

Original Research Article

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Effect of Seed Treatment with Nanoparticles on Seed Storability of Soybean

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ABSTRACT

The present storage study was carried out at Seed Quality and Research Laboratory, University of Agricultural Sciences, Dharwad during 2016-2017. In this study two different seed lots were taken first seed lot having higher germination percentage and second seed lot having lower germination percentage. Seeds were dry dressed with nanoparticles of silver and iron with different concentration and kept for storage. Seed lots revealed significant variation of the seed quality and storability due to nanoparticles treatments on soybean cv. DSb-21. High vigour seed lot recorded higher seed germination and seedling vigour index-I than the low vigour seed lot at the end of storage. The nanoparticles treatment FeNPs @500 ppm which recorded significantly higher seed germination (92.5%) and seedling vigour index- I (3127) than control at the beginning, maintained the trend till the end of 10 month of storage period. The rate of reduction in quality parameters was much higher in the low vigour seed lot. The seed treatment with nanoparticles reduced the rate of deterioration of seed in the storage.

Keywords

Soybean,
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Introduction

Soybean [*Glycine max* (L.) Merrill] is one of the most important protein and oilseed crop throughout the world. Soybean was introduced to India during 1880. Its oil is the largest component of the world's edible oils accounting for 30 per cent of the world oil production of edible oil.

Currently, it ranks first in oilseed production. Despite the high yielding potential and advantages of soybean cultivation, the yield per unit area of the crop is low in India. Poor germination and low seed viability are among the serious problems limiting the production of soybean. Soybean absorbs 50 per cent of its weight in moisture to germinate compared to only 30 per cent for maize. It must be planted

in soils with adequate moisture to ensure maximum germination.

Research on the storability of seeds with modified storage conditions, in India is of a recent origin with the development of organized seed production and marketing. It is stipulated that 80 per cent of certified seed produced in India requires storage for one planting season and 20 per cent of seed is carried over for subsequent sowing (Bal, 1976). However, with the awareness and infrastructure development, substantial quality of seeds may be stored for few planting seasons as a safeguard against monsoon failure and as a precaution against production of poor quality seeds. The loss of seed viability due to seed deterioration is inexorable, irreversible and inevitable which is mainly dependent on physical, physiological and chemical composition of seed (Delouche *et al.*, 1973).

However, the rate of deterioration could be slow down to a greater extent during storage by imposing certain seed treatments before storage. Use of nano-technological approaches expected to quench the reactive oxygen species and reduce the oxidative damage to improve the viability and vigour of seeds.

Metal nanoparticles are derived from salts of gold (Au), silver (Ag), iron (Fe), copper (Cu), zinc (Zn), titanium dioxide (TiO₂), cadmium (Cd), aluminium (Al) and silica (Si) etc. This study hypothesized that the soybean seeds stored for an extended period of time may result in the production of reactive oxygen species that damages the cell wall integrity as a consequence of lipid peroxidation.

Nanoparticles are known to donate electrons that pairs with the free radicals and smother the impact of these radicals. This process collectively contributes for circumventing the damages caused during seed storage, while

augmenting vigour and viability. Thus the use of these nanoparticles may find a solution for shorter longevity of soybean seeds. During the past decade, some work has been done in biological system to address a wide range of field problems utilizing nano-materials and nano-devices. Natarajan and Sivasubramanian (2008) have elucidated various nano-technological approaches that can be employed in seed science.

Keeping all these aspects in view, the present investigation entitled “Effect of seed treatment with nanoparticles on seed longevity of soybean” was carried out.

Materials and Methods

The present storage study was carried out at Seed Quality and Research laboratory, University of Agricultural Sciences, Dharwad during 2016- 2017.

Nanoparticles are dry dressed with soybean seeds of variety DSb-21 with AgNPs @ 500, 1000,1500 ppm and FeNPs@500, 1000& 1500ppm at the rate of 2 g per kg were packed in polythene pouches and stored at ambient conditions at National Seed Project Laboratory, UAS Dharwad for a period of 10 months. Required initial observations were recorded before storing the samples at National Seed Project Laboratory, University of Agricultural Sciences, Dharwad under ambient condition.

The data was statistically analyzed by using analysis of variance for completely randomized design in factorial concept for storage experiment. Main and interaction effects were compared by using ‘F’ test at 0.01 level of probability for laboratory experiments. CD values were calculated and treatments were compared as per standard procedure of analysis (Steel and Torrie, 1980).

