Seed Res. 50 (2): 128-136, December, 2022

Influence of Seed Treatment with Nanoparticles on Seed Quality and Storability of Groundnut Kernel cv. Kadiri Lepakshi (K-1812)

ZAHEDA BANU V[1*], RAME GOWDA[1], BASAVE GOWDA[1], NETHRA, N[1] AND NANDINI, R[1]

[1]Department of Seed Science and Technology, University of Agricultural Sciences,
GKVK Campus, Bengaluru, Karnataka-560065, India
*zahedabanuv277@gmail.com

(Received August 2022; Revised September 2022; Accepted September 2022)

ABSTRACT: A laboratory experiment was conducted to study the influence of seed treatment with nanoparticles on seed quality and storability of groundnut at the Seed Technology Research Unit, AICRP on Seed (Crops), University of Agricultural Sciences, Bangalore. Slightly aged seeds of groundnut *cv*. Kadiri Lepakshi (K-1812) obtained from the Dryland Agricultural Project, UAS, Bangalore were treated with SiO_2, $TiO_2$and FeO in both nano and bulk forms, kernels packed in cloth bag, under ambient conditions. Results revealed significant effect of nanoparticles on seed quality and storability in groundnut. Among the treatment combinations, dry dressing treatment with SiO_2 NPs@250 ppm recorded higher germination (99, 89,72%), field emergence (90, 80 and 63%) and lower seed moisture content (5.21, 5.75 and 7.42 %) and seed infection (1.33, 8.00 and 25.33 %)at 0, 3 and 6 months of storage followed by SiO_2 NPs@500 ppm. Polymer coating treatment also showed better results, but less compared to dry treatment. Polymer coating treatment with SiO_2 NPs@500ppm recorded higher germination (96, 85, 64 %), field emergence (86, 74 and 57 %) and lower seed moisture content (5.45, 5.98 and 7.81 %) and seed infection (1.33, 9.33 and 26.67 %) at 0, 3 and 6 months of storage. As a consequence, the findings revealed the positive influence of nanoparticles and therefore, could be used as safe seed treatment method to enhance seed quality and storability of groundnut kernels.

Keywords: Nanoparticles, groundnut kernel, seed quality and storability

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) belongs to the family Leguminosae, is a legume crop produced primarily for its edible seeds. India occupies first position in area and second position in production of groundnut after soybean but productivity is low, which needs a greater attention. The low productivity of groundnut is mainly attributed by different factors such as cultivation of crop on marginal and sub marginal lands, uncertain monsoon leading to frequent drought, poor adaptation of improved agronomic practices and inadequate availability of improved varieties of quality seeds.

Seed is a key input which decides the crop stand and yield under varied conditions. 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[1]. The storage potential of any seed depends on several factors like type of seed, period of storage, chemical composition, seed treatment, seed moisture, temperature and storage containers [2].The seed deterioration is inevitable, irreversible and inexorable but it can be delayed to some extent by proper management practices like preservation under controlled conditions and by advocating some seed in vigouration treatments [3]. As the most recent technologies available to prolong the vigour and viability of groundnut kernels on a large scale are not satisfactorily 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 strategies such as hydration and dehydration, halogenations, antioxidant treatments and seed disinfection technologies available to prolong the vigour and viability of seeds but does not allow storing of seeds for longer period and may also cause damage to seed coat. Thus, an improved seed in vigouration treatments in both fresh and old seeds to improve seed viability and vigour during storage is essential.

Nanotechnology is an emerging and fascinating field of science which permits novel applications in the field of agriculture and other disciplines. Preliminary studies showed the potential of nanoparticles (NPs) in improving seed germination and growth, plant protection, pathogen detection, and pesticide/herbicide residue detection [4]. In seed science research, nanotechnology tools offer application of various nanoparticles for improvement of seed germination and related physiological parameters, nano membranes and nano polymer coating to enhance the storability of the seeds by in corporation of pesticides, nanosensors for better management of seed infestation during storage and incorporation of novel genes into seeds for specific trait [5].

Silicon is one of the most widespread macro elements, numerous field studies have shown that supplying crops with adequate plant available silicon can suppress plant disease, reduce insect attack, improve environmental stress tolerance and increase crop productivity. Nano silicondioxide (SiO_2) results in increased seed germination by providing better nutrients availability with adequate pH and conductivity to the growing medium in maize seeds [6]. Therefore, an effort was made to adopt an advanced third generation seed treatment with nanoparticles to enhance seed quality parameters and to prolong seed viability/shelf life in groundnut during storage under ambient conditions.

MATERIAL AND METHODS

The storage study was carried out at the Seed Technology Research Unit, AICRP on Seed (Crops), University of Agricultural Sciences, Bangalore during 2022.

