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Foliar applications of chitin nanofiber augment plant growth, yield, and postharvest quality of coriander (*Coriandrum sativum* L.)

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ABSTRACT

Coriander leaves are highly perishable and require abundant nitrogen for growth and yield. This study evaluated the effect of foliar application of chitin nanofibers on the plant growth, leaf yield, and postharvest leaf quality of coriander. The treatments consisted of control (no nitrogenous fertilizer), 13 g urea (as a recommended dose of nitrogen), 13 ml chitin nanofiber, 26 ml chitin nanofiber, and 39 ml chitin nanofiber. Urea was soil-mixed, and chitin nanofiber was sprayed at 15 and 30 days after emergence. Foliar application of 39 ml of chitin nanofiber resulted in similar plant height and leaf number to that of urea. Leaf yield was identical for 26 ml of chitin nanofiber and urea. A 39 ml of chitin nanofiber-treated leaf was fresher, tender, and had lower shrinkage than the control. Moreover, it increased the shelf life of coriander by 1.5 days compared to the control. Overall, 39 ml of chitin nanofiber promoted the growth and yield of coriander, while also maintaining postharvest quality, including shelf life extension. Therefore, we suggest 39 ml of chitin nanofiber for growing coriander and maintaining postharvest quality, including shelf life. However, we recommend further experiments to confirm the results.

KEYWORDS

Nanomaterial; leaf tenderness; shrinkage; chemical attributes; shelf life

Introduction

Coriander (*Coriandrum sativum* L.) is a fresh leafy vegetable and at times, a medicinal plant belonging to the family Apiaceae. Its leaves possess a unique, strong aroma and flavor (Sahib et al., 2012). Originating from Italy, coriander is cultivated in the Mediterranean region, the Netherlands, Central and Eastern Europe, North Africa, North America, China, India, and Bangladesh (Baliga et al., 2015). Coriander is widely used for culinary, dietary, and medicinal purposes, including the preparation of flavorful dishes, salads, juices, and sauces. The leaves, frequently consumed as vegetables, are rich in vitamins [A, B2 (riboflavin), and C]

and dietary fiber. Mature coriander leaves contain 87.9% moisture, 6.5% total sugar, 3.3% protein, and 1.7% ash (Mandal and Mandal, 2015).

Coriander is a potential crop for Bangladesh. In recent years, farmers have shown increased interest in its cultivation due to its short growing period, high economic return, and low input costs. Farmers can often obtain an adequate marketable yield within a month. Bangladesh produces 7836 tons of fresh coriander leaves in 9212 ha, with an average yield of 850 kg ha⁻¹ (BBS, 2022). In hilly regions, coriander cultivation contributes significantly to farmers' livelihood. However, farmers use urea as a source of nitrogen (N) for coriander cultivation. High urea rates make it difficult for plants to absorb water due to increased osmotic pressure (Epstein and Bloom, 2005). Moreover, urea is prone to nitrification and nitrate leaching, resulting in low N use efficiency as well as soil salinity and environmental pollution (Souri, 2017; Souri and Neumann, 2017; Souri et al., 2019). Furthermore, over-application of urea may also compromise the quality and shelf life of coriander leaves, which are highly perishable (Aghaye Noroozlo et al., 2019; Souri and Hatamian, 2019).

Chitin nanofiber (CNF) can be used as a source of N fertilizer and a postharvest preservative for coriander leaves. Attention to chitin and chitin-based biopolymers, including nanomaterials, is growing in agricultural and horticultural production systems (Sun et al., 2023). Nano-chitosan gained popularity due to its unique physicochemical properties – such as size, structural arrangement, and reactivity – that confer strength, conductivity, elasticity, and chemical reactivity. Application of 80 ppm chitosan has been shown to enhance plant height, branching, and both fresh and dry weights in coriander (El-Gamal and Ahmed, 2016). Additionally, both chitosan and nano-chitosan have been reported to increase the growth, yield, and essential oil content of coriander (El Shayeb et al., 2021; Massoud et al., 2016).

The CNF, derived through nanofibrillation of chitin, consists of fibers with aspect ratio of more than 100 and diameters smaller than 100 nm (Li and Xia, 2004). CNF enhances plant growth and development through better root establishment, nutrient absorption, and stress tolerance (Shahrajabian et al., 2021). CNF also helps in the removal of cationic and anionic heavy metals from the soil (Shahrajabian et al., 2021), provides biodegradable mulching (Yanat and Schroën, 2023), and protects the crop against diseases and pathogens through antifungal and antibacterial properties (Egusa et al., 2019; Tanpichai et al., 2023). CNF is applied as seed coatings or foliar sprays to stimulate plant growth and increase crop productivity (Shahrajabian et al., 2021). Additionally, it has been used to extend the postharvest life of cucumber, banana, and mango (Munira et al., 2025; Tanpichai et al., 2023).

We hypothesize that CNF may augment the growth, yield, and postharvest quality of coriander. To date, limited or no reports that have explored the use of CNF for growth promotion and shelf life extension in coriander. Therefore,

this study evaluates the impact of CNF on the growth and yield and post-harvest quality in coriander.

