Augmentation of Seed Quality through Seed Priming with Nanoparticles in Groundnut (*Arachis hypogea* L)

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Received : April 2023
Accepted : July 2023

Abstract

An experiment was conducted to study the influence of seed treatment with nano particles on seed quality in groundnut at the Seed Technology Research Unit, All India Co-ordinated Research Project on Seed (Crops), University of Agricultural Sciences, Bangalore. Seeds of groundnut cv. KCG-6 were obtained from the Breeder Seed Production, Unit, GKVK, UAS, Bangalore. Then they were dried and shelled to get Sound Matured Kernels (SMK) and these SMKs were treated with different chemicals like SiO_2, TiO_2, ZnO, FeO and Sulphur in both in nano and bulk forms at different concentrations (0, 250, 500, 750 and 1000 ppm) and evaluated for various seed quality attributes in order to optimize the treatment protocol for nano priming besides to know the impact of nano chemicals on seed quality. The study revealed that dry dressing treatment with SiO_2 NPs @ 250 ppm recorded higher germination (100%), total dehydrogenase activity (2.57) and lowest electrical conductivity (225.20µS/cm) which was closely followed by SiO_2 NPs @ 500 ppm (99%, 2.52, 245.83µS/cm, respectively) when compared to untreated control (89%, 2.22 and 286.71µS/cm, respectively). Polymer coating treatments also exhibited better results, but relatively less compared to dry dressing treatments. Therefore, the findings suggested that seed treatment of nanoparticles in dry form improved seed quality of groundnut significantly.

Keywords : Groundnut, Nanoparticles, Nano priming, Seed quality

Groundnut (*Arachis hypogea* L.) belongs to the family Leguminosae and is a legume crop produced primarily for its edible seeds. The unpredictable legume groundnut is also known as monkey nut, peanut, earthnut and manilla nut. It is widely cultivated throughout the tropics and subtropics. It provides a major source of edible oil (48-50%) and protein (26-28%). It is also a rich source of dietary fibre, minerals and vitamins such as biotin, copper, niacin, folate, manganese, vitamin E, thiamine, phosphorus and magnesium (Bonku and Yu, 2020). It is primarily used as vegetable cooking oil and also used in soap making, manufacturing of cosmetics and lubricants, olein stearin and their salts. India stands first in terms of groundnut area with 4.89 million hectares accounting for 17.32 per cent of the world area and second in terms of production with 10.10 million tonnes accounting for 14.55 per cent of the world production and an average yield of 20.65 q/ha in India. It is grown in 0.57 million hectares with a production of 0.68 million tonnes and an average yield of 11.80 q/ha in Karnataka (Anonymous, 2020). In many parts of India, groundnut seed is usually stored for a period of about 8 to 9 months before sowing in the form of pods. However, seed viability and the vigour are getting lost quickly due to the production of free radicals by lipid peroxidation during storage (Konanki *et al*., 2019). As the most recent technologies available to prolong the vigour and viability of groundnut kernels on a large scale are not satisfactory, alleviating the practical problems of storage. Therefore, an alternative simple and practicable seed treatment technique(s) to control seed deterioration of groundnut seeds is the need of the hour. Several seed priming strategies like hydration and dehydration. halogenation, antioxidant treatments etc., require immediate sowing but does not allow storing of seeds for long period after priming.

Nanotechnology, a new emerging and fascinating field of science, permits advanced research in many areas and nano technological discoveries could open up novel applications in the field of agriculture. Nanoparticles helps in seed germination by activating hydrolytic enzymes involved in food mobilisation and facilitating water uptake by creating pores on the seed coat during penetration (Rame Gowda *et al.,* 2022). Additionally, it improves the absorption and utilisation of particles that are essential nutrients for plant growth and are important components of various enzymes that are responsible for driving many metabolic reactions in most of crops (Korishettar *et al*., 2016 and Sumalata *et al.,* 2017). The efficacy of nanoparticles is determined by their chemical composition, size, surface covering, reactivity and most importantly, the dose at which they are effective. Hence, standardizing the concentration and method of treatment for a particular crop plant is much more important in obtaining affirmative results (Surabhi *et al.,* 2018). Plants require micro elements in minute quantity for their growth and development, application of these elements in nano form can be cost effective, besides reducing the usage of pesticides drastically and it could be considered as eco-friendly approach. Nano SiO_2 and nano TiO_2 increases nitro reductase, also increases the seed germination and growth in groundnut crop. Nano-SiO_2, increased seed germination by way of providing better availability of nutrients with adequate pH and conductivity to the growing medium in maize seeds (Suriyaprabha *et al.*, 2012). Therefore, an effort was made to adopt seed treatment with nanoparticles and refinement of methodology to enhance seed quality in groundnut.

