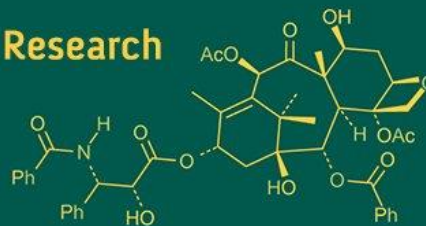


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Effect of green synthesized zinc oxide nanoparticles on seed quality attributes of onion (*Allium cepa* L.)

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Abstract

A laboratory experiment was conducted at the Department of Seed Science and Technology, University of Agricultural Sciences, Dharwad during 2025-26 to evaluate the effect of green synthesized zinc oxide (ZnO) nanoparticles on the seed quality attributes of onion (*Allium cepa* L.) cv. Bhima Super raised from fresh and aged seeds. The experiment was laid out in a Factorial Completely Randomized Design comprising two factors, viz., age of seed (fresh seed, A₁ and aged seed, A₂) and six seed priming treatments: ZnO nanoparticles at 125 ppm for 1 h (T₁), 150 ppm for 1 h (T₂), 150 ppm for 3 h (T₃), 175 ppm for 1 h (T₄), 200 ppm for 1 h (T₅) and an untreated control (T₆) with four replications. Seeds were primed in a 1:2 (seed: nanoparticle solution) ratio and shade dried to original moisture content and later evaluated for seed germination and other quality traits. Priming with ZnO nanoparticles at 200 ppm for 1 hour (T₅) recorded the significantly highest seed germination (94.63%), shoot length (11.98 cm), root length (8.12 cm), seedling dry weight (23.05 mg/10 seedlings), seedling vigour index-I (1882) and seedling vigour index-II (2161) and were significantly superior to the untreated control. Fresh seeds consistently outperformed aged seeds across all parameters, and the interaction between seed age and nano priming was significant for all the traits, with fresh seed primed at 200 ppm for 1 hour showing the best overall performance. The results indicated that green synthesized ZnO nanoparticles, applied at an optimum concentration and duration, can serve as an effective and sustainable seed priming agent for improving seed quality and restoring vigour in aged onion seed.

Keywords: Seed quality, seed priming, seedling vigour, zinc oxide nanoparticles

Introduction

Onion (*Allium cepa* L.) is regarded as a major vegetable crop grown globally for its edible bulb and its ability to adapt to diverse environments. It belongs to the family Amaryllidaceae (Alliaceae) and, is generally cultivated as a biennial. Onion bulbs are a good source of phosphorus, calcium, carbohydrates, protein, vitamins C, B6 and E, dietary fibre, folate and potassium, and their characteristic flavour and antioxidant potential are attributed to sulphur containing volatiles and flavonoids such as quercetin. India ranks first in area and second in production of onion after China, with an area of about 17.74 lakh hectares and production of 28.88 million tonnes. Within India, Maharashtra leads production with nearly 28.62 percent share, followed by Karnataka (15.94%), Madhya Pradesh, Bihar, Gujarat, Andhra Pradesh and Uttar Pradesh. In Karnataka, onion occupies about 173.55 thousand hectares with a production of 2,226.89 thousand metric tonnes and an average productivity of 12.83 t/ha (Anon., 2024) [3].

Nanotechnology has emerged as a promising tool for improving input-use efficiency and offering innovative solutions in crop management. Owing to their large surface area and unique physico-chemical properties, nanoparticles enhance the availability, absorption and effectiveness of nutrients and agrochemicals in plants, besides aiding in the remediation of soil and water contaminants and extending the postharvest life of produce (Savithramma *et al.*, 2012) [14]. Zinc oxide nanoparticles (ZnO NPs) have attracted considerable attention in agriculture because of their antimicrobial and UV-protective properties and their ability to promote plant growth and nutrient uptake. Zinc is an essential micronutrient required for a wide range of physiological and biochemical processes in plants. It is a structural constituent of enzymes such as carbonic anhydrase, alcohol dehydrogenase and superoxide dismutase,

and plays a central role in gene regulation, protein synthesis, carbohydrate metabolism and membrane integrity. Zinc is also required for the biosynthesis of indole-3-acetic acid (IAA) from tryptophan and participates in chlorophyll and carbohydrate synthesis pathways as well as in the regulation of stomatal activity through potassium homeostasis in guard cells; its deficiency adversely affects both crop yield and produce quality (Jamali *et al.*, 2011) [7].

