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Engineered zinc oxide quantum dots for enhancing seed germination and seedling vigour in blackgram (*Vigna mungo*)

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Abstract
Quantum dots (QDs) are an advanced form of nanoparticles having a size of 1-10 nm. In this study, zinc oxide (ZnO) QDs were synthesised at approximately 8 nm in size and used as an advanced nanomaterial to improve the seed quality attributes of blackgram. The results demonstrated that the seeds primed with 80 ppm ZnO QDs for 2 hours improved the speed of germination, germination percentage, root and shoot length, seedling vigour and field emergence. However, ZnO QDs at higher concentrations (> 300 ppm) reduced the physiological activities of the seed as the soaking period advanced. Catalase, peroxidase, α-amylase and dehydrogenase enzyme activities were also significantly and positively influenced by ZnO QDs. Hence, this study concludes that ZnO QDs seed priming improved the seed germination and seedling vigour of blackgram.

Keywords: Zinc oxide, quantum dots, nanoparticles, germination, vigour

1. Introduction
Quality seeds are the most critical and vital input in agriculture and is also responsible for ensuring global food security. In the present scenario of agriculture, the successful crop production needs high-quality seed with better germination and vigour with uniform field emergence. This can be achieved only through the use of various seed enhancement treatments. Several seed enhancement techniques have been developed by scientists all over the world, including seed polymer coating, seed colouring, seed pelleting, seed priming, seed invigoration, seed fortification, seed infusion and so on (Korishettar *et al*., 2016) [17].

Seed priming is a pre-sowing treatment that causes a physiological change in the seed, allowing it to germinate more quickly. It's a simple and efficient way to promote quick and uniform emergence, high seedling vigour and higher yields in many field crops, especially under challenging environmental circumstances (Jisha *et al*., 2013; Paparella *et al*., 2015) [13, 28]. Reduced imbibition lag time (Brocklehurst and Dearman, 2008) [2], enzyme activation (Lee and Kim, 2000) [18], build-up of germination-enhancing metabolites (Hussain *et al*., 2015) [11], metabolic repair during imbibition (Farooq *et al*., 2006) [8], and osmotic adjustment (Bradford, 1986) [3] contribute to higher and more synchronised germination of primed seeds. Furthermore, nano priming, a process that combines seed priming with nanoparticle treatment has proven to be an effective strategy for improving seed germination, seedling establishment and seed yield besides boosting resistance to environmental stressors. As a result, it appears that the seed nano priming process is distinct from other pre-sowing seed treatments that do not require drying. Systematic investigations on the physiological and molecular mechanisms of nano priming effects on seed germination have yet to be completed, leaving many issues unanswered, particularly about the mechanism of nanoparticles-induced seed germination.

Nanoparticles are molecules or atoms with a diameter of 1 to 100 nm that exhibit unique physiochemical, magnetic, and optical characteristics as well as a high surface-to-volume ratio not seen in large-scale materials. They also have higher solubility and surface reactivity than large size nanoparticles due to their large surface area (Monthioux *et al*., 2010) [23]. Among the metal nanoparticles, zinc oxide is considered to be the significant quantum dots materials due to its stability, non-toxicity, low-cost production and eco-friendly in nature (Lalitha *et al*., 2015) [9]. Seeds treated with ZnO nanoparticles showed higher seed metabolic efficiency because of physiochemical properties that boost the seed metabolism and they also enter into plant tissue and interfere with different metabolic activities.

ZnO can penetrate the seed coat and cause embryonic differentiation by activating enzymes involved in seed dormancy disruption (Miralles *et al*., 2012) [22]. Regarding the phytotoxicity, zinc oxide has been exhibited positive and negative effect on seed germination and plant growth (Zuverza-Mena *et al*., 2016) [36].

Quantum dots which were first discovered in 1980 are semiconductor crystals with diameters in the range of 1-10 nanometres (10-50 atoms). In recent years, Quantum dots have attracted much attention to use in several applications due to their small size and large surface area but least exploited in the field of agriculture. Quantum dots have wide range of applications in single electron transistors, solar cells, LEDs, quantum computing, cell biology research and medical research, but the application in agriculture largely remain unknown. However, some research suggests that quantum dots alter seed germination and plant development at higher concentrations and yet have no effect at lower concentrations, indicating that they serve as a plant growth regulator. Hence, this research is proposed with an aim to study the use of Zinc Oxide quantum dots in improving the seed germination and seedling vigour in the blackgram.