Materials and methods

Land selection and preparation for the field study

The field experiment was conducted from February to April 2024 at the Field Laboratory (22°47'57.4" N latitude and 89°31'51.0" E longitude) of Agrotechnology Discipline, Khulna University, Khulna, Bangladesh. A total area of 42 m² (7 m × 6 m) was plowed (20 February) using a tractor until a fine tilth was achieved. The area was divided into 35 plots (each 1.0 m × 0.8 m); there was a 30-cm distance between plots. Seven days after plowing, on 27 February 2024, vermicompost (400 g), triple superphosphate (10 g), muriate of potash (8 g), gypsum (9 g), zinc (250 mg), and boron (12 mg) were applied as a basal dose in each plot, followed by light irrigation.

Planting material, treatments, and experimental design

Coriander seeds (*BARI Dhania 2*) was obtained from the regional substation of Bangladesh Agricultural Research Institute (BARI), Magura. This variety, released by BARI in 2016, is characterized by plants bearing 18–21 leaves, 63 umbels, and six umbellets per umbel, with a fresh leaf yield potential of 3–4 t ha⁻¹ (Azad et al., 2020). Seeds were soaked for 24 h, then decanted and kept in a cloth for 72 h (1 to 3 March) to promote germination. Germinated seeds were sown (4 March) in rows spaced 20 cm apart, followed by irrigation. The first seedling emergence was recorded 8 days after sowing (12 March).

The experiment was a randomized block design (RCBD) with five treatments: control (no nitrogenous fertilizers); urea (recommended nitrogen dose as a positive control, 13 g granular urea plot⁻¹, which corresponds to 162.5 kg urea or 76 kg N ha⁻¹); 13 ml CNF (1%), 26 ml CNF (1%), and 39 ml CNF (1%), and replicated seven times. The requirement of urea (13 g per plot) for a plot of 0.8 m² was calculated following the recommended dose, and multiples of urea (13 g) were considered as CNF doses (13 ml, 26 ml, and 39 ml). Chitin is a polymer of N-acetyl D-glucosamine, and CNF is nano-chitin, containing 6%–8% nitrogen. The CNFs were prepared from shrimp shells in the Forestry and Wood Technology lab of Khulna University using a high-speed grinder and diluted to 1% solution (Ifuku, 2014). Urea was applied to the soil, and CNFs to the foliage. The CNF was diluted three times with water and sprayed on the plants in two spells. To ensure uniform spray, the CNF was diluted three times and sprayed with the same nozzle. The treatments were applied in two equal splits during the growing season; the first one (50% of the treatments) on 27 March [15 days

after emergence (DAE)] and the second one on 11 April (30 DAE). The field was weeded, irrigated, and hoed. Irrigation and hoeing were done on alternate days, and weeding was carried out every week. No other inter-cultural operations were needed.

Data collection

Data were collected on plant height (mm), number of leaves, leaflets, nodes, and branches per plant, as well as individual plant fresh weight (g) and leaf yield per plot. All the measurements, except leaf yield, were collected weekly, starting one week after the first treatment application. One representative plant was sampled from each plot (seven plants per treatment) to assess all growth parameters. At final harvest (24 April 2024), all plants from each plot were harvested, immediately packed in 35 ziplock bags, and transported to the Horticulture Laboratory under the Agrotechnology Discipline of Khulna University, about 500 m away. Leaf yield was determined using a digital scale.

Immediately after yield measurements, the coriander plants were subjected to postharvest analysis following a completely randomized design (CRD) with three replications, each consisting of 50 plants.

Physical attributes

Leaf daily weight loss (%), color, freshness, shrinkage, and tenderness were measured. Leaf weight loss was measured following a standard formula (Kabir et al., 2024; Prasad et al., 2019)

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Leaf color parameters were measured as L* (lightness), a* (greenness to redness), and b* (blueness to yellowness) using a spectrophotometer (HunterLab ColorFlex, Hunter Associates Inc., Reston, VA, USA). Chroma value [C* (chromacity), $C^* = (a^{*2} + b^{*2})^{1/2}$] and hue angle [h°, $h^\circ = \tan^{-1} b^*/a^*$] were calculated (McGuire, 1992).

Freshness, tenderness, and shrinkage were evaluated visually using a modified scale based on Dadhich et al. (2008). Freshness was assessed on a 1–5 scale: 1 = not fresh ($\leq 20\%$), 2 = slightly fresh (21% – 40%), 3 = moderately fresh (41% – 60%), 4 = fresh (60% – 80%), and 5 = very fresh ($\geq 80\%$). Tenderness was rated similarly: 1 = tough ($\leq 20\%$), 2 = slightly tender (21% – 40%), 3 = moderately tender (41% – 60%), 4 = tender (60% – 80%), and 5 = very tender ($\geq 80\%$). Shrinkage was also scored on a 1–5 scale: 1 = no shrinkage (0%), 2 = slight shrinkage (1% – 10%), 3 = moderate shrinkage (11% – 25%), 4 = shrunk (26% – 50%), and 5 = completely shrunk (51% – 100%).

Chemical attributes

Leaf total soluble solids (TSS) and vitamin C content were measured on the first day of storage. TSS was determined from the extracted juice using a refractometer (REF 105) and reported as degree Brix.

Vitamin C was estimated using the dye titration method employing 2,6-dichlorophenol indophenol, as described by Nerdy (2018).

$$\text{Vitamin C (mg per 100 g)} = \frac{e \times d \times b}{c \times a}$$

Where,

a = Weight of sample.

b = Volume made with metaphosphoric acid.

c = Volume of aliquot taken for estimation

d = Dye factor

e = Average burette reading for sample

Shelf life

Shelf life was counted based on optimum level of freshness, tenderness, and shrinkage (Dadhich et al., 2008).

