

Priming of turmeric (*Curcuma longa* L.) rhizome bits with chitosan enhances seedling growth and vigour

Deepa S Nair^{1*}, S N Shibana¹, G S Sreekala¹, P Shalini Pillai², Swapna Alex³, K N Anith⁴ & Ancy Joseph⁵

¹Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Agriculture, Thiruvananthapuram-695522, Kerala.

²Department of Agronomy, College of Agriculture, Thiruvananthapuram-695522, Kerala.

³Department of Molecular Biology and Biotechnology, College of Agriculture, Thiruvananthapuram-695522, Kerala.

⁴Department of Microbiology, College of Agriculture, Thiruvananthapuram-695522, Kerala.

⁵Aromatic and Medicinal Plants Research Station, Odakkali, Ernakulam- 683549, Kerala.

*Email: deepanair.s@kau.in

Received 16 April 2026; Revised 10 July 2026; Accepted 17 July 2026

Abstract

Chitosan is a biotic elicitor and established as an effective priming agent in various crops. An experiment was conducted to evaluate the effect of priming of rhizome bits with chitosan on sprouting and plantlet development in two turmeric varieties, Sobha and Sona. 1 g, 2 g & 4 g L⁻¹ of chitosan for 30 min and 1 h of soaking, was compared with untreated control. Chitosan treatment at the rate of 1 g L⁻¹ for 1 h recorded significantly higher shoot weight (7.36 g and 5.27 g), root weight (1.18 g and 0.71 g) and seedling vigour index (6030.67 and 5063.61) in Sobha and Sona, respectively. The priming of rhizome bits with chitosan 1 g L⁻¹ for 1 h recorded significantly superior performance in terms of growth parameters and seedling vigour index in both the varieties.

Keywords: Chitosan, priming, transplants, turmeric, vigour

Curcuma longa L., the most important of *Curcuma* species, has a long history of use as spice, herbal medicine, dyeing agent and cosmetic. Curcumin is the phytochemical that gives yellow colour to turmeric and is recognized as being responsible for most of the therapeutic effects (Ashraf, 2017). In turmeric, rhizomes are both the commercial product and

the planting material, limiting their availability for propagation. A solution to overcome the scarcity of planting material is the use of single bud rhizome bits wherein, the planting material requirement will be reduced to half to one-third. In this system of propagation, single bud rhizome bits of 5-7 g are used against 25 g of rhizome used in conventional system.

According to Prasath *et al.* (2014) transplanted ginger recorded on par yield with that of conventional planting, reduced the cost of planting material to about one-third, enabled early sprouting, uniform field establishment and reduced weed growth.

Chitosan is a biotic elicitor known to stimulate seedling growth and plant development processes, and has been established as an effective priming agent in various crops (Chakraborty *et al.*, 2020; Baviskar *et al.*, 2025). It is a biodegradable, biocompatible, and non-toxic polysaccharide derived from the deacetylation of chitin and is widely recognized as an eco-friendly plant biostimulant that also promotes plant growth, enhances stress tolerance, and induces defense responses against pathogens (Riseh *et al.*, 2024).

Priming is a method to improve the performance of plant propagules by exposing to pretreatments before planting (Khanthavong *et al.*, 2012). Chittaragi (2018) demonstrated that growth and yield of transplanted ginger is greatly influenced by priming treatments. Transplanting of uniform and healthy protrait plantlets would ensure improved yield and quality of the produce. According to Mahdavi & Rahimi (2013), chitosan promotes seed germination in ajowan by facilitating the restoration of seed moisture and absorption of soil moisture, by forming a semipermeable film on the seed surface. Priming single corms of freesia with 0.5 % chitosan solution for 20 min, improved plant growth, induced early and profuse flowering (Salachna & Zawadzinska, 2014).

Chitosan priming has been widely reported to enhance seed and vegetative propagule performance by promoting water uptake, activating reserve-mobilizing enzymes, stimulating cell division, and improving nutrient acquisition, thereby resulting in faster and more uniform sprouting and vigorous seedling growth (Riseh *et al.*, 2024). Chitosan functions as a multifunctional biostimulant by

promoting plant growth, enhancing seedling vigour, inducing resistance to biotic and abiotic stresses and stimulating antioxidant and defense mechanisms. Nevertheless, its agronomic performance is influenced by its physicochemical properties, dosage, application method and plant species (Pichyangkura & Chadchawan, 2015). In this context, an experiment was conducted to evaluate the effect of priming of turmeric rhizome bits using chitosan at different concentrations for specified periods on sprouting and plantlet development.