Seeds: Pods of groundnut cv. Kadiri Lepakshi (K-1812) were obtained from the Dryland Agricultural Project, UAS, Bangalore. They were cleaned, dried and graded to obtain uniform and well filled pods and cloth bags were obtained from AICRP on Seed (Crops), University of Agricultural Sciences, Bangalore.

Nanochemicals: Silicon dioxide (SiO_2), Titanium dioxide (TiO_2) and Iron oxide (FeO) in both bulk and nano forms were obtained from the Sigma-Aldrich whose particle size was less than 100 nm.

Dry treatment: The SMKs were treated with both nanoparticles and their bulk forms as dry treatment at different concentrations using CMC @ 2% 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 form of chemicals at different concentrations along with Hitron Polymer @ 3 ml/kg, subsequently polymer coated seeds were air dried overnight bring back to uniform and safe moisture level and evaluated for various seed quality parameters.

Stored under ambient conditions where the maximum temperature was 29.51°C and minimum temperature was 17.53°C and mean relative humidity of 87.43% and 52.00% at 07.00hr and 14.00hr, respectively for a period of six months (Feb – Aug, 2022). Further, various seed quality tests were conducted on monthly basis.

Experimental details

Chemicals: Three (SiO_2, TiO_2 and FeO)

Form of chemicals: Two (bulk and nano)

Concentrations: Two

Treatment methods: Two (dry dressing and polymer coating)

Treatment combinations: 3 x 2 x 2 x 2= 24 with a control

The seed moisture content (%), germination (%), seed infection (%) and electrical conductivity (µS/cm) were recorded as per ISTA[7]; field emergence (%) was also recorded by planting 100 seeds in three replications on a well-prepared seed bed with adequate moisture and final count was taken on 15th day taking into account emergence of normal seedlings and expressed in percentage.

The mean data of the storage experiment were statistically analyzed adopting completely randomized design with suitable ANOVA as outlined by Panse and Sukhatme [8]. The critical differences were calculated at five per cent level of probability wherever 'F' test was found significant for various seed quality parameters under the study.

RESULTS AND DISCUSSION

Results of the present investigation showed that seed treatment with nanoparticles had significant influence on seed quality parameters in groundnut. Dry dressing seed treatment with nanoparticles and their bulk form showed improved seed quality parameters at various concentrations. In dry dressing seed treatment, in the beginning of the storage month, there was a significant difference between the treatments for seed moisture content with SiO_2NPs @ 250 ppm gained lowest seed moisture content (5.21%) followed by SiO_2NPs @ 500 ppm (5.24%) and SiO_2B @ 500 ppm (5.25%) while the highest moisture content was noted in untreated seeds (5.44%). At the end of the storage period, SiO_2NPs @ 250 ppm recorded significantly lower seed moisture content (7.42%) followed by SiO_2NPs @ 500 ppm (7.47%) and SiO_2B @ 500 ppm (7.48%), while the untreated seeds gained slightly higher moisture content (8.05%). However, in polymer coating seed treatments, lower moisture content (5.45%) was recorded in SiO_2NPs @ 500 ppm, followed by SiO_2NPs @ 250 ppm (5.46%) and SiO_2B @ 500 ppm (5.49%). While the higher moisture content was recorded in FeO B @ 250 ppm (5.62%). At the end of the storage period, SiO_2NPs @ 500 ppm recorded significantly lower seed moisture content (7.81%) followed by SiO_2NPs @ 250 ppm (7.83%), while it was highest in FeO B @ 250 ppm (8.07%) compared to other treatments (Table 1a and 1b). Nevertheless, not

Table 1a. Influence of seed treatment with nano and bulk form of chemicals through dry dressing on seed moisture content (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	5.47	5.60	5.85	6.01	6.69	7.36	8.05	6.43
T_1- SiO_2 NPs @ 250 ppm	5.21	5.27	5.45	5.75	6.19	6.71	7.42	6.00
T_2- SiO_2 NPs @ 500 ppm	5.24	5.31	5.50	5.79	6.24	6.75	7.47	6.04
T_3- TiO_2 NPs @ 500 ppm	5.27	5.33	5.54	5.85	6.27	6.80	7.51	6.08
T_4- TiO_2 NPs @ 750 ppm	5.32	5.39	5.58	5.89	6.34	6.85	7.57	6.13
T_5- FeO NPs @ 250 ppm	5.34	5.42	5.61	5.91	6.37	6.87	7.58	6.16
T_6- FeO NPs @ 500 ppm	5.36	5.43	5.65	5.92	6.40	6.90	7.61	6.18
T_7- SiO_2 B @ 500 ppm	5.25	5.33	5.49	5.78	6.25	6.78	7.48	6.05
T_8- SiO_2B @ 750 ppm	5.29	5.38	5.54	5.82	6.30	6.83	7.54	6.10
T_9- TiO_2 B @ 250 ppm	5.31	5.39	5.57	5.84	6.32	6.85	7.55	6.12
T_{10}- TiO_2 B @ 1000 ppm	5.36	5.45	5.61	5.92	6.43	6.93	7.67	6.20
T_{11}- FeO B @ 500 ppm	5.41	5.50	5.66	5.98	6.47	6.97	7.71	6.24
T_{12}- FeO B @ 750 ppm	5.38	5.45	5.64	5.94	6.45	6.96	7.69	6.22
Mean	5.32	5.40	5.59	5.88	6.36	6.89	7.60	6.15
S.Em ±	0.03	0.03	0.04	0.03	0.04	0.07	0.06	
CD (0.05P)	0.08	0.08	0.09	0.09	0.10	0.19	0.17	
CV (%)	0.88	0.90	1.00	0.89	0.95	1.69	1.34	