Further, nanoparticles which are larger in size (10-100nm) and it requires higher concentration (> 1000 ppm) to improve the seed germination, seedling vigour, photosynthesis, physiological and biochemical activities in seeds. But, the Quantum dots with lesser size (≤10nm) are supposed to be more active than nanoparticles due to its large surface area, but it remains least explored in agriculture except carbon and graphene dots.

2. Materials and Methods

The laboratory studies for synthesis and characterization of ZnO quantum dots were carried out in the Department of Nano Science and Technology during 2020- 2021 and the studies on the enhancement of seed germination and seedling vigour through ZnO quantum dots were carried out in the Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore during 2020-2021. High physically and genetically pure seed lots of Blackgram (*Vigna mungo*) cv. VBN 8 were obtained from the National Pulse Research Centre, Vamban and the chemicals required for ZnO synthesis were purchased from Sigma-Aldrich (Bangalore, India) and had an analytical reagent grade purity of 99.9 percent.

2.1. Synthesis of ZnO quantum dots

The quantum dots were synthesized using zinc acetate and sodium hydroxide as precursors. Initially, the zinc acetate was used as starting materials to synthesise zinc oxide NPs using the precipitation method in which the addition of oxygen to the QDs was done with a sodium hydroxide solution. Under vigorous stirring, sodium hydroxide (0.1 M) was slowly added dropwise (0.5 ml/min) to aqueous solutions of zinc acetate (0.1 M). Subsequently, the reaction was kept overnight for addition and stabilisation until it produced a thick white precipitate. To separate the NPs, centrifugation was used, which was then rinsed with deionized water until it reached a neutral pH, then washed with methanol (CH_3OH) to remove any organic residues. For complete removal of solvent and volatile contaminants, the QDs were dried in an oven at 60°C for 12 hours. The QDs were ignited in a muffle furnace at 500°C for 15 - 20 minutes after drying. The QDs that had been ignited were kept in an airtight container for further use.

2.2. Characterization of ZnO quantum dots

Synthesized quantum dots were characterized using (i) UV Spectroscopy for adsorption wavelength of quantum dots, (ii) SEM characterization for surface topography, composition and particle size of the quantum dots, (iii) TEM characterization for internal structures of the quantum dots.

2.3. Seed priming with ZnO quantum dots

To standardize the priming duration and optimum concentration of ZnO quantum dots, a known quantity of blackgram seeds were taken and surface sterilized with 1% sodium hypochlorite. Meanwhile, different concentrations of ZnO quantum dots (20 ppm, 40 ppm, 60 ppm, 80 ppm, 100 ppm, 150 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm, 1000 ppm) were prepared with distilled water. All the concentrations of ZnO quantum dots were sonicated (Sonics, 1500 watts, 20 kHz) invariably for 4 minutes to uniformly disperse the quantum dots. Then the surface sterilized seeds were primed in a refrigerated shaker incubator (Orbitek, 150 rpm, 50Hz) with different concentrations of ZnO QDs separately at different intervals (30 minutes, 60 minutes, 90 minutes, 120 minutes, 150 minutes, 180 minutes) along with control, hydropriming and hydropriming with sonication. The following seed quality parameters were studied. The seeds of best performing treatments from the standardized duration along with control, hydropriming and hydropriming with sonication were tested for the field emergence percentage and enzyme activities *viz.*, catalase activity (Aebi, 1984) [5], peroxidase activity (Malik and Singh, 1980) [21], alpha amylase activity (Paul *et al.* 1970) [25], and dehydrogenase activity (Kittock and Law, 1968) [14].

2.3.1. Germination percentage

The germination test was carried out according to ISTA (2015) [12] using the roll towel method for blackgram with 4 replications of 100 seeds in a germination chamber maintained with a temperature of 25 □ 2 ºC and a relative humidity of 95 □ 2 per cent. According to ISTA, seedlings were classified as normal seedlings, abnormal seedlings, hard seeds, and dead seeds at the completion of the final count day i.e., at 7th day. The number of normal seedlings was counted and the mean germination was calculated and expressed as a percentage.

2.3.2. Seedling length

Ten normal seedlings were chosen at random from each replication in different treatments during the final count, in which the length from the tip of the main leaves to the bottom of the primary root, termed as the seedling length, was measured. The mean values were calculated from ten normal seedlings that were measured and expressed in centimetres.

2.3.3. Dry matter production

The ten normal seedlings that were selected for seedling measurements were folded and placed within a paper cover after removing cotyledon and seed coat, shade dried for 24 hours, and then dried at 80 □ 2°C in a hot air oven for 4 hours, and subsequently cooled in a desiccator for 30 minutes. With the use of electronic weighing balance, weight of the seedlings that were dried in the hot air oven was measured which is used to calculate the mean value and expressed in gram per 10 seedlings.