The present study on the effect of priming with chitosan was conducted during April 2021 to May 2021 with two turmeric varieties Sobha and Sona released from the Kerala Agricultural University. The experiment was conducted in Completely Randomised Design with 3 replications, each consisting of 25 rhizome bits. The treatments included, chitosan 1 g L⁻¹ for 30 min, chitosan 1 g L⁻¹ for 1 h, chitosan 2 g L⁻¹ for 30 min, chitosan 2 g L⁻¹ for 1 h, chitosan 4 g L⁻¹ for 30 min, and chitosan 4 g L⁻¹ for 1 h. The rhizome bits that were not exposed to chitosan treatment served as control.

Single-bud pieces (5-7 g) were sliced out from the healthy seed rhizomes. These rhizome bits were immersed in chitosan solutions of varying concentrations for two specific durations. The solutions were prepared by dissolving the required quantities of chitosan in 1 % (v/v) acetic acid solution. The chitosan used for the study was procured from Matsyafed Chitin and Chitosan Plant, Neendakara, Kollam, Kerala. After the specified period of chitosan treatment, the rhizome bits were shade dried and subsequently sown in 50 cell-portrays, the cells of which were filled with nursery medium composed of partially decomposed coir pith and vermicompost in 3:1 ratio. Irrigation was provided as needed, and the portrays were maintained under polyhouse conditions for 45 days.

The observations on days to sprout and sprouting per cent were recorded at 20 days after planting (DAP). Observations were also recorded on number of leaves, collar girth, shoot length, shoot weight, per cent survival, number of roots, root depth, root weight, root volume and seedling vigour index at 45 DAP.

Seedling vigour index = Sprouting per cent $\times$ Mean seedling length (cm)

The data were subjected to analysis of variance using the statistical package KAU GRAPES (Gopinath *et al.*, 2020) and the means were compared at a probability of 0.05 % confidence level.

In both the varieties, there was no significant difference noticed on parameters related to sprouting *viz.* days to sprout and sprouting per cent (Table 1). The number of days to sprout ranged from 11 to 14 in Sobha and 12 to 18 in Sona. The sprouting per cent was in the range of 93.33 % to 100 % in Sobha and 86.67 % to 98.67 % in Sona. This is in contradiction to the findings of Ramos-Garcia *et al.* (2009) that when gladiolus corms were dipped in chitosan 1.5 per cent for 120 min accelerated corm emergence by two days, compared to the control plants. Mahdavi & Rahimi (2013) also reported that germination per cent was enhanced from 52 to 80 % in ajowan, on priming the seeds with chitosan 0.20 %. Timely and uniform germination is an essential factor for improving seedling vigour and supporting later developmental stages in plants (Pandey & Mishra, 2022).

The data on shoot growth parameters, *viz.*, number of leaves, collar girth, shoot length and shoot weight at 45 DAP is illustrated in Table 2. There was no significant variation in the number of leaves in both the varieties among the various treatments. The collar girth was observed to be significantly different among the treatments tried in both the varieties. The highest girth being observed in plantlets derived from rhizomes primed with chitosan

Table 1. Days to Sprouting, sprouting and survival percentage of rhizome bits in response to priming with chitosan