Table 1b. Influence of seed treatment with nano and bulk form of chemicals through polymer coating on seed moisture content (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	5.47	5.60	5.85	6.01	6.69	7.36	8.05	6.43
T_1- SiO_2 NPs @ 250 ppm	5.46	5.53	5.73	6.02	6.47	7.01	7.83	6.29
T_2- SiO_2 NPs @ 500 ppm	5.45	5.70	5.81	5.98	6.45	6.97	7.81	6.31
T_3- TiO_2 NPs @ 250 ppm	5.55	5.62	5.81	6.11	6.56	7.16	7.97	6.40
T_4- TiO_2 NPs @ 500 ppm	5.51	5.58	5.76	6.05	6.51	7.10	7.89	6.34
T_5- FeO NPs @ 250 ppm	5.57	5.64	5.84	6.13	6.59	7.20	7.98	6.42
T_6- FeO NPs @ 500 ppm	5.59	5.65	5.86	6.15	6.62	7.21	8.02	6.44
T_7- SiO_2 B @ 500 ppm	5.49	5.55	5.74	6.02	6.49	7.04	7.86	6.31
T_8- SiO_2 B @ 1000 ppm	5.51	5.59	5.77	6.06	6.52	7.12	7.91	6.35
T_9- TiO_2 B @ 500 ppm	5.53	5.61	5.79	6.09	6.55	7.14	7.95	6.38
T_{10}- TiO_2 B @ 750 ppm	5.57	5.66	5.83	6.14	6.58	7.18	7.99	6.42
T_{11}- FeO B @ 250 ppm	5.62	5.72	5.91	6.21	6.68	7.26	8.07	6.50
T_{12}- FeO B @ 750 ppm	5.59	5.67	5.88	6.17	6.67	7.23	8.04	6.46
Mean	5.53	5.62	5.80	6.08	6.57	7.15	7.95	6.39
S.Em ±	0.05	0.03	0.04	0.03	0.06	0.04	0.05	
CD (0.05P)	0.13	0.09	0.11	0.09	0.17	0.11	0.16	
CV (%)	1.44	0.92	1.14	0.91	1.59	0.89	1.17	

much changes have been noticed in seed moisture content due to treatments during storage. The moisture content of seed increased as the storage period advanced which may be due to fluctuations in relative humidity and temperature in the surrounding environmental conditions since the seeds were stored in the cloth bag that might have result in metabolic release of water during respiration. The fluctuation of moisture content was significantly higher in untreated seeds compared to nanoparticle treated seeds. Probably the nanoparticles might have acted as physical barrier, which is assumed to restrict the movement of water vapour in and out of the treated seeds and hence, reduced the fluctuation of moisture content during the storage. Similar observations were reported by Chandravathi [9] in pearl millet and Hanegavi [10] in maize.

A significant influence on seed germination percentage by seed treatment with nanoparticles was observed during storage period of six months (Table 2a and 2b). In dry dressing treatment, in the initial month of storage, significantly higher germination was observed in SiO_2 NPs @ 250 ppm (99%) and it was statistically on par with SiO_2 NPs @ 500 ppm (98%), TiO_2 NPs @ 500 ppm (97%) and FeO NPs @ 250 ppm (97%), while the lowest germination was recorded in control (89%). Similar trend was noticed at all months of storage period, at the end of six months of storage period, highest germination was recorded in SiO_2 NPs @ 250 ppm (72%) which was on par with SiO_2 NPs @ 500 ppm (71%) followed by TiO_2 NPs @ 500 ppm (68%) and lowest was in control (59%). Whereas, in polymer coating seed treatment, in the initial month of storage, treatments varied considerably for seed germination (%). The highest germination was recorded in treatment SiO_2 NPs @ 500 ppm (96%) and it was statistically on par with TiO_2 NPs @ 500 ppm (95%) and FeO NPs @ 500 ppm (94%)while the lowest germination was recorded in the treatment FeO B @ 250 ppm (88%). At the end of six months of storage period the germination was higher in SiO_2 NPs @ 500 ppm(64%) which was on par with TiO_2 NPs @ 500 ppm (63%) followed by FeO NPs @ 500 ppm (62%) and lowest germination was observed in treatment FeO B @ 250 ppm (52%).