Material and Methods

Seeds : Freshly harvested pods of groundnut cv. KCG-6 were obtained from the Breeder Seed Production Unit, All India Co-ordinated Research Project on Seed (Crops), University of Agricultural Sciences, GKVK, Bengaluru. They were cleaned, dried and graded to obtain uniform and well filled pods. Then the Sound Matured Kernels (SMK) were separated manually and dried thoroughly for uniform moisture of 6 to 7 per cent. The SMKs were kept in an AC room where the temperature was 18 ± 2°C and the relative humidity was 40 to 45 per cent until further use.

Dry Treatment : The SMKs were treated with both nanoparticles and their bulk forms (commercially available) as dry treatment at different concentrations *viz*., Control (0), 250, 500, 750, 1000 ppm using CMC @ 2 per cent as binding agent and activated charcoal (1:3) as filler material for better and uniform coating of seeds with chemicals. The treated seeds were thoroughly mixed in glass jar for even and uniform coating and then shade dried for few hours and evaluated for various seed quality parameters.

Polymer Coating : The SMKs were coated with both nano and bulk forms of chemicals at different concentrations *viz*., Control (0), 250, 500, 750, 1000 ppm along with Hitron Polymer @ 3 ml/kg, subsequently polymer coated seeds were air dried overnight to bring back the seed moisture to safe level and evaluated for various seed quality parameters.

Experimental Details with Seed Treatment Combinations

Crop : Groundnut cv. KCG - 6

Chemicals : Five (both nano and bulk forms of SiO_2, TiO_2, ZnO, FeO and Sulphur)

Concentrations : Five (0, 250, 500, 750 and 1000 mg per kg seed)

Treatment methods : Two (dry dressing and polymer coating)

Treatment combinations : 5 x 4 x 2 x 2 = 100

Evaluation for Seed Quality Attributes

One hundred seeds with three replications were used to determine various quality aspects like standard germination (%) as per ISTA (2021), seedling length (cm), seedling vigour index-1 (Abdul-Baki and Anderson, 1973), total dehydrogenase activity at 480nm (Kittock and Law, 1968) and electrical conductivity (µS/cm). The mean data obtained on various observations were statistically analyzed by using suitable ANOVA. The critical differences were calculated at five per cent level of probability, wherever 'F' test was significant.

Results and Discussion

The seed treatment with dry form of SiO_2, TiO_2, ZnO, FeO and Sulphur (both nano and bulk) was carried out to know their effects on seed quality parameters in groundnut. Dry dressing seed treatment with nanoparticles and their bulk form showed improved seed quality parameters at various concentrations. Among the treatments maximum germination (100%) was observed in SiO_2 NPs @ 250 ppm which was on par with SiO_2NPs @ 500 ppm (99%), TiO_2 NPs @ 500 ppm (98%), TiO_2 NPs @ 750 ppm (98%), FeO NPs @ 250 ppm (98%) and followed by TiO_2 NPs @ 1000 ppm (97%) when compared to control (89%). Whereas, in polymer coating, seed treatment SiO_2 NPs @ 500 ppm recorded higher germination (96%) which was on par with TiO_2 NPs @ 500 ppm (95%), FeO NPs @ 750 ppm (95%), ZnO NPs @ 500 ppm (94%), FeO NPs @ 250 ppm (94%) compared to control (89%). Among the bulk particles, SiO_2 bulk @ 750 ppm, SiO_2 bulk @ 500 ppm, ZnO bulk @ 750 ppm recorded higher germination (91%) followed by TiO_2 bulk @ 750 ppm (90%) (Table 1). The increase in germination percentage due to SiO_2 NP noticed in the present study is in conformity with the report of Siddiqui and Al- Whabi (2014) in tomato.

