potential alternative to conventional urea fertilization.

Conclusion

The application of chitin nanofiber (CNF) showed promising effects on several vegetative and reproductive traits of brinjal. A 0.01% CNF concentration enhanced

plant height, 0.005% CNF increased leaf number, while 0.02% CNF improved leaf chlorophyll content, secondary branching, fruit length, and fruit shape index. However, overall growth and yield remained suboptimal, even under the recommended urea dose, which may have been partly associated with the high-temperature and excessive rainfall conditions prevailing during the experimental period. Although these environmental factors provide a plausible explanation for the reduced fruit production and limited number of harvests, their direct effects on plant responses and nutrient dynamics were not quantified in the present study. Further research under controlled environmental conditions and across multiple growing seasons, with detailed assessment of fruit set, flower drop, soil moisture and temperature, and nutrient losses, is warranted to better understand CNF–environment interactions and establish the agronomic potential of CNF as a component of sustainable brinjal production systems.

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Competing Interest

The authors report that there are no competing interests to declare.

Credit Author Statement

MK: Methodology, Investigation, Writing – Original draft; RTHR: Methodology, Investigation, Writing – Original draft; MYK: Supervision, Conceptualization, Analysis, Writing - review & editing, Fund acquisition; MYA: Conceptualization, Co-supervision; MIS: CNF preparation and evaluation.

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