Onion seeds are inherently short-lived and highly hygroscopic in nature, which leads to rapid moisture uptake and accelerated loss of viability, especially under subtropical storage conditions (Selvi and Saraswathy, 2018) [15]. Since onion seed reserves are concentrated in the radicle, ageing accelerates lipid peroxidation, weakens antioxidant enzyme activity and increases free radical mediated damage. The reduced vigour in such seeds leads to weak seedlings, delayed growth, and poor establishment. Considering the above aspects in view, the study was undertaken to know the effect of green synthesized zinc oxide (ZnO) nanoparticles on seed quality attributes of onion (*Allium cepa* L.).

Materials and Methods

A laboratory experiment was conducted during 2025-26 at the Department of Seed Science and Technology, University of Agricultural Sciences, Dharwad to study effect of green synthesized zinc oxide nanoparticles on seed quality attributes of onion cv. Bhima Super, using a Factorial Completely Randomized Design (FCRD) with two factors, viz., age of seed (fresh and aged seeds) and seed priming with green synthesized ZnO nanoparticles (T₁: 125 ppm for 1 h; T₂: 150 ppm for 1 h; T₃: 150 ppm for 3 h; T₄: 175 ppm for 1 h; T₅: 200 ppm for 1 h; T₆: untreated control) with four replications. Fresh and aged onion seeds were primed with the green synthesized ZnO nanoparticle suspension in a seed: nanoparticle solution ratio of 1:2 at different concentrations. After priming, seeds were shade dried under ambient conditions to bring them back to their original moisture content and later evaluated for seed quality parameters.

Seed quality was assessed by the standard germination test (rolled paper towel method, four replications of 400 seeds, 25±1 °C and 95±1% relative humidity, final count on the 14th day) (Anon., 2021) [2]. Shoot and root lengths of ten normal seedlings were measured on the 14th day, and the same seedlings were oven dried at 80±2 °C for 24 hours to record seedling dry weight. Seedling vigour indices I and II were computed following the formula of Abdul-Baki and Anderson (1973) [1].

Seedling Vigour Index-I = Germination (%) x [Root length + Shoot length (cm)]

Seedling Vigour Index-II = Germination (%) x Mean seedling dry weight (mg)

The data recorded were statistically analyzed by the analysis of variance for a factorial completely randomized design, and critical differences were worked out at the 1 percent level of significance, as described by Gomez and Gomez (1984) [6].

Results and Discussion

Seed germination was significantly influenced by seed priming with green synthesized ZnO nanoparticles and seed age is presented in Table 1. Seed priming with zinc oxide nanoparticles at 200 ppm for 1 h (T₅) recorded the

significantly highest mean seed germination (94.63%) while the lowest germination (86.50%) was recorded in the untreated control (T₆). Hence the percent increase in germination was 9.39%. Irrespective of priming treatment, fresh seeds (A₁-94.75%) recorded significantly higher germination than aged seeds (A₂-87.67%). The interaction between seed age and priming treatments was significant, with fresh seeds primed at 200 ppm for 1 h (A₁T₅) recorded the highest germination (97.00%) while the lowest (80.50%) was observed in aged, untreated seeds (A₂T₆).

The superiority of T₅ was attributed to the small size and high surface-to-volume ratio of ZnO nanoparticles, which facilitates their interaction with the seed surface, enhances water uptake and accelerates germination-related metabolic processes. Similar improvements in germination following ZnO nanoparticle priming were reported in chilli and green gram (Lakshmi *et al.*, 2017; Kumar *et al.*, 2020) [10, 9]. Lower germination in aged seeds was associated with ageing-induced oxidative damage, membrane lipid peroxidation and increased solute leakage (Ebene *et al.*, 2019) [5]. The significant interaction indicated that nano priming was more effective in fresh seeds, which possessed better membrane integrity and metabolic vigour (Kumar *et al.*, 2016) [8].