In dry dressing seed treatment, FeO NPs @ 500 ppm recorded significantly higher seedling length (37.40 cm) which was followed by TiO_2 NPs @ 500 ppm (36.90 cm), ZnO NPs @ 750 ppm (36.27 cm) and SiO_2 NPs @ 750 ppm (35.63 cm) compared to control (29.97 cm). Whereas, in polymer coating seed treatment FeO NPs @ 500 ppm recorded higher seedling length (35.63 cm) which was followed by SiO_2 @ 500 ppm (35.53), SiO_2 @ 500 ppm (34.84 cm), SiO_2 @ 250 ppm (34.70), S NPs @ 250 (34.70 cm), FeO NPs @ 750 ppm (34.60 cm) and TiO_2 NPs @ 250 ppm (34.50 cm) compared to control (29.87 cm) (Table 2). Karunakaran *et al*. (2017) also noticed increased seedling length (cm) with iron oxide nanoparticles treatment when compared to control and Sundaria *et al*. (2019) also observed seed priming by iron oxide NPs improved shoot length and root length.

Nanoparticle treatment causes the formation of nanopores for uptake of nanoparticles (NPs), these pores facilitate the increased uptake of water by the seeds. Besides this, NPs induce enhancement in the expression of aquaporin genes and alteration in seed metabolism. Nanoparticle enhances oxidative respiration resulting in reactive oxygen species (ROS, e.g. superoxide radical ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2) generation (in oxidative window range) which act as signalling molecules to trigger germination-related metabolic processes (Schwab *et al.,* 2016). Superoxide dismutase (SOD) catalyses the conversion of $O_2^{\cdot-}$ to H_2O_2 followed by diffusion of H_2O_2 to embryo allowing interplay between H_2O_2 and phytohormone gibberellic acid (GA). GA activates α-amylase to fasten the hydrolysis of starch to highly soluble sugars for supporting growth of embryo and ultimately the seed germination and thereby seedling growth and vigour (Abou-Zeid and Ismail, 2018; Shukla *et al.,* 2019 and Panda & Mondal, 2020).

In dry dressing seed treatment, The FeO NPs @ 500 ppm recorded higher seedling vigour index-I (3653) which was on par with TiO_2 NPs @ 500 ppm (3638), ZnO NPs @ 250 ppm (3521), S NPs @ 250 ppm (3472), SiO_2 NPs @ 750 ppm (3469) compared to control (2666). Whereas, in polymer coating seed treatment SiO_2 NPs @ 500 ppm recorded higher seedling vigour index-I (3423) which was on par with TiO_2 NPs @ 500 ppm (3409), FeO NPs @ 750 ppm (3287), ZnO NPs @ 500 ppm (3251), SiO_2 NPs @ 250 ppm (3250) compared to control (2648) (Table 3). Nano-particle treatment boosts primary

TABLE 1

Germination (%) as influenced by seed treatment with chemicals by dry dressing and polymer coating in groundnut

Forms (F)	Dry Dressing					Mean	Forms (F)	Polymer coating					Mean
	SiO_2	TiO_2	ZnO	FeO	S			SiO_2	TiO_2	ZnO	FeO	S	
F_1	95	95	94	95	92	94	F_1	93	93	92	93	92	92
F_2	91	89	92	90	91	91	F_2	90	89	90	89	90	90
Mean	93	92	93	93	92	92	Mean	91	91	91	91	91	91
	Concentration (C)							Concentration (C)					
C_1	88	88	88	88	88	88	C_1	88	88	88	88	88	88
C_2	96	95	95	94	93	94	C_2	91	91	91	92	91	91
C_3	95	92	94	94	94	94	C_3	94	94	92	92	92	93
C_4	94	93	94	95	93	94	C_4	92	92	92	93	92	92
C_5	92	92	93	92	90	92	C_5	93	90	92	90	90	91
Mean	93	92	93	93	92	92	Mean	91	91	91	91	91	91
	Interaction (F × C)							Interaction (F × C)					
F_1C_1	89	89	89	89	89	89	F_1C_1	89	89	89	89	89	89
F_1C_2	100	95	96	98	91	96	F_1C_2	94	94	93	94	93	94
F_1C_3	99	98	95	98	93	97	F_1C_3	96	95	94	92	93	94
F_1C_4	93	98	95	95	96	95	F_1C_4	93	93	93	95	91	93
F_1C_5	95	97	95	94	92	95	F_1C_5	93	92	92	93	92	92
F_2C_1	87	87	87	87	87	87	F_2C_1	88	88	88	88	88	88
F_2C_2	88	95	93	90	95	92	F_2C_2	87	88	89	89	89	88
F_2C_3	93	85	93	91	94	91	F_2C_3	91	92	89	92	90	91
F_2C_4	96	89	93	94	91	92	F_2C_4	91	90	91	90	92	91
F_2C_5	89	90	92	89	88	90	F_2C_5	93	88	93	87	88	90
Mean	93	92	93	93	92	92	Mean	91	91	91	91	91	91