Results and Discussion

Soybean is emerging as most versatile and economically important crop in today's farming system but, seed longevity is a major and challenging problem to be addressed. It is considered short lived as compared to other oil seed crops and its seed germination and vigour is often reduced prior to planting. Hence, the study was conducted to prolong the seed storability and maintaining higher vigour.

Nanotechnology is one of the fast developing technologies and its products are very useful in all fields, because of their small size (10^{-9} nm) and large surface area. Nanoparticles offer a larger surface-to-volume ratio and a higher concentration of partially coordinated surface sites than the corresponding bulk materials. The unique properties of nanoparticles are due to a strong interplay between elastic, geometric and electronic parameters. The result of these features is often improved by physical and chemical properties compared to that of bulk material. In recent past, efforts have been made to improve agricultural yield through exhaustive research in nanotechnology. The green revolution resulted in injudicious usage of pesticides and chemical fertilizers which caused the loss of soil biodiversity.

Several intrinsic and extrinsic factors influence the viability of seeds during storage. Among intrinsic and extrinsic factors, seed moisture content, relative humidity, temperature of storage, pests and diseases and oxygen availability are more important. Deterioration of seed is a natural process which is inevitable, inexorable and irreversible but the rate of deterioration of seed may differ due to genetic factor (Robert, 1972), storage environment (Roberts, 1961), period of storage (Reddy, 1985) and seed treatment (Zhang *et al.*, 2005) etc.

Noticeable and consistent variation in seed quality parameters were observed in the entire ten months of storage period irrespective of seed quality level and nanoparticles treatments. Final germination, root length, shoot length, seedling dry weight and seedling vigour index were significantly maximum (73.96 %, 16.63 cm, 12.72 cm, 1.08 g, and 2103.68, respectively) at the initial period but declined gradually to minimum value (43.21 %, 8.82 cm, 8.02 cm, 0.789 g, and 1247.96, respectively) at the end of ten months of storage period. Whereas, the initial EC value (0.530 dS m^{-1}) increased to 1.940 dS m^{-1} . Moisture content of seed (10.01, 9.93, 9.80, 9.48, 8.86 and 8.21 %) showed gradual decrease across the storage period. The marked decrease in the seed quality parameters under advancing storage period may be attributed to seed coat characters (Delouhe *et al.*, 1973), age induced physicochemical seed deterioration, lipid peroxidation leading to production of toxic metabolites that act upon cell and cell organelles (Maguire, 1977, Tappel, 1980 and Sohal, 1987) denaturation of proteins and enzymes (Roberts, 1961).

The present study revealed that, irrespective of nanoparticles treatments, seed lots differed significantly due to seed quality throughout the ten months of storage period. Seed germination percentage, shoot length, root length, seedling length, seedling dry weight, seedling vigour index and electrical conductivity showed significant difference due to seed lots. Seeds of high vigour seed lot (V_1) recorded higher seed quality parameters (87.32 %, 14.05 cm, 17.45 cm, 31.5 cm, 1.114 g, 2673, respectively) over the low vigour seed lot (V_2) (60.61 %, 11.39 cm, 15.81 cm, 25.31 cm, 1.048 g, 1534, respectively) at the initial month of storage.

The gradual reduction in these quality parameters with the increase in storage period

was noticed in both seed lots. At the end of ten months storage higher quality parameters were recorded in seeds of high vigour seed lot (57.54 %, 9.40cm,9.64 cm,19.04 0.656 g, 742, 31.88, 1764, 0.809 respectively) as compared to the seeds of low vigour seed lot (28.29 % , 6.65 cm, 7.99 cm, 14.64 cm, 594 g, 731, 0.769 g respectively).

Similar variation in electrical conductivity of seed leachates was observed at all the months of storage period. At initial month of storage lower electrical conductivity (0.48 dS m⁻¹) was recorded in V₁ and higher (0.58 dS m⁻¹) was recorded in V₂. At the end of ten months of storage lower electrical conductivity (1.73 dS m⁻¹) was recorded in V₁ and higher (2.15 dS m⁻¹) was recorded in V₂. Among the seed lots (V₁) high vigour seed lot maintained about 70 per cent meeting the minimum germination requirement prescribed as per

Minimum Seed Certification Standards (IMSCS) (Anon., 2013d) up to six months period, The present findings are in accordance with Vashisth and Nagarajan (2009) in Maize.