2.3.4. Vigour index

The seedling vigour index was computed using the method prescribed by Abdul-Baki and Anderson (1973) [1], where germination percentage multiplied with seedling length, which is the combination of both root length and shoot length. The vigour index was calculated, and the mean values were presented in whole numbers.

Vigour index = Germination (%) x total seedling length (cm)

2.3.5. Field emergence percentage

In raised nursery beds, four replicates of hundred seeds each from different treatments were seeded and the seedlings were evaluated after 15 days for normal root and shoot development. Eventually, seedlings with normal roots and shoots emerged after 15 days, were counted and the mean values were represented in percentages.

2.3.6 Statistical analysis

The experimental data were analysed using the analysis of variance (ANOVA) as a factorial combination of treatments. Mean values were separated on the basis of least significant difference (LSD) only if F test of ANOVA for treatments was significant at 0.05 probability level. Before analysis, values in percent data were arcsine transformed. If the F test was non-significant, the letters NS were used to denote it.

3. Results and Discussion

The results of seed priming with different concentrations of ZnO quantum dots (QDs) revealed that the seeds primed with 80 ppm ZnO quantum dots for 120 minutes recorded the highest germination of 91 per cent compared to control, which recorded only 81 per cent (Table 1). The increased seed germination owing to nanoparticles seed treatment might be attributed to the seed's increased water uptake capacity, triggered by nanoparticles by generating new pores on the seed coat (Khodakovskaya *et al*., 2009) [15]. The exact mechanism underpinning quantum dots induced seed priming has yet to be discovered for seed germination. The enhanced germination might be further related to the particles' nano size, which allows them to easily penetrate the seed coat, allowing for better absorption and usage by seeds. The penetration of nanoparticles into seed coat pores, resulting in increased water molecules penetration and triggering ROS-generating/starch-degrading enzyme activity to accelerate seed germination could be the most likely explanation (Mahakham *et al*., 2017; Khodakovskaya *et al*., 2011) [24, 16]. Similar findings were reported earlier *viz*., Biogenic ZnO (20-38nm at 600 ppm) and Cu (20-62nm at 400 ppm) nanoparticles have been proven to increase blackgram invigoration and seed germination (Raja *et al*., 2018) [29]. ZnO and ZVI (Zero valent iron) nanoparticles enhanced the germination, seedling development, vigour index and biochemical activity in blackgram seeds (Senthilkumar, 2011) [30]. Prasad *et al.* (2012) [27] found an improvement in germination and seedling vigour after exposing *Arachis hypogaea* seeds to 1000 ppm ZnO nanoparticle solution for 3 hours.

However, ZnO QDs at 1000 ppm for 180 minutes decreased the seed germination up to 14 per cent (Table 1). The increased absorption and accumulation of these quantum dots both in extracellular space and within the cells might have caused a reduction in cell division, cell elongation and inhibition of the hydrolytic enzymes involved in food mobilisation during the process of seed germination, which resulted in decreased germination at higher concentrations. Lee *et al.* (2010) [20] reported seed germination inhibition in Arabidopsis seedlings treated with Al_2O_3 and ZnO nanoparticles above 4000 mg l^{-1}. Quantum dots generally enhance or reduce the seed germination, seedling growth, biomass production and physiological and biochemical activities. However, for seed germination and root elongation, several studies have proved the phytotoxicity of nanoparticles in various media such as agar, filter paper on petri dishes and soil media (Zheng *et al*. 2005; Doshi *et al*. 2008; Khodakovskaya *et al*. 2009; Song *et al*. 2013) [10, 6, 15, 31]

The ZnO QDs at 80 ppm for 120 minutes recorded significantly higher seedling length (40.41 cm) which was on par with 80 ppm and 40 ppm at 150 and 180 minutes (40.11 cm and 40.08 cm, respectively) (Table 2). Better emergence and growth of seedlings might be attributed to enhanced synthesis and activity of hydrolytic enzymes during the early stages of germination, as well as effective mobilization of the available food stores in the seeds. However, the dry matter production at 80 ppm in 180 minutes has recorded the maximum value of 0.286 g while control recorded only 0.210 g (Table 3). It was reported that the ZnO nanoparticles increased the level of Indole-3-acetic acid (IAA) in the roots of *Cicer arietinum* and thereby resulted in increase in the growth rate of the seedlings (Pandey *et al*., 2010) [26]. On the other hand, ZnO QDs at 1000 ppm in 180 minutes recorded the lowest seedling length (32.60 cm) and dry matter production (0.198 g) which statistically on par with 1000 ppm at 150 minutes (Table 2 and Table 3). This revealed that in contrast to beneficial effect, these QDs also have inhibitory effect on seedling growth at higher concentration (ZnO QDs > 300 ppm). Higher concentrations of QDs penetration into cell walls and plasma membranes of epidermal layers in shoot and root, as well as storage in vascular tissues, might have hampered the cell division and elongation leading to affect the total seedling growth. These results were supported by the earlier findings by Lin *et al*. (2007) [19] who found that ZnO nanoparticles reduced the seedling biomass and induced root tip shrinkage, root epidermis collapse, cell internalisation, and translocation in *Lolium perenne*. Boonyanitipong *et al*. (2011) [4] indicated that the increasing ZnO nanoparticle concentrations caused decreased root elongation and the number of hairy roots. ZnO nanoparticles at higher concentration (2000 ppm) had inhibitory effect on growth and development in groundnut also (Prasad *et al*., 2012) [27].