The decline in germination percentage may be attributed to ageing leading to depletion of food reserves and decline in enzymatic activity of seed due to fungal invasion [11]. The SiO_2 NPs consistently maintained higher germination over control during storage. The reason might be that NPs would have induced oxidation-reduction reactions via the superoxide ion radicals during germination, resulting the quenching of free radicals in the aged seeds. In turn, oxygen produced in such process could also be used for respiration, which would further promote germination [12].

Irrespective of the treatments, field emergence (%) declined gradually with the advancement of storage

Table 2a. Influence of seed treatment with nano and bulk form of chemicals through dry dressing on germination (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	89	87	84	79	75	68	59	77
T_1- SiO_2 NPs @ 250 ppm	99	97	94	89	86	80	72	88
T_2- SiO_2 NPs @ 500 ppm	98	96	93	88	84	79	71	87
T_3- TiO_2 NPs @ 500 ppm	97	95	92	87	82	76	68	85
T_4- TiO_2 NPs @ 750 ppm	96	93	89	86	79	72	65	83
T_5- FeO NPs @ 250 ppm	97	94	91	86	81	75	67	84
T_6- FeO NPs @ 500 ppm	96	93	90	85	78	72	64	83
T_7- SiO_2 B @ 500 ppm	92	90	87	82	77	70	61	80
T_8- SiO_2B @ 750 ppm	95	93	90	85	78	71	64	82
T_9- TiO_2 B @ 250 ppm	94	92	89	84	78	71	63	82
T_{10}- TiO_2 B @ 1000 ppm	90	88	85	79	71	68	60	77
T_{11}- FeO B @ 500 ppm	91	89	86	80	73	69	60	78
T_{12}- FeO B @ 750 ppm	93	91	88	84	78	70	62	81
Mean	94	92	89	84	78	72	64	82
S.Em ±	0.44	0.56	0.57	0.53	0.59	0.47	0.58	
CD (0.05P)	1.28	1.63	1.66	1.53	1.73	1.38	1.68	
CV (%)	0.81	1.06	1.12	1.08	1.31	1.21	1.56	

Table 2b. Influence of seed treatment with nano and bulk form of chemicals through polymer coating on germination (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	89	87	84	79	75	68	59	77
T_1- SiO_2 NPs @ 250 ppm	93	90	88	82	77	70	61	80
T_2- SiO_2 NPs @ 500 ppm	96	94	90	85	80	73	64	83
T_3- TiO_2 NPs @ 250 ppm	93	90	86	82	76	69	60	79
T_4- TiO_2 NPs @ 500 ppm	95	93	89	84	79	72	63	82
T_5- FeO NPs @ 250 ppm	92	89	86	81	76	68	60	79
T_6- FeO NPs @ 500 ppm	94	92	89	83	78	71	62	81
T_7- SiO_2 B @ 500 ppm	91	87	84	78	73	65	57	76
T_8- SiO_2 B @ 1000 ppm	92	89	85	80	75	67	59	78
T_9- TiO_2 B @ 500 ppm	92	88	85	79	74	66	58	77
T_{10}- TiO_2 B @ 750 ppm	90	86	84	76	72	63	55	75
T_{11}- FeO B @ 250 ppm	88	85	82	78	70	62	52	74
T_{12}- FeO B @ 750 ppm	90	85	83	79	71	63	54	75
Mean	92	88	85	80	74	67	59	78
S.Em ±	0.68	0.86	0.52	0.65	0.68	0.61	0.65	
CD (0.05P)	1.99	2.49	1.51	1.89	1.99	1.77	1.89	
CV (%)	1.29	1.67	1.05	1.40	1.58	1.57	1.92	

period (Table 3a and 3b). In dry dressing seed treatments, at the initial month of storage among different treatments, highest field emergence was recorded in SiO_2 NPs @ 250 ppm (90 %) which was statistically on par with SiO_2 NPs @ 500 ppm (88%) andTiO_2 NPs @ 500 ppm (87%), while it was lowest in control (78%). At the end of storage period, highest field emergence was recorded in SiO_2 NPs @ 250 ppm (63 %) followed by SiO_2 NPs @ 500 ppm (62 %) and lowest was in control (53%).Whereas, in polymer coating seed treatments, at the initial month of storage, among different treatments higher field emergence was recorded in SiO_2 NPs @ 500 ppm (86%)