Treatments	Days to sprouting		Sprouting per cent (%) *		Per cent survival (%)**	
	Sobha	Sona	Sobha	Sona	Sobha	Sona
T ₁ : Chitosan 1 g L-1 for 30min	13.33 $\pm$ 1.15	17.00 $\pm$ 2.65	96.00 $\pm$ 6.93	97.33 $\pm$ 4.62	90.67 $\pm$ 16.17	97.33 $\pm$ 4.62
T ₂ : Chitosan 1 g L-1 for 1h	11.00 $\pm$ 4.00	12.00 $\pm$ 2.65	100.00 $\pm$ 0.00	98.67 $\pm$ 2.31	100.00 $\pm$ 0.00	98.67 $\pm$ 2.31
T ₃ : Chitosan 2 g L-1 for 30min	12.66 $\pm$ 0.57	14.00 $\pm$ 2.00	97.33 $\pm$ 4.62	97.33 $\pm$ 4.62	97.33 $\pm$ 2.31	97.33 $\pm$ 4.62
T ₄ : Chitosan 2 g L-1 for 1h	13.66 $\pm$ 2.08	15.00 $\pm$ 2.65	98.67 $\pm$ 2.31	98.67 $\pm$ 2.31	96.00 $\pm$ 4.00	98.67 $\pm$ 2.31
T ₅ : Chitosan 4 g L-1 for 30min	15.33 $\pm$ 1.15	18.00 $\pm$ 1.00	94.67 $\pm$ 2.31	86.67 $\pm$ 9.24	94.67 $\pm$ 2.31	86.67 $\pm$ 9.24
T ₆ : Chitosan 4 g L-1 for 1h	14.00 $\pm$ 2.00	13.66 $\pm$ 1.53	93.33 $\pm$ 2.31	98.67 $\pm$ 2.31	93.33 $\pm$ 2.31	98.67 $\pm$ 4.00
T ₇ : Control	14.00 $\pm$ 1.00	15.33 $\pm$ 2.08	97.33 $\pm$ 2.31	97.33 $\pm$ 2.31	96.00 $\pm$ 4.00	96.00 $\pm$ 2.31
SEm ($\pm$)	1.162	1.247	2.078	2.667	3.838	2.76
CD (0.05)	NS	NS	NS	NS	NS	NS
CV	14.982	14.402	3.719	4.792	6.966	4.97

The data represents mean of 3 replications (10 observational plants/replication) and the values are represented as mean $\pm$ SD (Standard Deviation);

*The data were recorded at 20 days after planting; ** The data were recorded at 45 days after planting

1 g L⁻¹ for 1 h in both the varieties, Sobha (2.36 cm) and Sona (2.21 cm). In the variety Sona, this was found to be on par with those plants exposed to same concentration of chitosan for 30 min, recording a collar girth of 2.13 cm. The control plants recorded the lowest collar girth (1.85 cm).

Significant variation was observed among the treatments with respect to shoot length in both the varieties. Rhizomes primed with chitosan 1 g L⁻¹ for 1 h was found superior with respect to shoot length (42.98 cm and 38.29 cm) in Sobha and Sona, respectively. The same treatment recorded significantly higher shoot weight (7.36 g and 5.27 g, respectively) in both the varieties. The control plants recorded the lowest shoot length (27.24 cm and 20.98 cm) and shoot weight (2.35 g and 2.95 g) in Sobha and Sona, respectively. Uthairatanakij *et al.* (2007) suggested that chitosan may induce a signal to synthesize plant hormones such as gibberellins and enhance growth and development by stimulating the signalling pathway related to auxin biosynthesis.

The treatments showed significant difference in the root growth parameters, *viz.*, number of roots, root depth, root weight per plant and root volume in both the varieties (Table 3). As in the case of shoot growth parameters, significantly higher root growth parameters were also observed in plantlets raised from rhizome bits primed with chitosan 1 g L⁻¹ for 1 h (Fig 1). The highest number of roots (5.67, 5.80), root depth (17.32 cm, 13.07 cm), root weight (1.18 g, 0.71 g) and root volume (1.14 cm³, 0.79 cm³) were recorded in Sobha and Sona, respectively. Stofella *et al.* (1992) reported a significant increase in radicle length in pepper (*Capsicum* spp.) on priming of seeds with chitosan. Studies have indicated that chitosan nanoparticles can stimulate seed germination and seedling growth in crops such as tomato and maize (Saharan *et al.*, 2015; Saharan *et al.*, 2016).

Table 2. Shoot growth parameters of turmeric plantlets at 45 DAP in response to priming with chitosan