	S.Em ±	CD (0.05P)	CV (%)		S.Em ±	CD (0.05P)	CV (%)
F × N	0.266	0.74		F × N	0.304	0.85	
F × C	0.421	1.18	1.11	F × C	0.481	1.29	1.29
F× N × C	0.596	1.67		F× N × C	0.981	1.91	

Treatment details : Chemicals (N): SiO_2, TiO_2 ZnO, FeO, S; Forms: F_1: Nano form; F_2: Bulk form; Concentrations: C_1: Control; C_2:250 ppm; C_3: 500 ppm; C_4: 750 ppm; C_5:1000 ppm

metabolism to increase seedling vigour by accelerating α-amylase activity, which causes rapid starch degradation in germinating which results in higher seedling vigour. A high sugar concentration in the cells reduces osmotic potential and water potential, triggering seedling growth and accelerating vigour (Nile *et al.,* 2022).

In dry dressing seed treatment, SiO_2 NPs @ 250 ppm recorded lower electrical conductivity (225.20 µS/cm) which was on par with ZnO NPs @ 250 ppm (231.71 µS/cm), TiO_2 NPs @ 500 ppm (232.44 µS/cm), TiO_2 bulk @ 500 ppm (237.06 µS/cm), FeO NPs @ 500 ppm (237.30 µS/cm), S NPs @ 750 ppm (240.13 µS/cm) and control (286.71 µS/cm). Whereas, in polymer

TABLE 2

Mean Seedling length (cm) as influenced by seed treatment with chemicals by dry dressing and polymer coating in groundnut

Forms (F)	Dry Dressing					Mean	Forms (F)	Polymer coating					Mean
	SiO_2	TiO_2	ZnO	FeO	S			SiO_2	TiO_2	ZnO	FeO	S	
F_1	34.17	33.97	34.21	34.25	32.43	33.74	F_1	32.83	32.89	32.87	33.18	32.85	32.93
F_2	29.69	29.62	29.72	29.74	29.71	29.76	F_2	29.46	29.01	29.75	29.51	29.83	29.51
Mean	31.93	31.80	31.97	31.99	31.07	31.75	Mean	31.15	31.10	31.32	31.19	31.36	31.22
	Concentration (C)							Concentration (C)					
C_1	28.92	28.92	28.92	28.92	28.92	28.92	C_1	28.60	28.60	28.60	28.60	28.60	28.60
C_2	33.33	31.97	33.42	33.02	32.45	32.84	C_2	31.98	31.68	30.95	31.53	32.53	31.74
C_3	32.87	33.41	32.13	33.50	30.90	32.56	C_3	33.12	32.22	32.32	33.30	32.17	32.63
C_4	32.32	32.69	33.20	31.82	31.78	32.35	C_4	30.42	31.02	32.13	32.77	32.37	31.74
C_5	32.22	31.97	32.26	32.72	31.32	32.10	C_5	31.62	30.88	32.55	30.85	31.15	31.41
Mean	31.93	31.80	31.97	31.99	31.07	31.75	Mean	31.15	31.10	31.32	31.19	31.36	31.22
	Interaction (F × C)							Interaction (F × C)					
F_1C_1	29.97	29.97	29.97	29.97	29.97	29.97	F_1C_1	29.87	29.87	29.87	29.87	29.87	29.87
F_1C_2	37.00	34.95	34.30	34.25	34.83	35.02	F_1C_2	34.70	34.50	33.17	34.03	34.70	34.22
F_1C_3	34.30	36.90	33.83	37.40	31.90	34.89	F_1C_3	35.53	34.84	34.47	35.63	34.03	34.50
F_1C_4	35.63	33.87	36.27	34.67	32.63	34.57	F_1C_4	31.73	32.43	33.97	34.60	32.70	33.09
F_1C_5	34.33	34.27	34.90	33.90	32.83	34.27	F_1C_5	32.33	33.47	32.97	33.03	33.17	32.99
F_2C_1	27.87	27.87	27.87	27.87	27.87	27.87	F_2C_1	27.33	27.33	27.33	27.33	27.33	27.33
F_2C_2	30.03	29.97	30.37	31.43	30.07	30.65	F_2C_2	29.27	28.87	28.73	29.03	30.37	29.25
F_2C_3	31.27	29.70	30.43	29.60	29.90	30.24	F_2C_3	30.70	30.93	30.23	31.60	30.30	30.76
F_2C_4	29.00	30.63	30.93	31.97	30.93	30.13	F_2C_4	29.10	29.60	30.30	30.97	32.03	30.39
F_2C_5	30.10	29.63	29.67	30.43	29.80	29.93	F_2C_5	30.90	28.30	32.13	28.67	29.13	29.83
Mean	31.93	31.80	31.97	31.99	31.07	31.75	Mean	31.15	31.10	31.32	31.19	31.36	31.22