The effect of seed priming with green synthesized ZnO nanoparticles and seed age on seedling dry weight is presented in Table 1. Seed priming at 200 ppm for 1 h (T₅) recorded the significantly highest mean seedling dry weight (23.05 mg) while the untreated control (T₆) recorded the lowest value (17.58 mg). Fresh seeds (A₁-23.07 mg) recorded significantly higher seedling dry weight than aged seeds (A₂, 18.06 mg), and the interaction between seed age and priming treatments was significant, wherein fresh seeds primed at 200 ppm for 1 h (A₁T₅) recorded the highest seedling dry weight (25.22 mg) while the untreated seed (A₂T₆) recorded the lowest value (13.73 mg).

The increase in seedling dry weight with ZnO nanopriming was attributed to zinc-mediated enzyme activity, protein synthesis and cell division, promoting efficient mobilization of seed reserves. Similar improvements in dry matter accumulation were reported in chilli and green gram (Lakshmi *et al.*, 2017; Kumar *et al.*, 2020) [10, 9]. The lower dry weight of aged seeds was associated with ageing-induced oxidative damage and reduced metabolic activity (Ebene *et al.*, 2019) [5]. The greater response of fresh seed to 200 ppm ZnO indicated more efficient utilization of zinc due to better membrane integrity and metabolic vigour (Kumar *et al.*, 2016) [8].

The effect of seed priming with green synthesized ZnO nanoparticles and seed age on shoot and root length are presented in Table 2. Seed priming at 200 ppm for 1 h (T₅) recorded the significantly highest mean shoot and root length (11.98 and 8.12 cm, respectively) while the significantly lowest (10.23 and 6.24 cm, respectively) were recorded in the untreated control (T₆). Fresh seeds (A₁-11.72 and 7.68 cm, respectively) recorded significantly higher shoot and root length than aged seeds (A₂-10.34 and 6.72 cm, respectively), and the interaction between seed age and priming treatments was significant with the fresh seed primed at 200 ppm for 1 h (A₁T₅) recorded the highest shoot and root length (12.61 and 8.53 cm, respectively) and the lowest (9.14 and 5.21 cm, respectively) in aged, untreated seed (A₂T₆).

The smaller particle size of ZnO nanoparticles allows deeper penetration which helps develop root and shoot axis and a more uniform distribution of zinc within the growing tissue, thereby promoting more vigorous cell division in the plumule than expected from an equivalent dose of bulk zinc (Prasad *et al.*, 2012) ^[13]. These results are in agreement with findings of Munir *et al.* (2018) ^[12] in wheat and Lopez *et al.* (2018) ^[11] in *Capsicum annuum* who reported significant improvement in shoot and root length following ZnO nanoparticle seed treatment.

The effect of seed priming with green synthesized ZnO nanoparticles and seed age on Seedling vigour index-I and seedling vigour index-II are presented in Table 3. Seed priming with ZnO nanoparticles at 200 ppm for 1 h (T₅) recorded the significantly highest mean seedling vigour index-I (1882 and 2161, respectively) while the lowest value (1437 and 1543, respectively) was recorded in the untreated

control (T₆). Fresh seed (A₁, 1836 and 2184, respectively) recorded significantly higher vigour index-I than aged seed (A₂, 1496 and 1585, respectively), and the interaction between seed age and priming treatments was significant, with fresh seed primed at 200 ppm for 1 h (A₁T₅) recorded the highest value (2035 and 2427, respectively) and aged, untreated seed (A₂T₆) the lowest (1155 and 1104, respectively).

The higher seedling vigour indices with ZnO nanopriming was attributed to enhanced antioxidant defence and reduced ROS accumulation, facilitating efficient reserve mobilization and seedling growth. Similar improvements in vigour indices were reported in green gram (Lakshmi *et al.*, 2017) ^[10]. The superior performance of fresh seeds primed with ZnO nanoparticles over aged, untreated seeds supports the role of zinc in enhancing enzyme activity, membrane integrity and seedling establishment (Cakmak, 2008) ^[4].