Treatments	Number of leaves		Collar girth (cm)		Shoot length (cm)		Shoot weight (g)	
	Sobha	Sona	Sobha	Sona	Sobha	Sona	Sobha	Sona
T ₁ ; Chitosan 1 g L ⁻¹ for 30min	2.13 ± 0.30	2.13 ± 0.11	1.70 ± 0.16 ^c	2.13 ± 0.14 ^{ab}	35.18 ± 5.94 ^b	32.04 ± 2.93 ^b	3.45 ± 1.12 ^b	3.30 ± 0.17 ^b
T ₂ ; Chitosan 1 g L ⁻¹ for 1h	2.46 ± 0.23	2.53 ± 0.30	2.36 ± 0.13 ^a	2.21 ± 0.03 ^a	42.98 ± 1.59 ^a	38.29 ± 2.96 ^a	7.36 ± 0.40 ^a	5.27 ± 0.67 ^a
T ₃ ; Chitosan 2 g L ⁻¹ for 30min	2.06 ± 0.30	2.06 ± 0.30	1.87 ± 0.06 ^{bc}	1.92 ± 0.02 ^c	33.60 ± 0.58 ^b	32.63 ± 1.57 ^{ab}	3.39 ± 0.29 ^{bc}	3.13 ± 0.43 ^b
T ₄ ; Chitosan 2 g L ⁻¹ for 1h	2.13 ± 0.30	1.93 ± 0.11	1.84 ± 0.02 ^{bc}	1.88 ± 0.09 ^c	32.92 ± 3.31 ^{bc}	32.56 ± 0.92 ^{ab}	3.59 ± 0.25 ^b	3.18 ± 0.17 ^b
T ₅ ; Chitosan 4 g L ⁻¹ for 30min	2.60 ± 0.00	1.86 ± 0.23	1.97 ± 0.22 ^{bc}	2.00 ± 0.12 ^{bc}	27.39 ± 3.86 ^{cd}	29.82 ± 4.04 ^b	2.66 ± 0.33 ^{bc}	3.18 ± 0.89 ^b
T ₆ ; Chitosan 4 g L ⁻¹ for 1h	2.06 ± 0.41	2.06 ± 0.30	2.03 ± 0.16 ^b	1.92 ± 0.09 ^c	31.58 ± 1.55 ^{bcd}	31.25 ± 2.39 ^b	2.98 ± 0.62 ^{bc}	3.48 ± 0.08 ^b
T ₇ ; Control	1.93 ± 0.61	2.33 ± 0.50	1.70 ± 0.26 ^c	1.85 ± 0.14 ^c	27.24 ± 1.96 ^d	20.98 ± 6.29 ^c	2.35 ± 0.68 ^c	2.95 ± 0.57 ^b
SEm (±)	0.205	0.171	0.094	0.058	1.83	1.981	0.349	0.293
CD (0.05)	NS	NS	0.284	0.177	5.551	6.01	1.058	0.89
CV	16.116	13.875	8.418	5.077	9.61	11.04	16.396	14.532

The data represents mean of 3 replications (10 observational plants/replication) and the values are represented as mean ± SD (Standard Deviation); Values that are followed by the same letter in a column do not differ significantly between them