The seed quality parameters showed significant difference due to nanoparticles seed treatment. Seeds treated with FeNPs (500 ppm) (N₄) recorded the higher germination, root length, shoot length, seedling length, seedling dry weight, seedling vigour index and lower electrical conductivity (76.38 %, 17.02 cm, 13.37 cm, 29.71 cm, 0.659 g, 2267, 1.097 g, 0.49 dS m⁻¹, respectively) followed by FeNPs (500 ppm) (N₄) (47.38 %, 17.02 cm, 13.37 cm, 29.71 cm, 1.091 g, 2251 and 0.51 dS m⁻¹) and lower (59.50 %, 16.29 cm, 12.22 cm, 26.51 cm, 1931, 1.063 g, and 0.56 dS m⁻¹, respectively) in untreated (control) (N₇) at the end of ten months storage (Table 1–5).

Table.1 Effect of seed vigour levels and nanoparticles seed treatments on germination (%) of soybean

Treatments	Storage period (months)					
	Initial	2	4	6	8	10
Seed quality (V)						
V₁-High vigour	87.32 (69.14)	84.57 (66.87)	78.86 (62.63)	73.43 (58.97)	65.79 (54.20)	57.54 (49.33)
V₂-Low vigour	60.61 (51.13)	56.79 (48.90)	52.93 (46.68)	46.18 (42.81)	37.75 (37.91)	28.89 (32.52)
S. Em. ±	0.37	0.35	0.38	0.31	0.45	0.39
C. D. at 1 %	1.42	1.35	1.43	1.17	1.71	1.48
Nanoparticles Treatments (N)						
N₁	73.63 (59.10)	70.00 (56.79)	65.75 (54.18)	60.25 (50.91)	51.75 (46.00)	43.38 (41.19)
N₂	74.13 (59.43)	70.75 (57.26)	66.25 (54.48)	60.75 (51.21)	52.88 (46.65)	44.50 (41.84)
N₃	72.88 (58.62)	69.63 (56.56)	64.88 (53.66)	58.75 (50.04)	50.25 (45.14)	40.88 (39.74)
N₄	76.38 (60.92)	73.50 (59.02)	68.13 (55.63)	62.13 (52.02)	55.25 (48.01)	47.38 (43.50)
N₅	75.00 (60.00)	72.00 (58.05)	67.13 (55.02)	61.63 (51.73)	53.88 (47.23)	45.63 (42.49)

N₆	73.38 (58.94)	70.13 (56.87)	65.38 (53.96)	59.50 (50.48)	50.00 (45.00)	41.88 (40.32)
N₇	72.38 (58.29)	68.75 (56.01)	63.75 (52.98)	55.63 (48.23)	48.38 (44.07)	38.88 (38.57)
S. Em. ±	0.70	0.66	0.70	0.57	0.84	0.72
C. D. at 1 %	2.67	2.52	2.68	2.18	3.20	2.77
Interaction (V×N)						
V₁N₁	86.75 (68.65)	83.50 (66.03)	78.50 (62.38)	74.00 (59.34)	67.00 (54.94)	58.00 (49.60)
V₁N₂	87.50 (69.30)	84.50 (66.82)	79.00 (62.73)	74.50 (59.67)	68.00 (55.55)	59.50 (50.48)
V₁N₃	85.75 (67.82)	83.25 (65.84)	77.75 (61.86)	72.50 (58.37)	62.50 (52.24)	54.50 (47.58)
V₁N₄	90.75 (72.29)	88.50 (70.18)	81.25 (64.34)	76.75 (61.17)	70.00 (56.79)	62.75 (52.39)
V₁N₅	88.75 (70.40)	86.25 (68.23)	80.00 (63.43)	76.00 (60.67)	69.50 (56.48)	60.50 (51.06)
V₁N₆	86.50 (68.44)	84.00 (66.42)	78.25 (62.20)	73.25 (58.86)	63.25 (52.68)	56.25 (48.59)
V₁N₇	85.25 (67.41)	82.00 (64.90)	77.25 (61.51)	67.00 (54.94)	60.25 (50.91)	51.25 (45.72)
V₂N₁	60.50 (51.06)	56.50 (48.73)	53.00 (46.72)	46.50 (42.99)	36.50 (37.17)	28.75 (32.42)
V₂N₂	60.75 (51.21)	57.00 (49.02)	53.50 (47.01)	47.00 (43.28)	37.75 (37.91)	29.50 (32.90)
V₂N₃	60.00 (50.77)	56.00 (48.45)	52.00 (46.15)	45.00 (42.13)	38.00 (38.06)	27.25 (31.47)
V₂N₄	62.00 (51.94)	58.50 (49.89)	55.00 (47.87)	47.50 (43.57)	40.50 (39.52)	32.00 (34.45)
V₂N₅	61.25 (51.50)	57.75 (49.46)	54.25 (47.44)	47.25 (43.42)	38.25 (38.20)	30.75 (33.68)
V₂N₆	60.25 (50.91)	56.25 (48.59)	52.50 (46.43)	45.75 (42.56)	36.75 (37.32)	27.50 (31.63)
V₂N₇	59.50 (50.48)	55.50 (48.16)	50.25 (45.14)	44.25 (41.70)	36.50 (37.17)	26.50 (30.98)
Mean	73.96 (59.32)	70.68 (57.22)	65.89 (54.26)	59.80 (50.65)	51.77 (46.01)	43.21 (41.10)
S. Em. ±	0.97	0.94	0.99	0.81	1.19	1.02
C. D. at 1 %	NS	NS	NS	3.08	4.53	NS