Seedling vigour indices were also significantly influenced due to ZnO quantum dots treatment. Among the treatments, ZnO QDs at 80 ppm for 120 minutes recorded the highest seedling vigour index (3665), which was on par with 80 ppm for 150 minutes (3584) and 40 ppm for 180 minutes (3582) (Table 4). The improved seedling vigour is might be due to the faster germination and seedling growth characteristics. Further, the increased emergence rate of shoot might also be induced by an increase in indole acetic acid (IAA) concentration as a result of water and nanoparticles entering the gap between a selective permeable membrane underneath the seed coat and the intracellular space in the seed coat parenchyma which in turn improved the seed vigour (Van-Dongen *et al*., 2003) [34]. The positive effects of ZnO nanoparticles during germination could also be attributed to trigger in hormone production, particularly auxins and gibberellins, which promotes seed reserves degradation and vigour (El-Kereti *et al*., 2013) [7].

The field emergence percentage was also found to be

significantly influenced due to the ZnO QDs over control. Among the selected concentrations, ZnO QDs at 80 ppm recorded the highest field emergence (87%), which was on par with 100 ppm (85%) and 60 ppm (84%) while control recorded only 77 per cent (Fig. 1). It might be because of overall favourable effects of Zn, such as greater nanoscale Zn precursor activity in synthesis of important biomolecules and a positive influence on phytohormone reactivity during germination (Shyla and Natarajan, 2014) [32].

The enzymes dehydrogenase and α-amylase activities were significantly influenced by the QDs treatments. The highest OD value (3.34) for dehydrogenase activity was recorded by 80 ppm of ZnO QDs followed by 60 ppm (3.15) and 100 ppm (3.10) when compare to control which recorded only 2.77 OD value (Fig. 2). The α-amylase activity was significantly increased by ZnO QDs at 80 ppm and 60 ppm (1.54 and 1.56 mm, respectively) over control (1.26 mm) (Fig. 2). Zn is a vital metal micronutrient that serves as a cofactor for the majority of dehydrogenase enzyme complexes involved in seed respiration and food mobilisation. The enhanced availability of these micronutrients at nanoscale, along with increased chemical reactivity, resulted in a rise in dehydrogenase and alpha amylase enzyme production and activity (Vijayalaxmi *et al*., 2013) [35]. The activity of antioxidant enzymes catalase and peroxidase were also significantly increased under ZnO QDs at 80 ppm (4.95 and 3.74 respectively) compared to control (3.79 and 2.02) (Fig. 2). It is presumed that ZnO might have promoted the formation of reactive oxygen species (ROS), resulting in oxidative stress and enhanced antioxidant enzyme activity as suggested by Sheteiwy *et al*. 2016 [33].

Table 1: Effect of seed priming with different concentrations of ZnO Quantum dots for various duration on seed germination in blackgram