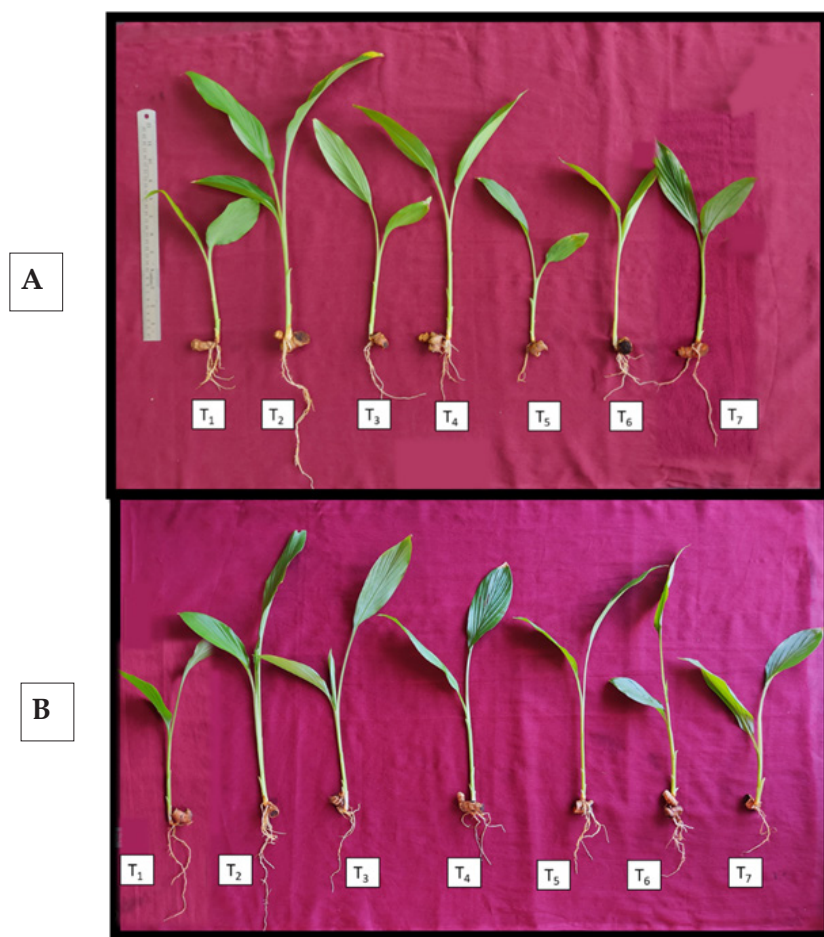


Fig. 1. Effect of priming of rhizome bits using chitosan on seedling growth in Sobha (A) and Sona (B) at 45 DAP [T1: Chitosan 1 g L⁻¹ for 30 min, T2: Chitosan 1 g L⁻¹ for 1 h, T3: Chitosan 2 g L⁻¹ for 30 min, T4: Chitosan 2 g L⁻¹ for 1 h, T5: Chitosan 4 g L⁻¹ for 30 min, T6: Chitosan 4 g L⁻¹ for 1 h and T7: Control]

The varietal variation with respect to plantlet growth parameters was also observed in turmeric in response to chitosan application at different concentrations for specified periods. This is in consensus with the findings of Guan *et al.* (2009), who reported that varietal variation was observed with the priming time and concentration of chitosan in maize.

There was no significant variation in survival of plantlets in both the varieties in response to chitosan priming treatments (Table 1). It ranged from 90.67 % to 100 % in Sobha and 86.67 % to 98.67 % in Sona. However, significant variation was observed in seedling vigour index among the treatments, in both the varieties Sobha

and Sona. Chitosan 1 g L⁻¹ for 1 h recorded the highest seedling vigour index of 6030.67 in the variety Sobha and 5063.61 in the variety Sona (Fig 2). Significantly lower seedling vigour index was observed in the untreated control in both the varieties. This was on par with higher doses of chitosan both in Sobha and Sona.

It was observed that the lower concentration of chitosan (1 g L⁻¹) gave better plantlet growth and vigour index in both the varieties. The higher concentrations of chitosan might be inhibitory, as chitosan (2 g L⁻¹ and 4 g L⁻¹) did not enhance the seedling growth and development, and the seedling vigour index was also lower at these higher doses. Baby *et*

Table 3. Root growth parameters of turmeric plantlets at 45 DAP in response to priming with chitosan

Treatments	Number of roots		Root depth (cm) *		Root weight per plant (g)		Root volume (cm ³)	
	Sobha	Sona	Sobha	Sona	Sobha	Sona	Sobha	Sona
T ₁ : Chitosan 1 g L ⁻¹ for 30min	3.53 ± 0.70 ^c	4.06 ± 1.16 ^b	11.98 ± 2.63 ^b	12.34 ± 1.16 ^a	0.63 ± 0.19 ^b	0.64 ± 0.07 ^a	0.60 ± 0.14 ^b	0.65 ± 0.11 ^a
T ₂ : Chitosan 1 g L ⁻¹ for 1h	5.67 ± 0.23 ^a	5.80 ± 0.59 ^a	17.32 ± 0.57 ^a	13.07 ± 0.48 ^a	1.18 ± 0.17 ^a	0.71 ± 0.04 ^a	1.14 ± 0.15 ^a	0.79 ± 0.05 ^a
T ₃ : Chitosan 2 g L ⁻¹ for 30min	4.00 ± 1.22 ^b	3.86 ± 1.42 ^b	10.32 ± 1.20 ^{bc}	9.13 ± 0.65 ^b	0.51 ± 0.18 ^{bc}	0.43 ± 0.02 ^b	0.36 ± 0.02 ^c	0.34 ± 0.04 ^b
T ₄ : Chitosan 2 g L ⁻¹ for 1h	4.13 ± 0.23 ^b	3.60 ± 1.25 ^{bc}	11.43 ± 1.77 ^b	10.10 ± 1.25 ^b	0.44 ± 0.13 ^{bc}	0.36 ± 0.08 ^b	0.31 ± 0.09 ^c	0.37 ± 0.17 ^b
T ₅ : Chitosan 4 g L ⁻¹ for 30min	3.93 ± 0.50 ^b	3.80 ± 1.93 ^{bc}	10.77 ± 0.24 ^{bc}	11.19 ± 1.93 ^{ab}	0.34 ± 0.03 ^c	0.43 ± 0.10 ^b	0.34 ± 0.18 ^c	0.46 ± 0.07 ^b
T ₆ : Chitosan 4 g L ⁻¹ for 1h	4.47 ± 0.42 ^b	2.73 ± 1.47 ^{cd}	11.68 ± 1.28 ^b	11.03 ± 1.47 ^{ab}	0.33 ± 0.18 ^c	0.38 ± 0.10 ^b	0.36 ± 0.09 ^c	0.33 ± 0.05 ^b
T ₇ : Control	2.73 ± 0.46 ^c	2.46 ± 0.65 ^d	8.34 ± 1.24 ^c	11.16 ± 1.42 ^b	0.31 ± 0.07 ^c	0.31 ± 0.03 ^b	0.30 ± 0.14 ^c	0.28 ± 0.16 ^b
SEm (±)	0.36	0.353	0.848	0.734	0.085	0.043	0.073	0.06
CD (0.05)	1.092	1.07	2.573	2.225	0.258	0.13	0.220	0.183
CV	15.328	16.242	12.567	11.575	27.547	15.818	25.788	22.698