	S.Em ±	CD (0.05P)	CV (%)		S.Em ±	CD (0.05P)	CV (%)
F × N	0.240	0.67		F × N	0.166	0.46	
F × C	0.380	1.06	2.93	F × C	0.263	0.74	2.07
F× N × C	0.538	1.51		F× N × C	0.373	1.04	

Treatment details : Chemicals (N): SiO_2, TiO_2, ZnO, FeO, S; Forms: F_1: Nano form; F_2: Bulk form; Concentrations: C_1: Control; C_2:250 ppm; C_3: 500 ppm; C_4: 750 ppm; C_5:1000 ppm

coating seed treatment, SiO_2 NPs @ 500 ppm recorded lower electrical conductivity (238.73) which was on par with SiO_2 NPs @ 250 ppm (242.05), TiO_2 NPs @ 500 ppm (242.65), SiO_2 bulk @ 1000 ppm (244.90), ZnO bulk @ 1000 ppm (244.82), TiO_2 NPs @ 500 ppm (247.02), S bulk @ 750 ppm (247.58) and control (286.71) (Table 4). The minimum value of electrical conductivity in nanoparticle treated seeds is because of the quenching of free radicals which consequently maintains the integrity of membrane (Kumar *et al.*, 2020). Nanoparticles at lower concentrations exhibited no detrimental effects on the seed surface,

TABLE 3

Seedling vigour index-1 as influenced by seed treatment with chemicals by dry dressing and polymer coating in groundnut