Priming treatments	Priming duration						Mean
	30 minutes	60 minutes	90 minutes	120 minutes	150 minutes	180 minutes	
Control	81 (64.15)	81 (64.15)	81 (64.15)	81 (64.15)	81 (64.15)	81 (64.15)	81 (64.15)
Hydropriming	81 (64.15)	83 (65.65)	84 (66.42)	84 (66.42)	84 (66.42)	85 (67.21)	84 (66.42)
Hydropriming + sonication	81 (64.15)	83 (65.65)	84 (66.42)	85 (67.21)	85 (67.21)	85 (67.21)	84 (66.42)
20 ppm	83 (65.65)	84 (66.42)	84 (66.42)	87 (68.86)	87 (68.86)	88 (69.73)	85 (67.21)
40 ppm	83 (65.65)	87 (68.86)	87 (68.86)	88 (69.73)	88 (69.73)	89 (70.63)	87 (68.86)
60 ppm	84 (66.42)	88 (69.73)	88 (69.73)	89 (70.63)	89 (70.63)	89 (70.63)	88 (69.73)
80 ppm	87 (68.86)	88 (69.73)	89 (70.63)	91 (72.54)	89 (70.63)	88 (69.73)	89 (70.63)
100 ppm	87 (68.86)	88 (69.73)	89 (70.63)	89 (70.63)	87 (68.86)	85 (67.21)	88 (69.73)
150 ppm	88 (69.73)	89 (70.63)	87 (68.86)	87 (68.86)	85 (67.21)	84 (66.42)	87 (68.86)
200 ppm	89 (70.63)	85 (67.21)	84 (66.42)	83 (65.65)	83 (65.65)	80 (63.43)	84 (66.42)
300 ppm	84 (66.42)	83 (65.65)	81 (64.15)	80 (63.43)	79 (62.72)	79 (62.72)	81 (64.15)
400 ppm	81 (64.15)	80 (63.43)	79 (62.72)	76 (60.66)	75 (60.00)	72 (58.05)	77 (61.34)
500 ppm	79 (62.72)	76 (60.66)	73 (58.69)	72 (58.05)	69 (56.16)	68 (55.55)	73 (58.69)
1000 ppm	77 (61.34)	76 (60.66)	75 (60.00)	69 (56.16)	68 (55.55)	67 (54.94)	72 (58.05)
Mean	83 (65.65)	84 (66.42)	83 (65.65)	83 (65.65)	82 (64.89)	82 (64.89)	
	T	D	T*D				
SED	1.10	0.72	2.70				
CD (0.05)	2.17	1.42	5.33				

Table 2: Effect of seed priming with different concentrations of ZnO Quantum dots for various duration on seedling length in blackgram

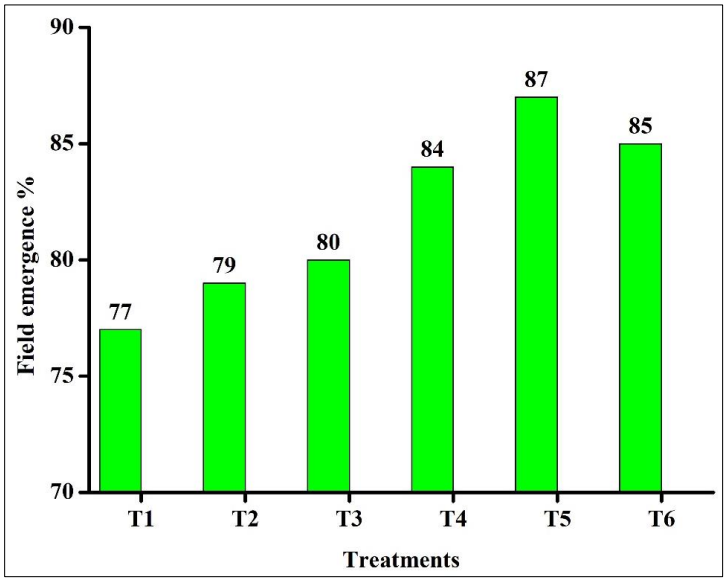
Priming treatments	Priming duration						Mean
	30 minutes	60 minutes	90 minutes	120 minutes	150 minutes	180 minutes	
Control	35.28	35.28	35.28	35.28	35.28	35.28	35.28
Hydropriming	36.12	36.66	37.85	38.24	38.47	38.67	37.67
Hydropriming + sonication	36.30	36.80	38.05	38.35	38.55	38.84	37.81
20 ppm	36.58	37.32	38.29	38.55	39.01	39.71	38.24
40 ppm	36.97	37.54	38.50	39.01	39.67	40.08	38.63
60 ppm	37.35	37.88	39.00	39.91	39.83	39.58	38.93
80 ppm	37.77	38.14	39.55	40.41	40.11	38.62	39.10
100 ppm	38.23	39.34	39.90	40.00	39.58	38.02	39.18
150 ppm	38.81	39.34	38.73	38.40	38.20	36.52	38.33
200 ppm	37.44	37.21	36.55	35.88	35.34	34.53	36.16
300 ppm	37.07	36.49	35.94	35.24	34.53	34.01	35.55
400 ppm	36.60	35.92	35.39	34.68	34.20	33.65	35.07
500 ppm	36.10	34.89	34.43	34.09	33.72	33.08	34.38
1000 ppm	35.74	34.21	33.93	33.57	33.13	32.60	33.86
Mean	36.88	36.93	37.24	37.26	37.12	36.66	
	T	D	T*D				
SED	0.190	0.124	0.466				
CD (0.05)	0.375	0.246	0.919				