The data represents mean of 3 replications (10 observational plants/replication) and the values are represented as mean ± SD (Standard Deviation); Values that are followed by the same letter in a column do not differ significantly between them; * Length of the longest root

al. (2020) reported that the priming treatments had a significant effect in improving the initial vigour in ginger sprouts, which can render a stimulatory effect in growth of transplants. Enhanced vigour index would attribute to better seedling establishment and growth in the field (Ebene *et al.*, 2010). Mahdavi (2016) also reported that priming with chitosan at low concentration could be used for improving germination and seedlings growth of anise. According to him, priming with chitosan from 0.01 to 0.2 per cent showed an increasing trend in germination and seedling growth. However, these parameters declined at a higher concentration of chitosan 0.5 %. Similarly, low seedling growth and vigour index was observed in *Ocimum basilicum*, at higher concentration of chitosan. This inhibitory effect of chitosan at higher concentrations could be due to absorptive obstruction of water and other essential minerals from soil due to the sticky chitosan coating on the propagule. The sticky coating could be attributed to higher concentration of chitosan used for priming (Kim *et al.*, 2005). When seeds of *Lens culinaris* were subjected to priming with varying concentration of chitosan (0.5 to 2.0 per cent), it was observed that the lowest concentration of chitosan (0.5%) significantly improved seedling growth parameters (Kumari *et al.*, 2025). The primed seeds recorded elevated hydrolytic enzyme (amylase, protease, dehydrogenase and phytase) activities over the untreated control. The hydrolytic enzymes facilitate the mobilisation of stored food reserves like starch, proteins and lipids to supply energy and nutrients for embryonic development and thus, the seed germination. Al- Omairi & Al-Hilfy (2021) also opined that the chitosan treatment improves germination and seedling growth by enhancing amylase enzyme activity and accelerating carbohydrate breakdown. However, Mahdavi & Rahimi (2013) observed enhanced seedling vigour index with increasing chitosan concentration from 0.01 to 0.50 per cent in ajowan. Sen & Mendel (2016)