Forms (F)	Dry Dressing					Mean	Forms (F)	Polymer coating					Mean
	SiO_2	TiO_2	ZnO	FeO	S			SiO_2	TiO_2	ZnO	FeO	S	
F_1	3123	3230	3216	3270	3092	3186	F_1	3054	3081	3033	3050	3013	3046
F_2	2748	2653	2720	2678	2692	2698	F_2	2654	2594	2676	2635	2678	2647
Mean	2936	2961	2968	2954	2892	2942	Mean	2854	2837	2854	2842	2846	2847
	Concentration (C)							Concentration (C)					
C_1	2550	2550	2550	2550	2550	2550	C_1	2522	2522	2522	2522	2522	2522
C_2	3109	3126	3162	3026	3054	3095	C2	2903	2891	2822	2893	2970	2896
C_3	3009	3099	3094	3168	2959	3066	C_3	3113	3139	2976	2974	2946	3030
C_4	3101	2977	3030	3086	3002	3039	C_4	2795	2845	2947	3036	2983	2921
C_5	2910	3056	3005	2941	2896	2961	C_5	2935	2790	3005	2788	2807	2865
Mean	2936	2961	2968	2954	2892	2942	Mean	2854	2837	2854	2842	2846	2847
	Interaction (F × C)							Interaction (F × C)					
F_1C_1	2666	2666	2666	2666	2666	2666	F_1C_1	2648	2648	2648	2648	2648	2648
F_1C_2	3134	3276	3521	3399	3472	3360	F_1C_2	3250	3232	3095	3210	3239	3205
F_1C_3	3146	3638	3270	3653	3147	3371	F_1C_3	3423	3409	3251	3031	3165	3256
F_1C_4	3469	3386	3373	3187	3046	3292	F_1C_4	2940	3027	3148	3287	2976	3075
F_1C_5	3200	3383	3250	3244	3130	3241	F_1C_5	3007	3090	3022	3072	3040	3046
F_2C_1	2434	2434	2434	2434	2434	2434	F_2C_1	2396	2396	2396	2396	2396	2396
F_2C_2	3085	2976	2803	2653	2636	2830	F_2C_2	2556	2550	2548	2575	2702	2586
F_2C_3	2871	2560	2918	2684	2770	2761	F_2C_3	2870	2804	2701	2735	2727	2804
F_2C_4	2732	2568	2687	2984	2959	2786	F_2C_4	2649	2664	2747	2918	2990	2767
F_2C_5	2620	2728	2760	2638	2661	2681	F_2C_5	2863	2490	2988	2503	2573	2684
Mean	2936	2961	2968	2954	2892	2942	Mean	2854	2837	2854	2842	2846	2847

	S.Em ±	CD (0.05P)	CV (%)		S.Em ±	CD (0.05P)	CV (%)
F × N	22.23	62.37		F × N	16.05	45.05	
F × C	35.15	98.61	2.92	F × C	25.39	71.24	2.18
F× N × C	49.71	139.46		F× N × C	35.91	100.75	

Treatment details : Chemicals (N): SiO_2, TiO_2, ZnO, FeO, S; Forms: F_1: Nano form; F_2: Bulk form; Concentrations: C_1: Control; C_2:250 ppm; C_3: 500 ppm; C_4: 750 ppm; C_5:1000 ppm

hence reducing solute/electrolyte leakage from the seeds.

In dry dressing seed treatment, SiO_2 NPs @ 250 ppm recorded higher total dehydrogenase activity (2.57) which was on par with FeO bulk @ 750 ppm (2.56) and followed by SiO_2 bulk @ 250 ppm (2.54), ZnO NPs @ 750 ppm (2.53), SiO_2 NPs @ 500 ppm (2.52) and control (2.22). Whereas, in polymer coating seed treatment, SiO_2 NPs @ 500 ppm recorded higher total dehydrogenase activity (2.65) which was on par with SiO_2 bulk @ 500 ppm (2.63), ZnO NPs @500

TABLE 4

Electrical conductivity (µS/cm) as influenced by seed treatment with chemicals by dry dressing and polymer coating in