Table 3a. Influence of seed treatment with nano and bulk form of chemicals through dry dressing on field emergence (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)			
	0	3	6	Mean
T_0- Control	78	68	53	66
T_1- SiO_2 NPs @ 250 ppm	90	80	63	78
T_2- SiO_2 NPs @ 500 ppm	88	79	62	76
T_3- TiO_2 NPs @ 500 ppm	87	77	61	75
T_4- TiO_2 NPs @ 750 ppm	85	74	60	73
T_5- FeO NPs @ 250 ppm	86	76	60	74
T_6- FeO NPs @ 500 ppm	85	73	59	72
T_7- SiO_2 B @ 500 ppm	81	69	54	68
T_8- SiO_2 B @ 750 ppm	84	72	57	71
T_9- TiO_2 B @ 250 ppm	83	71	56	70
T_{10}- TiO_2 B @ 1000 ppm	80	68	53	67
T_{11}- FeO B @ 500 ppm	81	68	54	68
T_{12}- FeO B @ 750 ppm	82	70	55	69
Mean	84	72	57	71
S.Em ±	0.58	0.56	0.61	
CD (0.05P)	1.6	1.61	1.77	
CV (%)	1.21	1.33	1.84	

Table 3b. Influence of seed treatment with nano and bulk form of chemicals through polymer coating on field emergence (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)			
	0	3	6	Mean
T_0- Control	78	68	53	66
T_1- SiO_2 NPs @ 250 ppm	82	71	54	69
T_2- SiO_2 NPs @ 500 ppm	86	74	57	72
T_3- TiO_2 NPs @ 250 ppm	81	70	53	68
T_4- TiO_2 NPs @ 500 ppm	85	73	56	71
T_5- FeO NPs @ 250 ppm	83	71	52	69
T_6- FeO NPs @ 500 ppm	84	72	55	70
T_7- SiO_2 B @ 500 ppm	82	67	49	66
T_8- SiO_2 B @ 1000 ppm	84	69	51	68
T_9- TiO_2 B @ 500 ppm	83	68	50	67
T_{10}- TiO_2 B @ 750 ppm	81	67	48	65
T_{11}- FeO B @ 250 ppm	78	65	46	63
T_{12}- FeO B @ 750 ppm	80	66	47	64
Mean	82	69	52	68
S.Em ±	0.80	0.40	0.59	
CD (0.05P)	2.32	1.16	1.73	
CV (%)	1.69	1.00	2.00	

which was statistically on par with TiO_2 NPs @ 500 ppm (85 %), while the lowest germination was recorded in FeO B @ 250 ppm (78%). At the end of storage period, the field emergence was highest in SiO_2 NPs @ 500 ppm (57 %) followed by TiO_2 NPs @ 500 ppm(56 %) lowest field emergence was recorded in FeO B @ 250 ppm (46 %).Ageing causes deterioration of seed, resulting in decrease of field emergence percentage. Major contribution of silicon in reinforcement of cell walls by deposition of solid silica. These structures are very resistant to decomposition, offers mechanical strength and also protects the seed or plant from environmental stress[13].

The major storage fungi observed during storage were *Aspergillus niger*, *Aspergillus flavus*, *Penicillium* sp. *Rhizopus* sp. Even at the beginning of storage, the seeds of SiO_2 NPs @ 250 ppm recorded minimum seed infection (1.33%) which was on par with SiO_2 NPs @ 500 ppm (2.67%) and TiO_2 NPs @ 500 ppm (2.67%), while the maximum seed infection was recorded in control (6.67%). At the end of the storage period, ofSiO_2 NPs @ 250 ppm recorded significantly lower seed infection (25.33%) which was on par with of SiO_2 NPs @ 500 ppm (26.67%), TiO_2 NPs @ 500 ppm (26.67%), while the maximum seed infection was recorded in control (30.67%) in dry dressing seed treatment. Whereas, in polymer coating seed treatments at the beginning of the storage month, significant variation was observed for seed infection with SiO_2 NPs @ 500 ppm recorded minimum seed infection (1.33%) which was on par with SiO_2 NPs @ 250 ppm (2.67%), TiO_2 NPs @ 500 ppm (2.67%), while the maximum seed infection was recorded in control (6.67%). At the end of the storage period, SiO_2 NPs @ 500 ppm recorded significantly lower seed infection (26.67%) which was on par with SiO_2 NPs @ 250 ppm (28.00%), TiO_2 NPs @ 500 ppm (28.00%), while the maximum seed infection was noticed in FeO B @ 250 ppm (32.00%) (Table 4a and 4b).Higher seed infection with fungi might be due to increased moisture absorptionby the untreated seeds and lower percentage of infection in treated seeds due to the toxic effect of nanoparticles on pathogen, along with lower moisture absorption. Thus, the deterioration of treated seeds was less compared to untreated seeds in dry dressing treatment. However, none of the treatments protected the groundnut seed kernel to zero level. Main mechanism of silicon is its role in triggering a range of natural defences. Further it has been shown to stimulate the activity of active compounds such as chitinase, peroxidase, polyphenol oxidases and flavonoid phytoalexins all of which can protect seed against fungal pathogens[13]. Silicon also can activate some defence mechanisms. It appears that silicon has an important function in plant protection, because it is deposited on the walls of epidermis and vascular tissues and play an important role as a physico-mechanical barrier[14].