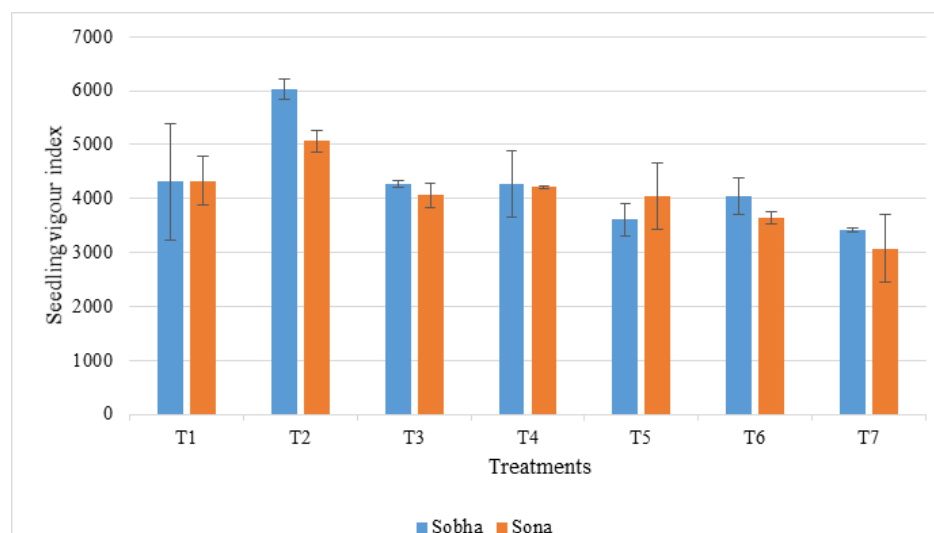


Fig. 2. Seedling vigour index of turmeric plantlets at 45 DAP in response to priming with chitosan [T₁: Chitosan 1 g L⁻¹ for 30 min, T₂: Chitosan 1 g L⁻¹ for 1 h, T₃: Chitosan 2 g L⁻¹ for 30 min, T₄: Chitosan 2 g L⁻¹ for 1 h, T₅: Chitosan 4 g L⁻¹ for 30 min, T₆: Chitosan 4 g L⁻¹ for 1 h and T₇: Control]

are of the view that extended priming periods are associated with reduced germination rates and lower seedling vigour. This has been contradicted in the present study, wherein chitosan priming at higher exposure time of 1 h gave better seedling growth compared to 30 min exposure.

In conclusion, the rhizome bits exposed to chitosan 1 g L⁻¹ for 1 h was observed to give better results in terms of growth parameters such as, collar girth, shoot length, shoot weight, number of roots, root depth, root weight per plant and root volume and seedling vigour index in both the varieties. Chitosan treatment at the rate of 1 g L⁻¹ for 1 h enhanced the shoot length by 58 % in Sobha and 83 % in Sona, over the control at 45 DAP. The collar girth enhanced by 39 % and 19 %, over the control in Sobha and Sona, respectively. The chitosan treatment did not influence the days to sprouting, sprouting per cent and survival per cent.

It was observed that at lowest concentration of chitosan 1 g L⁻¹ for an exposure period of 1 h gave better plantlet growth and vigour index in both the varieties compared to a lower exposure time of 30 min. Thus, enhancing

dose above 1 g L⁻¹ is not advantageous as it is not reflected in growth and vigour and adds to the cost of input material. It can be concluded that priming turmeric seed rhizome with chitosan at 1 g L⁻¹ for one hour period is effective in enhancing the seedling growth and vigour compared to unprimed rhizome. It is an ideal elicitor and eco-friendly strategy for production of vigorous and good quality planting material.

Acknowledgement

The authors wish to express thanks to Kerala Agricultural University for the financial assistance and the facilities given for the research work.

References

- Al-Omairi A A, & Al-Hilfy I H 2021 Effect of soaking maize seeds with selenium and chitosan on improving germination, vigour and viability of seed and seedling. IOP Conf. Ser.: Earth Environ. Sci. 904(1): 012075.
- Ashraf K 2017 A comprehensive review on *Curcuma longa* Linn.: Phytochemical, pharmacological, and molecular study. Int. J. Green Pharm. 11: 04.