Forms (F)	Dry Dressing					Mean	Forms (F)	Polymer coating					Mean
	SiO_2	TiO_2	ZnO	FeO	S			SiO_2	TiO_2	ZnO	FeO	S	
F_1	246.59	257.23	255.37	254.58	259.47	255.91	F_1	255.55	257.42	260.80	266.75	265.47	261.60
F_2	252.88	254.22	258.07	257.65	260.23	255.35	F_2	263.12	268.39	261.28	261.72	262.83	263.47
Mean	249.74	255.73	256.72	256.12	259.85	255.63	Mean	261.27	261.97	261.04	264.23	264.15	262.53
	Concentration (C)							Concentration (C)					
C_1	278.84	278.84	278.84	278.84	278.84	278.84	C_1	287.79	287.79	287.79	287.79	287.79	287.79
C_2	239.43	243.75	249.49	254.90	247.86	247.09	C_2	254.91	255.30	259.73	257.41	255.56	256.58
C_3	243.46	239.85	254.05	239.48	257.02	246.77	C_3	243.84	245.57	257.14	259.78	251.87	251.64
C_4	239.55	257.73	249.47	250.07	250.35	249.43	C_4	263.32	256.93	250.77	252.39	256.19	255.92
C_5	247.40	258.48	251.76	257.31	265.18	256.03	C_5	254.51	266.27	249.80	263.81	269.34	260.75
Mean	249.74	255.73	256.72	256.12	259.85	255.63	Mean	261.27	261.97	261.04	264.23	264.15	262.53
	Interaction (F × C)							Interaction (F × C)					
F_1C_1	286.71	286.71	286.71	286.71	286.71	286.71	F_1C_1	286.71	286.71	286.71	286.71	286.71	286.71
F_1C_2	225.20	250.44	231.71	249.47	248.20	243.43	F_1C_2	242.05	242.65	258.56	254.48	251.90	250.80
F_1C_3	245.83	232.44	256.76	237.30	260.92	244.83	F_1C_3	238.73	247.02	251.17	271.08	254.32	251.59
F_1C_4	245.03	256.86	243.64	255.45	240.13	248.22	F_1C_4	256.64	254.14	252.81	252.40	264.80	256.16
F_1C_5	249.53	259.72	255.02	256.07	261.37	256.34	F_1C_5	264.13	256.11	254.77	269.07	269.62	262.74
F_2C_1	270.96	270.96	270.96	270.96	270.96	270.96	F_2C_1	288.87	270.96	270.96	270.96	270.96	270.96
F_2C_2	241.57	237.06	267.27	260.34	247.52	250.75	F_2C_2	262.79	268.54	260.90	260.34	259.21	262.35
F_2C_3	241.08	247.26	248.34	253.75	253.11	248.71	F_2C_3	249.02	248.40	263.10	248.47	249.41	251.68
F_2C_4	234.06	258.60	255.30	244.68	260.56	250.64	F_2C_4	270.00	259.71	248.72	252.38	247.58	255.68
F_2C_5	245.28	257.24	248.49	258.55	268.99	255.71	F_2C_5	244.90	276.44	244.82	258.55	269.06	258.75
Mean	249.74	255.73	256.72	256.12	259.85	255.63	Mean	261.27	261.97	261.04	264.23	264.15	262.53

	S.Em ±	CD (0.05P)	CV (%)		S.Em ±	CD (0.05P)	CV (%)
F × N	0.165	4.63		F × N	1.769	4.96	
F × C	2.609	7.32	2.50	F × C	2.797	7.85	2.61
F× N × C	3.690	10.35		F× N × C	3.956	10.10	

Treatment details : Chemicals (N): SiO_2, TiO_2, ZnO, FeO, S; Forms: F_1: Nano form; F_2: Bulk form; Concentrations: C_1: Control; C_2:250 ppm; C_3: 500 ppm; C_4: 750 ppm; C_5:1000 ppm

ppm (2.62), FeO bulk @ 500 ppm (2.61) and control (2.2) (Table 5). The enhanced dehydrogenase enzyme activity in nanoparticle treated seeds could be due to the important metal micronutrients which acts as cofactors for most of the enzyme complexes particularly the dehydrogenase which is involved in respiration and food mobilization in seeds. The enhanced availability of the micronutrients at nano scale along with its increased chemical reactivity showed the increased synthesis and activity of dehydrogenase enzymes (Burgass and Powell, 1984).

Among the dry dressing and polymer coating treatments, dry dressing treatments demonstrated

Table 5

Total dehydrogenase activity as influenced by seed treatment with chemicals by dry dressing and polymer coating in