Table 3: Effect of seed priming with different concentrations of ZnO Quantum dots for various duration on dry matter production in blackgram

Priming treatments	Priming duration						Mean
	30 minutes	60 minutes	90 minutes	120 minutes	150 minutes	180 minutes	
Control	0.210	0.210	0.210	0.210	0.210	0.210	0.210
Hydropriming	0.213	0.221	0.219	0.220	0.226	0.240	0.223
Hydropriming + sonication	0.214	0.226	0.223	0.222	0.222	0.232	0.223
20 ppm	0.221	0.233	0.227	0.234	0.234	0.249	0.233
40 ppm	0.232	0.241	0.234	0.241	0.245	0.255	0.241
60 ppm	0.235	0.245	0.238	0.245	0.252	0.269	0.247
80 ppm	0.242	0.248	0.248	0.253	0.260	0.286	0.256
100 ppm	0.242	0.260	0.256	0.254	0.266	0.256	0.256
150 ppm	0.256	0.254	0.252	0.245	0.251	0.254	0.252
200 ppm	0.261	0.246	0.244	0.236	0.247	0.248	0.247
300 ppm	0.237	0.233	0.234	0.234	0.232	0.230	0.233
400 ppm	0.232	0.224	0.227	0.223	0.218	0.219	0.224
500 ppm	0.219	0.221	0.219	0.217	0.207	0.203	0.214
1000 ppm	0.207	0.201	0.209	0.209	0.198	0.198	0.204
Mean	0.230	0.233	0.231	0.232	0.233	0.239	
	T	D	T*D				
SED	0.0033	0.0022	0.0083				
CD (0.05)	0.0066	0.0043	0.0163				

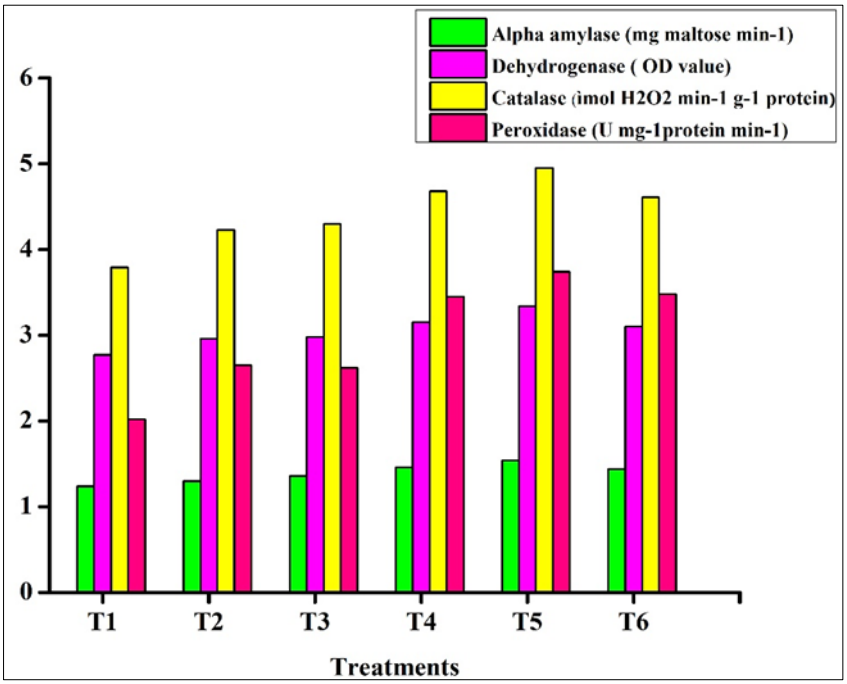
Table 4: Effect of seed priming with different concentrations of ZnO Quantum dots for various duration on seedling vigour in blackgram

Priming treatments	Priming duration						Mean
	30 minutes	60 minutes	90 minutes	120 minutes	150 minutes	180 minutes	
Control	2868	2868	2868	2868	2868	2868	2868
Hydropriming	2937	3030	3180	3212	3232	3301	3149
Hydropriming + sonication	2952	3041	3195	3272	3290	3317	3178
20 ppm	3024	3135	3217	3341	3380	3495	3265
40 ppm	3056	3254	3337	3434	3493	3582	3359
60 ppm	3137	3333	3432	3564	3558	3535	3427
80 ppm	3273	3355	3532	3665	3584	3398	3468
100 ppm	3313	3463	3564	3574	3430	3244	3431
150 ppm	3415	3515	3357	3329	3260	3069	3324
200 ppm	3344	3175	3069	2966	2921	2760	3039
300 ppm	3114	3016	2922	2819	2716	2674	2877
400 ppm	2977	2876	2785	2637	2554	2423	2709
500 ppm	2841	2652	2525	2456	2337	2249	2510
1000 ppm	2763	2601	2534	2328	2253	2173	2442
Mean	3072	3094	3108	3105	3063	3006	
	T	D	T*D				
SED	43.36	28.38	106.20				
CD (0.05)	85.60	56.04	209.67				