Table 4a. Influence of seed treatment with nano and bulk form of chemicals through dry dressing on seed infection (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	6.67	8.00	10.67	13.33	17.33	22.67	30.67	15.62
T_1- SiO_2 NPs @ 250 ppm	1.33	2.67	5.33	8.00	12.00	17.33	25.33	10.28
T_2- SiO_2 NPs @ 500 ppm	2.67	2.67	6.67	8.00	13.33	17.33	26.67	11.05
T_3- TiO_2 NPs @ 500 ppm	2.67	4.00	6.67	9.33	13.33	18.67	26.67	11.62
T_4- TiO_2 NPs @ 750 ppm	4.00	6.67	8.00	10.67	14.67	20.00	28.00	13.14
T_5- FeO NPs @ 250 ppm	4.00	5.33	8.00	10.67	13.33	18.67	27.65	12.52
T_6- FeO NPs @ 500 ppm	5.33	6.67	9.33	12.00	16.00	21.33	29.33	14.28
T_7- SiO_2 B @ 500 ppm	5.33	6.67	9.33	13.33	16.00	21.33	29.33	14.47
T_8- SiO_2 B @ 750 ppm	4.00	5.33	6.67	9.33	14.67	20.00	26.67	12.38
T_9- TiO_2 B @ 250 ppm	4.00	5.33	8.00	12.00	14.67	20.00	28.00	13.14
T_{10}- TiO_2 B @ 1000 ppm	6.67	8.00	10.67	14.67	17.33	22.67	30.67	15.81
T_{11}- FeO B @ 500 ppm	6.67	6.67	9.33	14.67	17.33	22.67	29.33	15.24
T_{12}- FeO B @ 750 ppm	5.33	6.67	9.33	13.33	16.00	21.33	29.33	14.47
Mean	4.51	5.54	8.31	11.49	15.08	20.31	28.31	13.36
S.Em ±	1.28	1.43	1.33	1.57	1.43	1.48	1.61	
CD (0.05P)	3.72	4.16	3.88	4.56	4.16	4.30	4.69	
CV (%)	49.17	44.79	27.80	23.66	16.45	12.62	9.86	

Table 4b. Influence of seed treatment with nano and bulk form of chemicals through polymer coating on seed infection (%) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)							
	0	1	2	3	4	5	6	Mean
T_0- Control	6.67	8.00	10.67	13.33	17.33	22.67	30.67	15.62
T_1- SiO_2 NPs @ 250 ppm	2.67	4.00	6.67	10.67	16.00	20.00	28.00	12.57
T_2- SiO_2 NPs @ 500 ppm	1.33	2.67	5.33	9.33	13.33	17.33	26.67	10.86
T_3- TiO_2 NPs @ 250 ppm	4.00	5.33	8.00	12.00	16.00	18.67	29.33	13.33
T_4- TiO_2 NPs @ 500 ppm	2.67	4.00	6.67	10.67	14.67	18.67	28.00	12.19
T_5- FeO NPs @ 250 ppm	5.33	5.33	9.33	13.33	17.33	21.33	30.67	14.66
T_6- FeO NPs @ 750 ppm	4.00	5.33	8.00	12.00	16.00	19.67	29.33	13.52
T_7- SiO_2 B @ 500 ppm	5.33	6.67	9.33	12.00	16.00	20.00	28.00	13.90
T_8- SiO_2 B @ 1000 ppm	4.00	5.33	8.00	10.67	14.67	18.67	29.33	12.95
T_9- TiO_2 B @ 500 ppm	4.00	5.33	8.00	12.00	17.33	21.33	30.67	14.09
T_{10}- TiO_2 B @ 750 ppm	5.33	6.67	12.00	14.67	17.33	21.33	30.67	15.43
T_{11}- FeO B @ 250 ppm	6.67	8.00	12.00	16.00	18.67	22.67	32.00	16.57
T_{12}- FeO B @ 750 ppm	6.67	6.67	10.67	13.33	17.33	21.33	30.67	15.24
Mean	4.51	5.64	8.82	12.31	16.31	21.31	29.54	14.06
S.Em ±	1.43	1.28	1.17	1.38	1.28	1.61	1.11	
CD (0.05P)	4.16	3.72	3.40	4.02	3.72	4.69	3.23	
CV (%)	54.97	39.33	22.96	19.47	13.61	13.74	6.51	