Statistical analysis

Field data were analyzed using a one-way analysis of variance (ANOVA) based on a randomized complete block design (RCBD) design. Postharvest data were analyzed using ANOVA under a completely randomized design (CRD). Data were processed using Microsoft Excel 2013, and the statistical analysis was done using IBM SPSS Statistics for Windows (Version 27.0.1.0) [IBM Corp., Armonk, NY, USA]. Treatment means were compared using Tukey's Honestly Significance Difference (HSD) Test at 5%.

Results

Environmental conditions and soil properties

During the field experiment, the minimal and maximal temperatures were 15.6°C and 28.8°C at 6:00 am and 26°C and 41.2°C at 6:00 pm (Figure 1). The minimal RHs were 36% and 40% at 6:00 am and 6:00 pm, respectively; the maximal RHs were 92% and 85% at 6:00 am and 6:00 pm, respectively. There was no rainfall in most of the days during the study period. However, it rained 18 mm in a single day (Figure 1). The soil of the study area had low organic matter (0.47%), neutral pH (7.0), and low electrical conductivity (EC) (1.17 dS m⁻¹). The total nitrogen (N), phosphorus (P), potassium (K), and

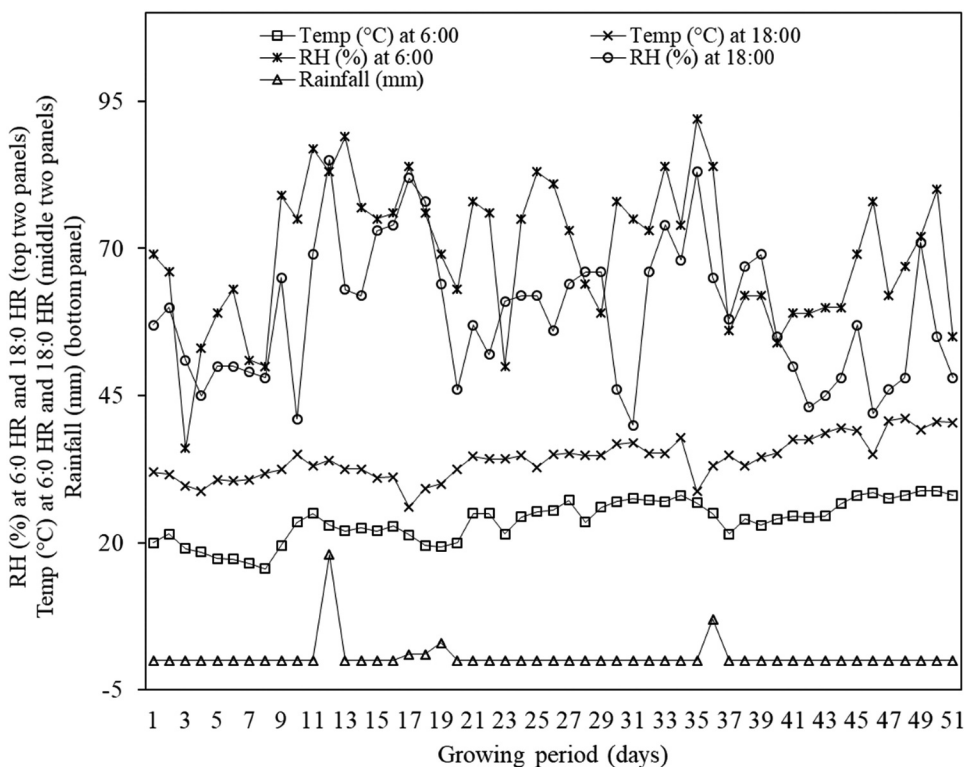


Figure 1. Field daily relative humidity at 6:00 HR and 18:00 HR (top two panels), maximal and minim air temperatures ($^{\circ}\text{C}$) (middle two panels), and rainfall (mm) (bottom panel) during the period of the experiment (4 March 2024 to 23 April 2024, total growing period of 51 days). Weather data were collected from Khulna Meteorological Station nearby (less than 50 m) from the experimental site.

sulfur (S) contents were 1.98%, 10.73 ppm, 39.18 ppm, and 5.58 ppm, respectively, indicating poor nutritional status of the soil (Table A1).

During the postharvest study, the morning (10:00 am) and afternoon (3:00 pm) humidity ranged from 67% – 77% and 51% – 70%, respectively. Similarly, the morning (10:00 am) and afternoon (3:00 pm) temperatures ranged from 30.1 $^{\circ}\text{C}$ – 31.9 $^{\circ}\text{C}$ and 29.5 $^{\circ}\text{C}$ – 31.9 $^{\circ}\text{C}$, respectively (Table A2).

Growth attributes

Coriander plant height differed significantly at 29 and 43 days after emergence (DAE) (Table 1). The tallest plant (175.3 mm) was recorded from 39 ml CNF, which was statistically similar to urea (150.4 mm), 26 ml CNF (149.3 mm), and 13 ml CNF (127.6 mm), and the shortest one from the control (92.5 mm) at 29 DAE. Similarly, the tallest plant (412.8 mm) was obtained from 39 ml CNF, which was statistically similar to urea (399.8 mm), 26 ml CNF (390.5 mm), and 13 ml CNF (330.8 mm), and the shortest one from the control treatment

Table 1. Effect of chitin nanofiber (CNF) on plant height of coriander at different days after emergence (DAE).