T_1 - Control T_2 - Hydropriming T_3 - Hydropriming + sonication T_4 – 60 ppm T_5 – 80 ppm T_6 - 100 ppm

Fig 1: Effect of seed priming with different concentrations of ZnO QDs for 120 minutes on field emergence in blackgram



T1 - Control T2 - Hydropriming T3 - Hydropriming + sonication T4 – 60 ppm T5 – 80 ppm T6 - 100 ppm

Fig 2: Effect of seed priming with different concentrations of ZnO QDs for 120 minutes on biochemical activities in blackgram

4. Conclusion

Application of Quantum dots in agriculture remains least explored. However, the present study demonstrates the scope of quantum dots in seed sciences. From this study, it could be concluded that ZnO QDs are capable of entering the seeds through pores present on the seed coat during water imbibition, induce water uptake ability of seeds, enhance enzymatic activity and free radical scavenging system, lower the oxidative damage and eventually improve seed germination, seedling length, seedling dry weight and seedling vigour. It is understood that this work is the first of its kind in blackgram and preliminary in nature, further intensive, in-depth field research is necessary to properly analyse the cause of quantum dots induced seed germination and their penetration into the seeds during imbibition which will serve as a torch bearer in this frontier area.

5. References

1. Abdul-Baki AA, Anderson JD. Vigor determination in soybean seed by multiple criteria 1. Crop science 1973;13(6):630-633.
2. Brocklehurst PA, Dearman J. Interactions between seed priming treatments and nine seed lots of carrot, celery and onion. I. Laboratory germination. Annals of Applied Biology 1983;102(3):577-84.
3. Bradford KJ. Manipulation of seed water relations via osmotic priming to improve germination under stress. HortScience 1986;21(5):1105-12.
4. Boonyanitipong P, Kositsup B, Kumar P, Baruah S, Dutta J. Toxicity of ZnO and TiO_2 nanoparticles on germinating rice seed *Oryza sativa* L. International Journal of Bioscience, Biochemistry and Bioinformatics 2011;1(4):282.
5. Catalase AH. Methods of enzymatic analysis. Bergmeyer HU, editor 1974;2:674-8.
6. Doshi R, Braida W, Christodoulatos C, Wazne M, O'Connor G. Nano-aluminum: transport through sand columns and environmental effects on plants and soil communities. Environmental Research 2008;106(3):296-303.
7. El-Kereti MA, El-Feky SA, Khater MS, Osman YA, El-sherbini ESA. ZnO nanofertilizer and He-Ne Laser irradiation for promoting growth and yield of sweet basil plant. Recent Patents on Food Nutrition and Agriculture 2013;5:169-181.
8. Farooq MS, Basra SM, Hafeez K. Seed invigoration by osmohardening in coarse and fine rice. Seed Science and Technology 2006;34(1):181-7.
9. Gnanasekaran L, Hemamalini R, Ravichandran K. Synthesis and characterization of TiO_2 quantum dots for photocatalytic application. Journal of Saudi Chemical Society 2015;19(5):589-94.
10. Hong F, Zhou J, Liu C, Yang F, Wu C, Zheng L, Yang P. Effect of nano-TiO_2 on photochemical reaction of chloroplasts of spinach. Biological trace element research 2005;105(1):269-79.
11. Hussain S, Zheng M, Khan F, Khaliq A, Fahad S, Peng S, *et al*. Benefits of rice seed priming are offset permanently by prolonged storage and the storage conditions. Scientific reports 2015;5(1):1-2.
12. ISTA. International Rules for Seed Testing. International Seed Testing Association 2015. Bassersdorf, Switzerland.
13. Jisha KC, Vijayakumari K, Puthur JT. Seed priming for abiotic stress tolerance: an overview. Acta Physiologiae Plantarum 2013; 35(5):1381-96.
14. Kittock DL, Law AG. Relationship of Seedling Vigor to Respiration and Tetrazolium Chloride Reduction by Germinating Wheat Seeds 1. Agronomy Journal 1968;60(3):286-8.
15. Khodakovskaya M, Dervishi E, Mahmood M, Xu Y, Li Z, Watanabe F, Biris AS. Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. ACS nano 2009;3(10):3221-7.
16. Khodakovskaya MV, de Silva K, Nedosekin DA, Dervishi E, Biris AS, Shashkov EV et al. Complex