A linear increase in the electrical conductivity of seed leachate (µS/cm) with increasing storage period was observed (Table 5a and 5b). In dry dressing seed treatment, electrical conductivity differed significantly, at initial month highest electrical conductivity (228.50 µS/cm) was recorded in control followed by TiO_2 B @ 1000 ppm (144.48 µS/cm) and lowest was recorded in SiO_2 NPs @ 250 ppm (120.82 µS/cm) which was on par with SiO_2 NPs @ 500 ppm (126.46 µS/cm), TiO_2 NPs @ 500 ppm (127.64 µS/cm). Similar trend was noticed at the end of storage period, control recorded highest electrical conductivity (392.45 µS/cm) while, SiO_2 NPs @ 250 ppm recorded lowest electrical conductivity (249.82 µS/cm) followed by SiO_2 NPs @ 500 ppm (256.96 µS/cm). Whereas, in polymer coating seed treatments, at initial month highest electrical conductivity was recorded in

Table 5a. Influence of seed treatment with nano and bulk form of chemicals through dry dressing on electrical conductivity of seed leachate (µS/cm) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)				
	0	2	4	6	Mean
T_0- Control	228.50	257.92	310.62	392.45	297.37
T_1- SiO_2 NPs @ 250 ppm	120.82	139.82	184.82	249.82	173.82
T_2- SiO_2 NPs @ 500 ppm	126.46	145.96	191.46	256.96	180.21
T_3- TiO_2 NPs @ 500 ppm	127.64	147.12	193.68	257.82	181.57
T_4- TiO_2 NPs @ 750 ppm	129.45	149.45	195.96	259.45	183.58
T_5- FeO NPs @ 250 ppm	129.39	148.26	195.45	258.69	182.95
T_6- FeO NPs @ 500 ppm	131.73	152.82	197.12	262.84	186.13
T_7- SiO_2 B @ 500 ppm	141.50	160.24	205.63	269.52	194.22
T_8- SiO_2 B @ 750 ppm	133.73	154.12	197.73	263.18	187.19
T_9- TiO_2 B @ 250 ppm	136.46	156.82	201.84	265.24	190.09
T_{10}- TiO_2 B @ 1000 ppm	144.48	165.62	208.46	274.83	198.35
T_{11}- FeO B @ 500 ppm	143.39	163.68	207.84	272.18	196.77
T_{12}- FeO B @ 750 ppm	138.69	157.69	203.12	267.19	191.67
Mean	140.94	161.50	207.21	273.09	195.69
S.Em ±	1.38	1.69	1.92	2.89	
CD (0.05P)	4.01	4.90	5.58	8.40	
CV (%)	1.77	1.88	1.66	1.89	

Table 5b. Influence of seed treatment with nano and bulk form of chemicals through polymer coating on electrical conductivity of seed leachate (µS/cm) in groundnut during storage

Treatments	Storage period in months (Feb, 2022 to Aug, 2022)				
	0	2	4	6	Mean
T_0- Control	228.50	257.92	310.62	392.45	297.37
T_1- SiO_2 NPs @ 250 ppm	208.80	234.75	281.74	351.46	269.19
T_2- SiO_2 NPs @ 500 ppm	205.37	230.37	278.37	348.37	265.62
T_3- TiO_2 NPs @ 250 ppm	216.47	240.98	288.69	360.42	276.64
T_4- TiO_2 NPs @ 500 ppm	214.47	240.67	287.67	359.67	275.62
T_5- FeO NPs @ 250 ppm	218.58	244.58	292.58	361.19	279.23
T_6- FeO NPs @ 500 ppm	211.52	236.34	283.14	354.47	271.37
T_7- SiO_2 B @ 500 ppm	221.42	248.17	299.74	366.84	284.04
T_8- SiO_2 B @ 1000 ppm	219.20	245.67	294.86	362.20	280.48
T_9- TiO_2 B @ 500 ppm	221.13	247.24	296.19	364.28	282.21
T_{10}- TiO_2 B @ 750 ppm	223.44	247.44	299.98	367.74	284.65
T_{11}- FeO B @ 250 ppm	227.14	254.62	305.94	396.82	293.63
T_{12}- FeO B @ 750 ppm	224.39	250.84	303.17	382.14	290.14
Mean	218.49	244.58	294.05	366.00	280.78
S.Em ±	2.19	3.13	4.08	4.67	
CD (0.05P)	6.37	9.09	11.85	13.58	
CV (%)	1.78	2.27	2.46	2.26	

control (228.50 µS/cm) followed by FeO B @ 250 ppm (227.14 µS/cm) and lowest (205.37 µS/cm) was recorded in SiO_2 NPs @ 500 ppm which was on par with SiO_2 NPs @ 250 ppm (208.80 µS/cm). At the end of storage period, FeO B @ 250 ppm recorded highest electrical conductivity (396.82 µS/cm) while, SiO_2 NPs @ 500 ppm recorded lowest electrical conductivity (348.37 µS/cm) followed by SiO_2 NPs @ 250 ppm (351.46 µS/cm). The results depict that the micro layer formed by the nanoparticles over seeds surface maintains the seed coat integrity thereby reduces the leakage of solutes from the seeds. The differences in electrical conductivity of seed leachate indicated that there is increased membrane permeability and decrease in integrity of cellular membrane. Deteriorated seeds were found to leach out more solutes resulting with higher electrical conductivity compared to vigourous and healthy seeds[15]. Sahebi[16] reported that silicon increases the plasma membrane integrity by providing more stable lipids involved in their cell membrane.