Treatment	Plant height (mm) ^a			
	22 DAE	29 DAE	36 DAE	43 DAE
Control	71.2 ± 3.8	92.5 ± 1.6 b	244.5 ± 24.6	248.6 ± 3.0 b
Urea	82.3 ± 5.8	150.3 ± 3.0 a	289.9 ± 17.5	399.8 ± 3.0 a
13 ml CNF	78.3 ± 4.8	127.6 ± 1.5 ab	233.8 ± 18.9	330.8 ± 2.1 ab
26 ml CNF	87.2 ± 3.6	149.3 ± 2.0 a	284.9 ± 13.5	390.5 ± 3.3 a
39 ml CNF	83.6 ± 3.3	175.3 ± 1.4 a	261.2 ± 21.8	412.8 ± 3.9 a
<i>P</i>	0.149	0.01	0.170	< 0.01

^aThe value represents the mean (average of seven measurements) ± SE (standard error). Means followed by dissimilar letters differed significantly according to Tukey's Honestly Significance Difference (HSD) Test @ 5%.

Table 2. Effect of chitin nanofiber (CNF) on leaf number of coriander plant at different days after emergence (DAE).

Treatment	Leaf number plant ⁻¹ ^a			
	22 DAE	29 DAE	36 DAE	43 DAE
Control	5.6 ± 0.7	6.4 ± 0.6	17.0 ± 2.2	9.4 ± 1.3 b
Urea	5.8 ± 0.5	8.0 ± 1.0	15.8 ± 2.5	15.6 ± 2.5 1ab
13 ml CNF	6.4 ± 0.7	7.0 ± 0.7	13.2 ± 1.5	12.2 ± 0.7 ab
26 ml CNF	5.8 ± 0.4	8.6 ± 0.7	16.8 ± 5.8	17.4 ± 4.3 ab
39 ml CNF	6.4 ± 0.7	7.8 ± 1.0	20.2 ± 3.6	21.0 ± 4.3 a
<i>P</i>	0.828	0.270	0.733	0.013

^aThe value represents the mean (average of seven measurements) ± SE (standard error). Means followed by dissimilar letters differed significantly according to Tukey's Honestly Significance Difference (HSD) test @ 5%.

(248.6 mm) at 43 DAE (Table 1). However, coriander plant height did not vary at 22 and 36 DAEs. Leaf number did not show any significant difference at the early growth stages; however, at 43 DAE, the leaf number differed significantly (Table 2). The highest leaf number (21) was obtained from 39 ml CNF, which was statistically similar to 26 ml CNF (17.40), urea (15.60), and 13 ml CNF (12.20) and the lowest from the control (Table 2).

Yield attributes

The highest plant fresh weight was obtained from urea, which was statistically similar to 39 ml CNF and 26 ml CNF on 43 DAE (data not shown). Yields per plot varied significantly among the treatments. The highest yield (363 g) was obtained from the urea treatment, which was statistically similar to 26 ml CNF (207.67 g), and the lowest yield (90.67 g) was recorded from 13 ml CNF (Figure 2).

Physical attributes

The weight loss of coriander did not vary among the treatments. However, a higher proportion of water was lost on the first day (Table 3). The freshness of the coriander plant differed significantly at

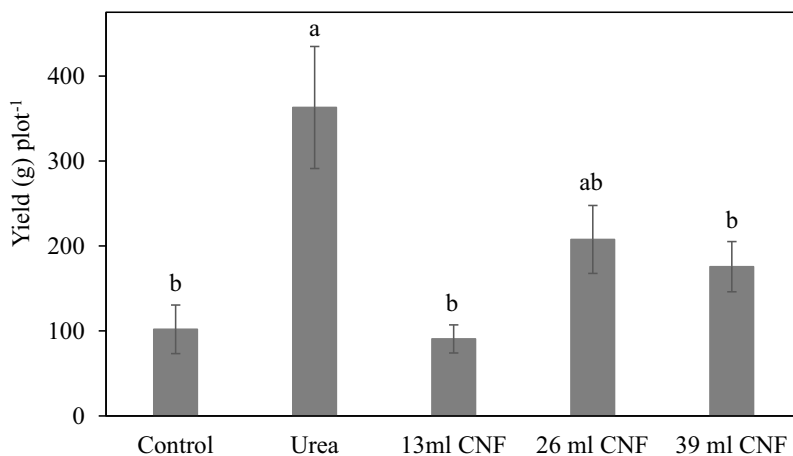


Figure 2. Effects of CNF on coriander (*Coriandrum sativum* L.) yield per plot. The error bar represents mean \pm SE (standard error). The treatment means (average of seven measurements) are separated by Tukey's HSD test at $\alpha = 5\%$.

Table 3. Effect of chitin nanofiber (CNF) on plant daily weight loss of coriander.

Treatment	Weight loss (%) ^a			
	Day 2	Day 3	Day 4	Day 5
Control	35.2 \pm 1.5	30.2 \pm 1.2	19.9 \pm 1.5	14.5 \pm 1.0
Urea	32.3 \pm 1.0	29.4 \pm 1.2	20.8 \pm 1.5	17.2 \pm 1.8
13 ml CNF	32.5 \pm 1.4	29.3 \pm 0.4	17.7 \pm 0.03	15.4 \pm 1.1
26 ml CNF	28.4 \pm 1.5	28.8 \pm 0.8	19.5 \pm 0.4	15.6 \pm 1.0
39 ml CNF	29.8 \pm 2.7	28.4 \pm 0.4	20.1 \pm 0.2	17.9 \pm 1.7
<i>P</i>	0.107	0.689	0.285	0.429

^aThe value represents the mean (average of three measurements) \pm SE (standard error).