Table 1: Effect of green synthesized zinc oxide (ZnO) nanoparticles on seed germination (%) and seedling dry weight (mg/10 seedlings)

Treatments	Seed germination (%)			Seedling dry weight (mg/10 seedlings)		
	A ₁	A ₂	Mean	A ₁	A ₂	Mean
T ₁ : 125 ppm for 1 h	93.75(75.55)*	87.50(69.30)	90.63(72.43)	22.06	17.55	19.78
T ₂ : 150 ppm for 1 h	94.75(76.80)	88.25(69.96)	91.50(73.38)	22.60	18.03	20.31
T ₃ : 150 ppm for 3 h	95.00(77.11)	88.00(69.74)	91.50(73.43)	23.14	18.68	20.91
T ₄ : 175 ppm for 1 h	95.50(77.77)	89.50(71.10)	92.50(74.43)	24.01	19.50	21.76
T ₅ : 200 ppm for 1 h	97.00(78.85)	92.25(72.31)	94.63(75.58)	25.22	20.88	23.05
T ₆ : Control (Untreated)	92.50(74.11)	80.50(63.80)	86.50(68.96)	21.44	13.73	17.58
Mean	94.75(76.70)	87.67(69.37)	91.21(73.03)	23.07	18.06	20.57
	S.Em(±)	C.D (1%)		S.Em(±)	C.D (1%)	
Age of seeds (A)	0.17	0.64		0.07	0.26	
Treatments (T)	0.29	1.12		0.12	0.45	
A x T	0.41	1.58		0.17	0.63	

*Figures in parenthesis indicate arcsine root transformed values; A₁ = Fresh seed, A₂ = Aged seed

Table 2: Effect of green synthesized zinc oxide (ZnO) nanoparticles on shoot length (cm) and root length (cm)

Treatments	Shoot length (cm)			Root length (cm)		
	A ₁	A ₂	Mean	A ₁	A ₂	Mean
T ₁ : 125 ppm for 1 h	11.38	9.78	10.58	7.38	6.25	6.81
T ₂ : 150 ppm for 1 h	11.47	10.26	10.86	7.41	6.93	7.17
T ₃ : 150 ppm for 3 h	11.66	10.63	11.14	7.52	6.80	7.16
T ₄ : 175 ppm for 1 h	11.91	10.90	11.41	7.97	7.42	7.69
T ₅ : 200 ppm for 1 h	12.61	11.34	11.98	8.53	7.71	8.12
T ₆ : Control (Untreated)	11.32	9.14	10.23	7.26	5.21	6.24
Mean	11.72	10.34	11.03	7.68	6.72	7.20
	S.Em(±)	C.D (1%)		S.Em(±)	C.D (1%)	
Age of seeds (A)	0.02	0.08		0.02	0.08	
Treatments (T)	0.04	0.15		0.04	0.14	
A x T	0.05	0.21		0.05	0.20	

A₁ = Fresh seed; A₂ = Aged seed.

Table 3: Effect of green synthesized zinc oxide (ZnO) nanoparticles on seedling vigour index-I and seedling vigour index-II

Treatments	Seedling vigour index - I			Seedling vigour index - II		
	A ₁	A ₂	Mean	A ₁	A ₂	Mean
T ₁ : 125 ppm for 1 h	1758	1402	1580	2063	1535	1799
T ₂ : 150 ppm for 1 h	1787	1516	1652	2141	1590	1866
T ₃ : 150 ppm for 3 h	1821	1533	1677	2197	1643	1920
T ₄ : 175 ppm for 1 h	1898	1639	1768	2293	1745	2019
T ₅ : 200 ppm for 1 h	2035	1728	1882	2427	1894	2161
T ₆ : Control (Untreated)	1718	1155	1437	1982	1104	1543
Mean	1836	1496	1666	2184	1585	1885
	S.Em(±)	C.D (1%)		S.Em(±)	C.D (1%)	
Age of seeds (A)	4.08	15.68		6.93	26.66	
Treatments (T)	7.06	27.16		12.01	46.18	
A x T	9.99	38.42		16.98	65.31	

A₁ = Fresh seed; A₂ = Aged seed

Conclusion

Seed priming with green synthesized zinc oxide nanoparticles significantly improved the seed quality attributes of onion. Priming at 200 ppm for 1 hour (T₅) was consistently the best treatment, recording the highest seed germination, shoot and root length, seedling dry weight and seedling vigour indices, and was significantly superior to the untreated control across both fresh and aged seed. Fresh seed responded more strongly to nanopriming than aged seed, and the fresh seeds primed with 200 ppm for 1 hour zinc oxide nanoparticle gave the best overall seed quality performance. These results suggest that green synthesized ZnO nanoparticles, applied at an optimized concentration and duration, offers an eco-friendly and effective seed priming technique for improving seed quality and partially restoring the vigour of aged onion seed.

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