CONCLUSION

The nanoparticles are capable of entering into seeds through the cracks and crevices available on the seed coat during imbibition. This improves the enzymatic activity and free radical scavenging system by quenching the free radicals thereby lowering the oxidative damages, eventually promoting viability and vigour of seeds. The results showed that dry dressing seed treatment with certain optimum concentration of nanoparticles improved seed quality and storability. Among the treatments, SiO_2 NPs @ 250 ppm and 500 ppm was found to be superior in maintaining or enhancing the storability of groundnut kernels. 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.

REFERENCES

1. KONANKI ST, VIJAY KUMAR K, SHAKUNTALA NM, SANGEETHA IM, HASAN KHAN AND HIREGOUDAR S (2019). Studies on efficacy of nanoparticles in improving seed physiological parameters in groundnut (*Arachis hypogaea* L.). *International Journal of Chemical Studies,* **7**(5): 1786-1791.
2. DELOUCHE JC AND BASKIN CC (1973). Accelerated ageing technique for predicting the relative storability of seed lots. *Seed Science and Technology,* **1**:427-452.
3. BASU RN (1994). An appraisal of research on wet and dry physiological seed treatments and their applicability with special reference to tropical and sub-tropical countries. *Seed Science and Technology,* **22**:107-126.
4. KHOTLR, SANKARAN S, MAJA JM, EHSANIR AND SCHUSTER EW (2012). Applications of nanomaterials in agricultural production and crop protection-A review. *Crop Protection,* **35**:64-70.

5. CHINNAMUTHUCR AND BOOPATHI P (2009). Nanotechnology and agroecosystem. *Madras Agricultural Journal,* **96**(1-6):17-31.

6. SURIYAPRABHA R, KARUNAKARAN G, YUVAKKUMAR R, RAJENDRAN V AND KANNAN N (2012). Silica nanoparticles for increased silica availability in maize (*Zea mays*. L) seeds under hydroponic conditions. *Current Nanoscience,* **8**(6): 902-908.

7. ISTA (2013). International Rules for Seed Testing. *Seed Science and Technology*, **27**: 25-30.

8. PANSE VG AND SUKHATME PV (1985). Statistical Methods for Agricultural Workers. ICAR Publication, New Delhi, pp. 350.

9. CHANDRAVATHI B (2008). Effect of hydropriming and polymer coating on field performance and storability of Pearl millet [*Pennisetum glaucum* (L.)], *M Sc. (Agri.) Thesis,* University of Agricultural Sciences. Dharwad, Karnataka (India).

10. HANEGAVI (2009). Influence of seed invigouration and polymer coating on field performance and storability of maize (*Zea mays* L.). *M.Sc. (Agri.) Thesis*, University of Agricultural Sciences. Dharwad (India).

11. MANJUNATHA SN, HUNJE R, VYAKARANAHAL BS AND KALAPPANAVAR IK (2008). Effect of seed coating with polymer, fungicide and containers on seed quality of Chilli. *Karnataka Journal of Agricultural Sciences,* **21**(2): 270-273.

12. ZHENG L, HONG F, LU S AND LIU C (2005). Effect of nano-TiO_2 on strength of naturally aged seeds and growth of spinach. *Biological Trace Element Research,***106**: 279-297.

13. HECKMANJ (2013). Silicon: A beneficial substance. *Better Crops*, **97**(4): 14-16.

14. MAJF AND YAMAJI N (2008). Functions and transport of silicon in plants. *Cellular and MolecularLife Sciences,* **65**(19): 3049-3057.

15. MASKRI AL, KHAN MM, KHAN IA AND HABSI KAL (2003). Effect of accelerated ageing on viability, vigor (RGR), lipid peroxidation and leakage in carrot (*Daucus carota* L.) seeds. *International Journal of Agriculture and Biology,* **5**(4): 580-584.

16. SAHEBI M, HANAFI MM, SITI NAA, RAFII MY, AZIZI P, TENGOUA FF, MAYZ A, AZW AJN AND SHABANIMOFRAD M (2015). Importance of silicon and mechanisms of biosilica formation in plants. *Biomed Research International,* **15**: 1-16.