Table 4. Effect of chitin nanofiber (CNF) on plant freshness of coriander at postharvest.

Treatment	Freshness ^a				
	Day 1	Day 2	Day 3	Day 4	Day 5
Control	5	5	4.0 \pm 0.0 b	3.0 \pm 0.0 b	2.0 \pm 0.0 b
Urea	5	5	4.7 \pm 0.4 ab	4.0 \pm 0.0 a	3.0 \pm 0.0 a
13 ml CNF	5	5	4.0 \pm 0.0 b	3.0 \pm 0.0 b	2.0 \pm 0.0 b
26 ml CNF	5	5	5.0 \pm 0.0 a	3.3 \pm 0.4 ab	2.3 \pm 0.4 ab
39 ml CNF	5	5	5.0 \pm 0.0 a	4.0 \pm 0.0 a	3.0 \pm 0.0 a
<i>P</i>	–	–	0.01	0.01	0.01

^aThe value represents the mean (average of three measurements) \pm SE (standard error). For freshness, the scale ranged from 1–5, where 1 = not fresh ($\leq 20\%$), 2 = slightly fresh (21% – 40%), 3 = moderately fresh (41% – 60%), 4 = fresh (60% – 80%), and 5 = very fresh ($\geq 80\%$). Means followed by dissimilar letters differed significantly according to Tukey's Honestly Significance Difference (HSD) test @ 5%.

3, 4, and 5 days after harvest (DAH). At 3 DAH, the most fresh (5.0) leaves was observed from 39 ml CNF, which was statistically similar to 26 ml CNF (5.0) and urea (4.7) (Table 4). At 4 DAH, 39 ml CNF also showed the highest freshness (4.0), which was statistically similar to urea (4.0) and 26 ml CNF (3.3). Similarly, 39 ml CNF-treated leaves remained fresh (3.0), which was statistically identical to urea (3.0) and

Table 5. Effect of chitin nanofiber (CNF) on plant tenderness of coriander at postharvest.

Treatment	Tenderness ^a				
	Day 1	Day 2	Day 3	Day 4	Day 5
Control	5	5	4.00 ± 0	3 ± 0 b	2 ± 0 a
Urea	5	5	4.67 ± 0.33	3 ± 0 a	3 ± 0 a
13 ml CNF	5	5	4.00 ± 0	3.33 ± 0.4 ab	2 ± 0 a
26 ml CNF	5	5	4.33 ± 0.33	4 ± 0 a	2.33 ± 0.4 ab
39 ml CNF	5	5	4.33 ± 0.33	4 ± 0 a	3 ± 0 a
<i>P</i>	–	–	0.382	0.01	0.01

^aThe value represents the mean (average of three measurements) ± SE (standard error). For tenderness measurement, the scale ranged from 1–5, where 1 = Tough (≤20%), 2 = slightly tender (21% – 40%), 3 = moderate tender (41% – 60%), 4 = Tender (60% – 80%) and 5 = Very tender (≥80%). Means followed by dissimilar letters differed significantly according to Tukey's Honestly Significance Difference (HSD) test @ 5%.

26 ml CNF (2.3) at 5 DAH. However, the control treatment resulted in poor leaf freshness.

Tenderness in coriander leaf differed only at later storage periods (DAHs 4 and 5). The highest tenderness (4) was observed from 39 ml CNF and urea, which showed statistically similar results to 26 ml CNF (3.33) at 4 DAH (Table 5). Shrinkage in coriander leaf showed a significant difference at 3 DAH. The highest shrinkage (3) was observed from 13 ml CNF and control (3), which was statistically similar to 26 ml CNF (2.33) and urea (2.33), and the 39 ml CNF-treated leaf shrank minimally (2) (Table 6). None of the color parameters (L^* , a^* , b^* , C^* , h°) differed significantly among the treatments (Table 7).

Chemical attributes of coriander leaf

TSS (°Brix) was highest for urea (8.1), which was statistically similar to 39 ml CNF (8.0) and the control (7.9) (Figure 3). However, TSS was lowest for 13 ml CNF (7.2). Vitamin C (mg per 100 g) was highest for 26 ml CNF (15.6), which was statistically similar to 13 ml CNF (15.5), and it was lowest for 39 ml CNF (11.2) (Figure 4).

Table 6. Effect of chitin nanofiber (CNF) on plant shrinkage of coriander at postharvest.

Treatment	Shrinkage ^a				
	Day 1	Day 2	Day 3	Day 4	Day 5
Control	1	2	3.0 ± 0.0 a	3.0 ± 0.6	3.7 ± 0.3
Urea	1	2	2.3 ± 0.4 ab	2.3 ± 0.3	3.3 ± 0.3
13 ml CNF	1	2	3.0 ± 0.0 a	2.7 ± 0.3	3.7 ± 0.3
26 ml CNF	1	2	2.3 ± 0.4 ab	2.0 ± 0.0	3.0 ± 0.0
39 ml CNF	1	2	2.0 ± 0.0 b	2.0 ± 0.0	3.0 ± 0.0
<i>P</i>	–	–	0.024	0.226	0.233

^aThe value represents the mean (average of three measurements) ± SE (standard error). Shrinkage scale ranged from 1–5, where 1 = no shrinkage (0%), 2 = slight shrinkage (1% – 10%), 3 = moderate shrinkage (11% – 25%), 4 = shrunk (26% – 50%), and 5 = completely shrunk (51% – 100%). Means followed by dissimilar letters differed significantly according to Tukey's Honestly Significance Difference (HSD) test @ 5%.