- Baby A S, Menon J S, & Ashwini S 2020 Effect of various priming treatments on vigor and growth of ginger transplants (*Zingiber officinale* Rosc.) in nursery. Res. J. Agric. Sci. 11(6): 1378-1381.
- Baviskar S, Raut R, Shende P, Madke V, Kamdi S, Mahentesh V, & Shivran A 2025 Chitosan is an efficient tool for precision agriculture and sustainability: A review. Plant Archives. 25(1): 1679-1695.
- Chakraborty M, Hasanuzzaman M, Rahman M, Khan M A R, Bhowmik P, Mahmud N U, Tanveer M & Islam T 2020. Mechanism of plant growth promotion and disease suppression by chitosan biopolymer. Agriculture 10(12): 624.
- Chittaragi D 2018 Priming seed rhizome to enhance growth and yield of transplanted ginger (*Zingiber officinale* Rosc.). M. Sc. Thesis, Kerala Agricultural University, Thrissur, Kerala.
- Ebone L A, Caverzan A, Tagliari A, Chiomento J L T, Silveira D C, & Chavarria G 2010 Soybean seed vigor: uniformity and growth as key factors to improve yield. Agronomy 10: 545.
- Gopinath P P, Parsad R, Joseph B, & Adarsh V S 2020 GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. <https://www.kaugrapes.com/home>. version 1.0.0.
- Guan Y J, Hu J, Wang X J, & Shao C X 2009 Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. J. Zhejiang Univ. Sci. 10(6): 427-433.
- Khanthavong P, Phattarakul N, Jamjod S, Aye T M, & Rerkasem B 2012 Effect of stake priming with complete nutrient solution on cassava root and starch yield. CMUJ. Nat. Sci. 11(1): 75.
- Kim H J, Chen F, Wang X, & Rajapakse N C 2005 Effect of chitosan on the biological properties of sweet basil (*Ocimum basilicum* L.). J. Agric. Food Chem. 53(9): 3696-3701.
- Kumari R, Sudhanshu K, Priyanka K, Vikash K, Tushar R, Anand K, Vandita K, Subrat K B, Bineeta M B, & Ravi R K 2025 Seed priming with chitosan and its nanoparticles improve physiological, biochemical and crop performances in lentil (*Lens culinaris* L.). Plant Sci. Today 12: 7873.
- Mahdavi B & Rahimi A 2013 Seed priming with chitosan improves the germination and growth performance of ajowan (*Carum copticum*) under salt stress. Eurasia J Biosci. 7: 69-76.
- Mahdavi B 2016 Effects of priming treatments on germination and seedling growth of anise *Pimpinella anisum* L. Agric. Sci. Dev. 5(3): 28-32.
- Pandey P T & Mishra D 2022 Seed Priming: An Effective Technique for Seed Germination. World J. Pharm. Pharm. Sci. 11: 427-449.
- Pichyangkura R & Chadchawan S 2015 Biostimulant activity of chitosan in horticulture. Scientia Horticulturae. 196: 49-65.
- Prasath D, Kandiannan K, Srinivasn V, & Anandaraj M 2014 November Standardization of single-sprout transplanting technique in ginger. In : Abstract of poster presented in the 6th Indian Horticulture Congress. DOI:10.13140/2.1.3227.8726
- Ramos-Garcia M, Ortega-Centeno S, Hernandez-Lauzardo A N, Alia-Tejagal I, Bosquez-Molina E, & Bautista-Banos S 2009 Response of gladiolus (*Gladiolus* spp.) plants after exposure corms to chitosan and hot water treatments. Scientia Horticulturae, 121(4): 480-484.
- Riseh R S, Vazvani M G, Vatankhah M, & Kennedy J F 2024 Chitosan coating of seeds improves the germination and growth performance of plants: A review. International Journal of Biological Macromolecules. 278: 134750.
- Saharan V, Sharma G, Yadav M, Choudhary M K, Sharma S S, Pal A, Raliya R, & Biswas P 2015 Synthesis and *in vitro* antifungal efficacy of Cu-chitosan nanoparticles against pathogenic fungi of tomato. Int. J. Biol. Macromol. 75: 346-353.

- Saharan V, Kumaraswamy R V, Choudhary R C, Kumari S, Pal A, Raliya R, & Biswas P 2016 Cu-chitosan nanoparticle mediated sustainable approach to enhance seedling growth in maize by mobilizing reserved food. *J. Agric. Food Chem.* 64(31): 6148-6155.
- Salachna P & Zawadzinska A 2014 Effect of chitosan on plant growth, flowering and corms yield of potted freesia. *J. Ecol. Eng.* 15(3): 97-102.
- Sen S K & Mandal P 2016 Solid matrix priming with chitosan enhances seed germination and seedling invigoration in mung bean under salinity stress. *J. Cent. Eur. Agric.* 17(3): 749-762.
- Stofella P J, Di Paola M L, Pardossi A, & Tognoni F 1992 Seedling root morphology and shoot growth after seed priming or pregermination of bell pepper. *Hort Science*, 27(3): 214-215.
- Uthairatanakij A, da Silva J A T, & Obsuwan K 2007. Chitosan for improving orchid production and quality. *Orchid Sci. Biotech.* 1: 1-5.