Figures in parentheses indicate arc sine values

V₁= Seed lot- 1 (Seed lot with high vigour 85% germination), V₂= Seed lot- 2 (Seed lot with low vigour, 55% germination)

N₁= TiNPs @500 ppm, N₂= TiNPs @ 1000 ppm, N₃= TiNPs @1500 ppm, N₄= ZnNPs @500 ppm, N₅= ZnNPs @ 1000 ppm, N₆=ZnNPs @ 1500 ppm, N₇= without nanoparticle treatment (control)

Table.2 Effect of seed vigour levels and nanoparticles seed treatments on seedling vigour index-I of soybean

Treatments	Storage period(months)					
	Initial	2	4	6	8	10
Seed quality (V)						
V₁-High vigour	2673	2589	2413	2249	2017	1768
V₂-Low vigour	1534	1437	1340	1170	955	732
S. Em. ±	20.17	16.11	15.82	14.19	16.22	13.81
C. D. at 1 %	76.96	61.46	60.37	54.15	61.89	52.68
Priming treatments (N)						
N₁	2078	1989	1854	1693	1428	1203
N₂	2135	2041	1911	1759	1538	1301
N₃	1999	1913	1784	1620	1387	1137
N₄	2267	2179	2031	1871	1645	1413
N₅	2252	2169	2007	1840	1640	1412
N₆	2062	1963	1845	1696	1465	1233
N₇(control)	1932	1836	1704	1486	1298	1049
S. Em. ±	37.73	30.13	29.60	26.55	30.34	25.83
C. D. at 1 %	143.97	114.98	112.94	101.31	115.78	98.55
Interaction (V × N)						
V₁N₁	2634	2558	2382	2230	1933	1712
V₁N₂	2713	2619	2449	2309	2108	1845
V₁N₃	2538	2462	2299	2143	1847	1610
V₁N₄	2891	2809	2605	2474	2263	2000
V₁N₅	2887	2814	2583	2441	2227	1993
V₁N₆	2620	2520	2370	2234	2022	1752
V₁N₇	2430	2338	2203	1909	1719	1463
V₂N₁	1523	1421	1326	1157	923	694
V₂N₂	1556	1462	1372	1208	968	757
V₂N₃	1461	1364	1268	1097	927	664
V₂N₄	1644	1550	1456	1268	1027	825
V₂N₅	1616	1524	1432	1238	1054	831
V₂N₆	1504	1406	1319	1159.	908	715
V₂N₇	1433	1334	1206	1063	877	635
Mean	2103.68	2012.98	1876.62	1709.36	1486.00	1249.93
S. Em. ±	53.36	42.62	41.86	37.55	42.91	36.53
C. D. at 1 %	NS	NS	NS	143.28	163.74	139.37

V₁= Seed lot-1 (Seed lot with high vigour 85% germination)

V₂= Seed lot-2 (Seed lot with low vigour, 55% germination)

N₁= AgNPs @500 ppm, N₂= AgNPs @1000 ppm, N₃= AgNPs @ 1500 ppm, N₄= FeNPs @500 ppm, N₅= FeNPs @1000 ppm, N₆=FeNPs @1500 ppm, N₇= without nanoparticle treatment (control)

Table.3 Effect of seed vigour levels and nanoparticles seed treatments on seedling vigour index-II of soybean.