Table 7. Daily leaf color [L^* , a^* , b^* , Chroma (C^*), and h°] of coriander at postharvest as affected by the preharvest treatments.

Treatments	Day 1	Day 2	Day 3	Day 4	Day 5
L^*					
Control	34.7 ± 0.0	41.5 ± 2.1	39.9 ± 0.4	38.4 ± 0.0	38.6 ± 0.7
Urea	35.8 ± 0.8	39.9 ± 1.0	40.2 ± 0.4	39.9 ± 0.1	40.4 ± 1.0
13 ml CNF	36.3 ± 0.2	42.0 ± 0.7	39.3 ± 1.1	37.4 ± 0.8	37.4 ± 1.2
26 ml CNF	38.3 ± 1.3	40.1 ± 0.5	39.7 ± 1.0	38.1 ± 0.8	37.7 ± 0.2
39 ml CNF	36.0 ± 1.1	40.20 ± 0.9	39.9 ± 0.6	38.2 ± 1.9	39.2 ± 1.1
<i>P</i>	0.118	0.624	0.917	0.529	0.218
a^*					
Control	-9.5 ± 0.2	-9.4 ± 0.5	-6.6 ± 0.8	-4.6 ± 0.4	-3.8 ± 0.5
Urea	-9.6 ± 0.2	-10.2 ± 0.5	-7.1 ± 0.7	-6.8 ± 0.4	-4.3 ± 0.5
13 ml CNF	-8.3 ± 0.5	-8.3 ± 0.5	-6.6 ± 1.7	-4.6 ± 0.8	-2.9 ± 0.6
26 ml CNF	-9.9 ± 1.0	-9.3 ± 0.3	-7.8 ± 0.8	-4.6 ± 1.2	-3.5 ± 0.6
39 ml CNF	-9.0 ± 0.3	-9.3 ± 0.8	-5.7 ± 0.7	-4.0 ± 0.7	-2.5 ± 0.6
<i>P</i>	0.250	0.259	0.707	0.181	0.259
b^*					
Control	16.3 ± 0.2	18.1 ± 1.1	16.7 ± 1.5	15.4 ± 0.7	14.9 ± 1.2
Urea	16.8 ± 0.3	18.9 ± 0.7	18.8 ± 0.4	17.6 ± 0.7	13.9 ± 1.1
13 ml CNF	15.3 ± 0.6	18.3 ± 1.4	14.1 ± 1.6	15.0 ± 0.4	13.8 ± 0.7
26 ml CNF	17.8 ± 1.2	19.2 ± 0.5	17.4 ± 0.8	14.8 ± 0.8	15.2 ± 0.5
39 ml CNF	16.5 ± 0.7	19.2 ± 0.8	17.5 ± 0.8	14.5 ± 0.9	13.0 ± 1.3
<i>P</i>	0.267	0.870	0.116	0.086	0.579
Chroma (C^*)					
Control	18.8 ± 0.2	20.4 ± 1.2	18.0 ± 1.7	16.1 ± 0.8	15.4 ± 1.3
Urea	19.3 ± 0.3	21.5 ± 0.7	20.7 ± 0.6	18.8 ± 0.7	14.5 ± 1.2
13 ml CNF	17.4 ± 0.8	20.1 ± 1.4	15.0 ± 1.8	15.7 ± 0.6	14.1 ± 0.8
26 ml CNF	20.3 ± 1.4	21.4 ± 0.5	18.9 ± 1.1	16.9 ± 0.8	15.6 ± 0.5
39 ml CNF	18.7 ± 0.8	21.1 ± 0.7	18.9 ± 0.9	15.1 ± 0.7	13.2 ± 1.3
<i>P</i>	0.236	0.807	0.114	0.061	0.568
Hue (h°)					
Control	120.2 ± 0.4	117.4 ± 0.2	111.8 ± 1.0	106.7 ± 1.0	104.2 ± 0.7
Urea	120.0 ± 0.3	118.4 ± 1.3	113.8 ± 1.0	111.1 ± 0.9	107.1 ± 1.5
13 ml CNF	118.5 ± 0.5	114.5 ± 0.6	109.4 ± 1.7	106.8 ± 2.5	101.5 ± 1.7
26 ml CNF	119.0 ± 1.4	115.7 ± 0.9	112.0 ± 2.7	107.0 ± 4.3	102.9 ± 2.1
39 ml CNF	118.6 ± 1.2	116.1 ± 1.9	111.5 ± 1.0	105.0 ± 2.0	100.6 ± 1.7
<i>P</i>	0.566	0.314	0.479	0.428	0.120

Data presented as mean ± SE (standard error), where an L^* is lightness (0 = black and 100 = white); a^* (negative = greener and positive = redder); and b^* (negative = bluer, positive = more yellow). Chroma (C^*) means color saturation and h° represents hue angle.

Shelf life

The shelf life of coriander leaves differed significantly among the treatments. The highest shelf life was counted from 39 ml CNF (4.63 days), which was statistically similar to 26 ml CNF (4.33), 13 ml CNF (3.85), and urea (3.78) (Figure 5). However, the control resulted in the lowest shelf life (3.11 days).