genetic, photothermal, and photoacoustic analysis of nanoparticle-plant interactions. Proceedings of the National Academy of Sciences 2011;108(3):1028-33.
17. Korishettar P, Vasudevan SN, Shakuntala NM, Doddagoudar SR, Hiregoudar S, Kisan B. Seed polymer coating with Zn and Fe nanoparticles: An innovative seed quality enhancement technique in pigeonpea. Journal of Applied and Natural Science 2016;8(1):445-50.
18. Lee SS, Kim JH. Total sugars, α-amylase activity, and germination after priming of normal and aged rice seeds. Korean Journal of Crop Science 2000;45(2):108-11.
19. Lin D, Xing B. Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. Environmental pollution 2007;150(2):243-50.
20. Lee CW, Mahendra S, Zodrow K, Li D, Tsai YC, Braam J, Alvarez PJ. Developmental phytotoxicity of metal oxide nanoparticles to Arabidopsis thaliana. Environmental Toxicology and Chemistry: An International Journal 2010;29(3):669-75.
21. Malik CP, Singh MB. Assay of peroxidase. Plant enzymology and histo-enzymology 1980. New Delhi: Kalyani publishers.
22. Miralles P, Church TL, Harris AT. Toxicity, uptake, and translocation of engineered nanomaterials in vascular plants. Environmental science & technology 2012;46(17):9224-39.
23. Monthioux M, Serp P, Caussat B, Flahaut E, Razafinimanana M, Valensi F et al. Carbon nanotubes. InSpringer Handbook of Nanotechnology Springer, Berlin, Heidelberg. 2017, pp. 193-247.
24. Mahakham W, Sarmah AK, Maensiri S, Theerakulpisut P. Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles. Scientific reports 2017;7(1):1-21.
25. Paul AK, Mukherji S, Sircar SM. Metabolic changes in rice seeds during storage. Indian Journal of Agricultural Science 1970;40(12):1031-6.
26. Pandey AC, S. Sanjay S, S. Yadav R. Application of ZnO nanoparticles in influencing the growth rate of Cicer arietinum. Journal of Experimental Nano science 2010;5(6):488-97.
27. Prasad TN, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR et al. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. Journal of plant nutrition 2012;35(6):905-27.
28. Paparella S, Araújo SS, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. Seed priming: state of the art and new perspectives. Plant cell reports 2015;34(8):1281-93.
29. Raja K, Sowmya R, Sudhagar R, Moorthy PS, Govindaraju K, Subramanian KS. Biogenic ZnO and Cu nanoparticles to improve seed germination quality in blackgram (*Vigna mungo*). Materials Letters 2019;235:164-7.
30. Senthilkumar S. Customizing nanoparticles for the maintenance of seed vigour and viability in blackgram (*Vigna Mungo*) Cv. VBN 4. M. Sc. (Agri.) Thesis. 2011.
31. Song U, Jun H, Waldman B, Roh J, Kim Y, Yi J, Lee EJ. Functional analyses of nanoparticle toxicity: a comparative study of the effects of TiO_2 and Ag on tomatoes (*Lycopersicon esculentum*). Ecotoxicology and environmental safety 2013;93:60-7.
32. Shyla KK, Natarajan N. Customizing zinc oxide, silver and titanium dioxide nanoparticles for enhancing groundnut seed quality. Indian Journal of Science and Technology 2014;7(9):1376-81.
33. Sheteiwy MS, Fu Y, Hu Q, Nawaz A, Guan Y *et al*. Seed priming with polyethylene glycol induces antioxidative defense and metabolic regulation of rice under nano-ZnO stress. Environmental Science and Pollution Research 2016;23(19):19989-20002.
34. Van Dongen JT, Ammerlaan AM, Wouterlood M, Van Aelst AC, Borstlap AC. Structure of the developing pea seed coat and the post-phloem transport pathway of nutrients. Annals of Botany 2003;91(6):729-37.
35. Vijayalaxmi V, Ramamoorthy K, Natarajan N. Effect of nanoparticle (TiO_2) on naturally aged seeds of maize (*Zea mays* L.). 13th Nation. Seed Sem., Innovations in Seed Research and Development, UAS, Bangalore 2013; 8(10):90.
36. Zuverza-Mena N, Martínez-Fernández D, Du W, Hernandez-Viezcas JA, Bonilla-Bird N, López-Moreno ML et al. Exposure of engineered nanomaterials to plants: Insights into the physiological and biochemical responses-A review. Plant Physiology and Biochemistry 2017;110:236-64