Treatments	Storage period(months)					
	Initial	2	4	6	8	10
Seed quality (V)						
V₁-High vigour	97.27	90.32	80.45	71.94	59.17	46.57
V₂-Low vigour	63.49	57.54	51.91	42.60	34.55	22.13
S. Em. ±	0.18	0.11	0.14	0.10	0.11	0.11
C. D. at 1 %	0.68	0.43	0.52	0.36	0.42	0.43
Priming treatments (N)						
N₁	80.00	73.55	66.13	57.88	47.49	34.30
N₂	80.80	74.52	67.04	58.52	48.58	35.36
N₃	78.47	72.17	64.25	55.58	45.42	31.78
N₄	84.25	78.47	69.79	60.80	51.56	38.34
N₅	82.25	76.37	68.39	59.92	49.99	36.60
N₆	79.48	72.98	65.09	56.81	43.65	34.31
N₇(control)	77.41	69.46	62.56	51.40	41.32	29.79
S. Em. ±	80.00	0.21	0.25	0.18	0.20	0.21
C. D. at 1 %	80.80	0.81	0.97	0.68	0.78	0.80
Interaction (V × N)						
V₁N₁	96.52	89.53	80.03	72.54	60.34	47.00
V₁N₂	97.84	90.66	80.82	73.39	61.35	48.36
V₁N₃	94.80	87.99	78.20	70.09	55.34	43.35
V₁N₄	102.28	96.28	84.25	76.76	64.32	51.99
V₁N₅	99.59	93.20	82.58	75.35	63.34	49.76
V₁N₆	96.09	89.21	79.24	71.30	56.60	45.14
V₁N₇	93.76	85.38	78.02	64.15	52.91	40.41
V₂N₁	63.48	57.57	52.24	43.22	34.65	21.60
V₂N₂	63.75	58.39	53.26	43.64	35.81	22.36
V₂N₃	62.13	56.36	50.30	41.06	35.51	20.21
V₂N₄	66.23	60.67	55.33	44.84	38.80	24.70
V₂N₅	64.92	59.54	54.19	44.48	36.64	23.43
V₂N₆	62.87	56.76	50.94	42.32	30.70	23.48
V₂N₇	61.07	53.54	47.09	38.64	29.73	19.17
Mean	80.38	73.93	66.18	57.27	46.86	34.35
S. Em. ±	0.47	0.30	0.36	0.25	0.29	0.29
C. D. at 1 %	1.81	1.14	1.37	0.96	1.10	1.13

V₁= Seed lot-1 (Seed lot with high vigour 85% germination)

V₂= Seed lot-2 (Seed lot with low vigour, 55% germination)

N₁= AgNPs @500 ppm, N₂= AgNPs @1000 ppm, N₃= AgNPs @ 1500 ppm, N₄= FeNPs @500 ppm, N₅= FeNPs @1000 ppm, N₆=FeNPs @1500 ppm, N₇= without nanoparticle treatment (control)

Table.4 Effect of seed vigour levels and nanopaticles seed treatments on seedling dry weight (g) of soybean (g/10 seedlings)

Treatments	Storage period(months)					
	Initial	2	4	6	8	10
Seed quality (V)						
V₁-High vigour	1.114	1.068	1.020	0.979	0.899	0.809
V₂-Low vigour	1.048	1.013	0.979	0.925	0.917	0.769
S. Em. ±	0.002	0.001	0.003	0.003	0.003	0.003
C. D. at 1 %	0.006	0.005	0.010	0.013	0.012	0.010
Nanoparticles treatments (N)						
N₁	1.081	1.044	1.003	0.954	0.925	0.784
N₂	1.087	1.049	1.009	0.958	0.927	0.787
N₃	1.071	1.031	0.985	0.939	0.910	0.769
N₄	1.097	1.063	1.022	0.974	0.942	0.802
N₅	1.091	1.056	1.015	0.967	0.936	0.797
N₆	1.076	1.036	0.992	0.948	0.868	0.828
N₇(control)	1.063	1.004	0.973	0.926	0.847	0.757
S. Em. ±	0.003	0.002	0.005	0.006	0.006	0.005
C. D. at 1 %	0.011	0.009	0.019	0.025	0.023	0.020
Interaction (V × N)						
V₁N₁	1.114	1.071	1.020	0.980	0.901	0.810
V₁N₂	1.119	1.073	1.024	0.984	0.903	0.814
V₁N₃	1.106	1.057	1.006	0.966	0.886	0.796
V₁N₄	1.127	1.088	1.037	1.002	0.918	0.828
V₁N₅	1.122	1.081	1.033	0.992	0.912	0.822
V₁N₆	1.110	1.062	1.013	0.972	0.892	0.802
V₁N₇	1.100	1.043	1.011	0.958	0.879	0.789
V₂N₁	1.048	1.018	0.986	0.927	0.949	0.757
V₂N₂	1.055	1.025	0.994	0.932	0.952	0.760
V₂N₃	1.035	1.005	0.964	0.912	0.934	0.742
V₂N₄	1.068	1.038	1.007	0.945	0.965	0.775
V₂N₅	1.061	1.031	0.998	0.942	0.961	0.771
V₂N₆	1.042	1.011	0.970	0.924	0.844	0.853
V₂N₇	1.026	0.966	0.936	0.895	0.815	0.725
Mean	1.08	1.04	1.00	0.952	0.908	0.789
S. Em. ±	0.004	0.003	0.007	0.009	0.009	0.007
C. D. at 1 %	NS	0.012	NS	NS	0.033	0.028