Discussion

During the field experiment, conditions were warm (maximum temperature 41.2°C; RH 92%) with scanty rainfall, which affected the growth and yield of coriander. Moreover, the soil nutrient content, particularly low N, affected the

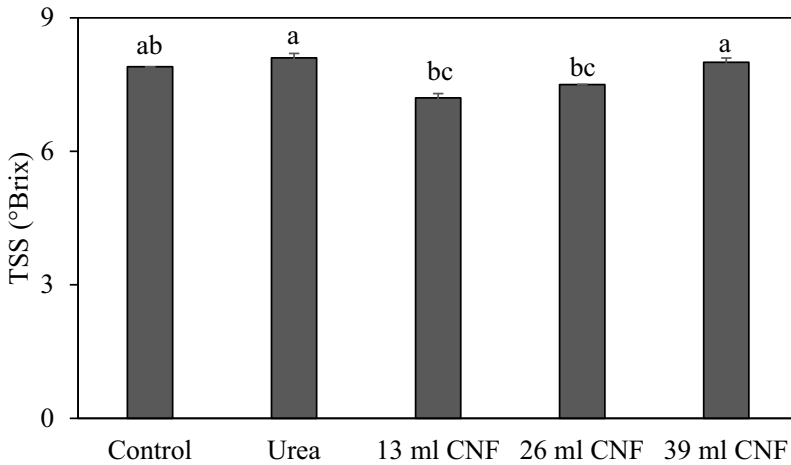


Figure 3. Effects of CNF on TSS (% Brix) of coriander (*Coriandrum sativum* L.). The error bar represents mean \pm SE (standard error). The treatment means (average of seven measurements) are separated by Tukey's HSD test at $\alpha = 5\%$.

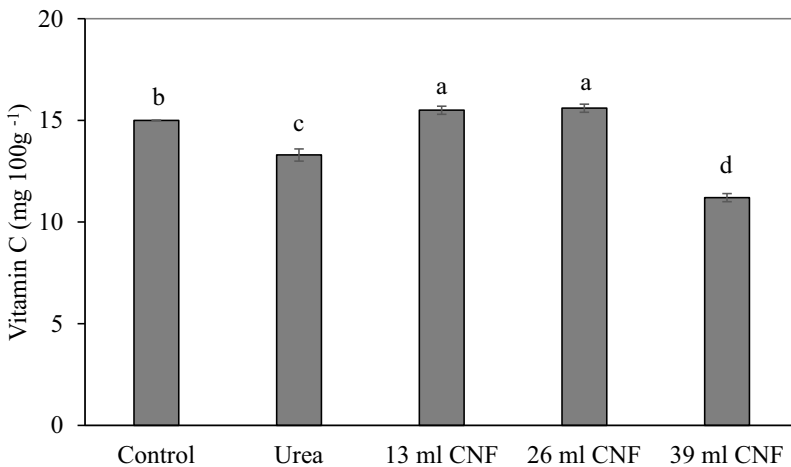


Figure 4. Effects of CNF on Vitamin C (mg 100 g⁻¹) of coriander (*Coriandrum sativum* L.). The error bar represents mean \pm SE (standard error). The treatment means (average of seven measurements) are separated by Tukey's HSD test at $\alpha = 5\%$.

growth of coriander. Previous studies also reported low N content of soil (Saha et al., 2019). The storage room was also hot and humid (average temperature 31.9°C; RH 77%). Such environmental conditions rapidly reduce the postharvest keeping quality of coriander leaves, including shelf life, as high temperature leads to increased leaf respiration (Cannon et al., 2012).

Coriander plant height and leaf number were increased by urea and CNF, particularly at the late plant growth stages, indicating the potentiality of CNF to enhance plant growth. Chitin promotes plant growth, improves

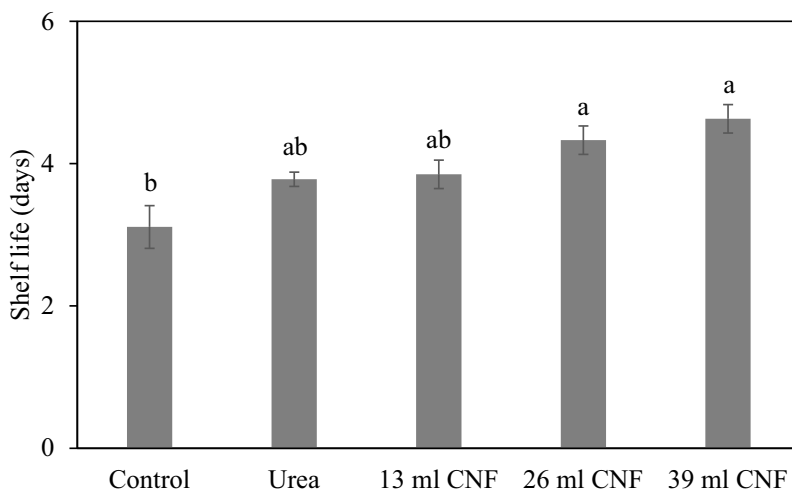


Figure 5. Effects of CNF on shelf life (days) of coriander (*Coriandrum sativum* L.). The error bar represents mean \pm SE (standard error). The treatment means (average of seven measurements) are separated by Tukey's HSD test at $\alpha = 5\%$.