Forms (F)	Dry Dressing					Mean	Forms (F)	Polymer coating					Mean
	SiO_2	TiO_2	ZnO	FeO	S			SiO_2	TiO_2	ZnO	FeO	S	
F_1	2.38	2.34	2.34	2.37	2.21	2.33	F_1	2.45	2.40	2.44	2.43	2.43	2.43
F_2	2.40	2.38	2.39	2.40	2.37	2.39	F_2	2.46	2.41	2.48	2.45	2.48	2.46
Mean	2.39	2.37	2.36	2.38	2.29	2.36	Mean	2.45	2.40	2.46	2.44	2.46	2.44
			Concentration (C)							Concentration (C)			
C_1	2.26	2.26	2.26	2.26	2.26	2.26	C_1	2.27	2.27	2.27	2.27	2.27	2.27
C_2	2.56	2.28	2.22	2.43	2.21	2.56	C_2	2.48	2.41	2.42	2.42	2.55	2.46
C_3	2.44	2.29	2.46	2.29	2.27	2.44	C_3	2.59	2.48	2.57	2.51	2.53	2.54
C_4	2.29	2.44	2.45	2.49	2.41	2.29	C_4	2.57	2.39	2.53	2.49	2.48	2.49
C_5	2.38	2.40	2.43	2.44	2.30	2.38	C_5	2.43	2.46	2.52	2.44	2.44	2.46
Mean	2.39	2.37	2.36	2.38	2.29	2.36	Mean	2.45	2.40	2.46	2.44	2.46	2.44
			Interaction (F × C)							Interaction (F × C)			
F_1C_1	2.22	2.22	2.22	2.22	2.22	2.22	F_1C_1	2.22	2.22	2.22	2.22	2.22	2.22
F_1C_2	2.57	2.34	2.09	2.48	2.04	2.30	F_1C_2	2.52	2.43	2.41	2.54	2.60	2.49
F_1C_3	2.52	2.20	2.39	2.21	2.21	2.31	F_1C_3	2.65	2.53	2.62	2.40	2.52	2.52
F_1C_4	2.19	2.50	2.53	2.41	2.23	2.37	F_1C_4	2.40	2.41	2.52	2.47	2.37	2.48
F_1C_5	2.42	2.42	2.44	2.51	2.32	2.42	F_1C_5	2.49	2.40	2.46	2.45	2.44	2.45
F_2C_1	2.30	2.51	2.30	2.30	2.30	2.36	F_2C_1	2.32	2.32	2.32	2.32	2.32	2.32
F_2C_2	2.54	2.23	2.35	2.38	2.38	2.38	F_2C_2	2.45	2.40	2.44	2.37	2.50	2.43
F_2C_3	2.37	2.38	2.53	2.38	2.33	2.40	F_2C_3	2.63	2.44	2.52	2.61	2.54	2.56
F_2C_4	2.39	2.38	2.37	2.56	2.59	2.46	F_2C_4	2.52	2.37	2.54	2.52	2.60	2.51
F_2C_5	2.33	2.38	2.42	2.37	2.28	2.36	F_2C_5	2.37	2.53	2.58	2.42	2.44	2.47
Mean	2.39	2.37	2.36	2.38	2.29	2.36	Mean	2.45	2.40	2.46	2.44	2.46	2.44
	S.Em ±		CD (0.05P)	CV (%)				S.Em ±		CD (0.05P)		CV (%)	
F × N	0.019		0.05				F × N	0.012			0.03		
F × C	0.017		0.04			2.46	F × C	0.020			0.05		2.00
F× N × C	0.037		0.10				F× N × C	0.028			0.07		

Treatment details : Chemicals (N): SiO_2, TiO_2 ZnO, FeO, S; Forms: F_1: Nano form; F_2: Bulk form; Concentrations: C_1: Control; C_2:250 ppm; C_3: 500 ppm; C_4: 750 ppm; C_5:1000 ppm

better results compared to polymer coating seed treatment, which may be due to the polymer we used was bit old. But in general, the shelf life of most of polymers is one year in unopened containers.

Results concluded that dry dressing seed treatment with certain optimum concentration of nanoparticles showed improved seed quality parameters. Among the treatments, maximum germination, total dehydrogenase activity and lower electrical conductivity were recorded with SiO_2NPs @ 250 ppm (100%, 2.57 and 225.20µS/cm) and higher seedling length, seedling vigour index-I were recorded with FeO NPs @ 500 ppm (37.40 cm and 3653). Polymer coating seed treatment also showed better results over untreated seeds but less compared to dry dressing treatments. Further investigations are required to understand the positive and negative impacts on the crop metabolism and soil health. Studies on the safe use and disposal, its impact on the environment and human health shall also be a concern although the technology found useful in enhancing quality of seeds.

Acknowledgements : The authors are highly grateful to the Indian Council of Agricultural Research, New Delhi for funding the research project through Emeritus Scientist Scheme and to conduct research at the Seed Technology Research Unit, AICRP on Seed (Crops), University of Agricultural Sciences, GKVK, Bengaluru.

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