plant nutrition, and enhances stress resistance (Shahrajabian et al., 2021). It enhances plant growth by supplying nitrogen and boosting nutrient uptake (Rai et al., 2025). Soil application of chitin promotes the growth of beneficial bacteria (*Cellulomonadaceae*, *Flavobacterium*), fungi (*Mortierella*, *Fusarium*), and *actinomycetes* (5 A, 8 A), which promote plant growth by suppressing plant pathogens (Shahrajabian et al., 2021). Co-application of a low dose of chitin (50 mg/g soil) and *Streptomyces nigrescens* (AMV1033) reduces the numbers of young (juvenile) root knot nematodes, *Meloidogyne incognita* (Eberlein and Westphal, 2023). Chitin nanofiber also increases the growth and yield of rice by slow and sustainable N release for an extended period (Shams et al., 2025). Similarly, chitosan enhances the growth of coriander (El Shayeb et al., 2021; Massoud et al., 2016). Chitosan also improves shoot and root growth of rice seedlings under drought stress by increasing relative water content, photosynthetic efficiency, and enzyme (guaiacol peroxidase and ascorbate peroxidase) activity, and decreasing electrolyte leakage (Moolphuerk et al., 2022). Only CNF or a combination of CNF and protein or CNF and CaCO_3 promotes the height of the komatsuna plant (Endo et al., 2023). In the present study, though the plant height of coriander differed significantly at 29 and 43 DAE, it was non-significant at 36 DAE, which might be due to the prevalence of high temperatures. Bangladesh experienced unusually hot spring months (March – April) this year, which may have impacted plant growth. Leaf number increased by the CNF treatments at late growth stages, which might be the cumulative effect of treatments.

A statistically similar yield of coriander leaf from urea and 26 ml CNF suggests the potentiality of using CNF for coriander leaf production. Chitin nanowhiskers at 6 mg kg⁻¹ soil increase wheat yield by 23% (Xue weijie et al., 2018). However, chitosan does not affect bulb yield and chemical composition of sweet onion (Díaz-Pérez et al., 2024). It is noticeable that the yield of 39 ml CNF was lower than 26 ml CNF, indicating that higher CNF concentration may arrest the growth of coriander. Similarly, a higher concentration of carbon nanotubes decreased the shoot and root growth of mustard (Mondal et al., 2011). Moreover, CNF does not lose through denitrification, volatilization, leaching, and runoff. CNF amends the soil, increases water-holding and nutrient retention capacities, and enhances plant nitrogen uptake. It also possesses antifungal, antibacterial, and antiviral properties (Egusa et al., 2019). As the experimental field had low nitrogen (Saha et al., 2019), foliar application of CNF promoted the yield of coriander, suggesting CNF as a source of nitrogenous fertilizer for coriander leaf production.

CNF treatments had no effects on the postharvest weight loss of the leaf. Moreover, CNF and urea resulted in statistically similar leaf freshness, tenderness, and shrinkage, suggesting no effect of growth-time foliar application of CNF. However, CNF-coated cucumber was fresher than control (Tanpichai et al., 2023). The dissimilar results might be due to differences in crop and/or CNF concentrations, high storage room temperatures, or time and method of applications. Similarly, leaf color attributes (L*, a*, b*, C*, h°) of coriander at postharvest were not affected by the preharvest treatments. Inconsistent effects of CNF on total soluble solids and vitamin C of coriander fresh leaves were reported. However, chitosan/gallic acid/chitin nanofiber films increased TSS content in strawberries (Cabrera-Barjas et al., 2024). The treatment effects may disappear due to a 14-day gap between the application of treatments and chemical analysis. Moreover, the differences in chemical analysis might be due to variations in crop and/or CNF concentrations or time and method of applications.

The shelf life of coriander increased with CNF concentration; the highest shelf life (4.63 days) was obtained from 39 ml CNF, which was 1.5 days more than the control (3.11 days). Similar results were obtained from deacetylated-CNF coated cucumber and CNF-coated banana (Munira et al., 2025; Tanpichai et al., 2023), and chitosan also showed enhanced shelf life in mangoes (Kabir et al., 2025).

Conclusion

Although urea resulted in the highest leaf yield, 39 ml CNF resulted in the highest plant height, leaf number, and TSS. 39 ml CNF also increased the shelf life of coriander leaf by 1.5 days (48% higher) compared to the control. Therefore, 39 ml CNF, instead of urea, can be used to grow coriander in the field and to maintain postharvest quality. However, more field and lab experiments should be conducted before the final recommendation.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Table A1. Properties of the soil of the study area.

Properties	Values
Organic matter (%)	0.47
pH	7.0
EC (dS m ⁻¹)	1.17
Total N (%)	1.98
Total P (ppm)	10.73
Total K (ppm)	39.18
Total S (ppm)	5.58

EC = Electrical conductivity, N = Nitrogen, P = Phosphorus, K = Potassium, and S = Sulfur.

Table A2. Daily temperature and relative humidity during the postharvest experiment.

Date	Morning humidity (%) (10:00 am)	Afternoon humidity (%) (3:00 pm)	Morning temperature (°C) (10:00 am)	Afternoon temperature (°C) (3:00 pm)
24-Apr-2024	–	60	–	29.5
25-Apr-2024	72	51	30.1	29.6
26-Apr-2024	72	69	30.1	30.8
27-Apr-2024	67	70	31.9	31.9
28-Apr-2024	77	66	31.1	30.7