V₁= Seed lot-1 (Seed lot with high vigour 85% germination)

V₂= Seed lot-2 (Seed lot with low vigour, 55% germination)

N₁= AgNPs@500 ppm, N₂= AgNPs@1000 ppm, N₃= AgNPs@1500 ppm, N₄= FeNPs@500 ppm, N₅= FeNPs @1000 ppm, N₆=FeNPs @1500 ppm, N₇= without nanoparticle treatment (control)

Table.5 Effect of seed vigour levels and nanoparticles seed treatments on electrical conductivity (dS^{-1}m) of soybean

Treatments	Storage period(months)					
	Initial	2	4	6	8	10
Seed quality (V)						
V ₁ -High vigour	0.48	0.57	0.71	1.11	1.47	1.73
V ₂ -Low vigour	0.58	0.68	0.80	1.26	1.68	2.15
S. Em. ±	0.00	0.01	0.01	0.01	0.01	0.02
C. D. at 1 %	0.02	0.02	0.02	0.04	0.03	0.07
Nanoparticles treatments (N)						
N ₁	0.53	0.63	0.76	1.18	1.57	1.91
N ₂	0.52	0.62	0.74	1.16	1.55	1.84
N ₃	0.55	0.65	0.78	1.22	1.67	2.07
N ₄	0.49	0.59	0.72	1.13	1.46	1.81
N ₅	0.51	0.60	0.73	1.15	1.48	1.82
N ₆	0.55	0.64	0.77	1.20	1.61	1.97
N ₇ (control)	0.56	0.66	0.79	1.24	1.69	2.16
S. Em. ±	0.01	0.01	0.01	0.02	0.01	0.04
C. D. at 1 %	0.03	0.05	0.04	0.08	0.06	0.14
Interaction (V × N)						
V ₁ N ₁	0.48	0.57	0.71	1.11	1.46	1.69
V ₁ N ₂	0.46	0.56	0.69	1.09	1.46	1.58
V ₁ N ₃	0.51	0.60	0.74	1.16	1.62	1.96
V ₁ N ₄	0.43	0.53	0.67	1.05	1.30	1.55
V ₁ N ₅	0.45	0.55	0.68	1.07	1.32	1.56
V ₁ N ₆	0.51	0.59	0.72	1.13	1.54	1.81
V ₁ N ₇	0.53	0.61	0.74	1.18	1.62	1.97
V ₂ N ₁	0.58	0.68	0.81	1.25	1.67	2.13
V ₂ N ₂	0.57	0.67	0.79	1.24	1.64	2.10
V ₂ N ₃	0.59	0.70	0.82	1.28	1.73	2.18
V ₂ N ₄	0.56	0.66	0.77	1.22	1.63	2.08
V ₂ N ₅	0.57	0.66	0.78	1.23	1.64	2.08
V ₂ N ₆	0.59	0.69	0.81	1.28	1.68	2.13
V ₂ N ₇	0.59	0.71	0.83	1.30	1.75	2.35
Mean	0.530	0.711	0.756	1.184	1.575	1.940
S. Em. ±	0.01	0.02	0.02	0.03	0.02	0.05
C. D. at 1 %	NS	NS	NS	NS	0.08	NS

V₁= Seed lot -1 (Seed lot with high vigour 85% germination)

V₂= Seed lot -2 (Seed lot with low vigour, 55% germination)

N₁= AgNPs @500 ppm, N₂= AgNPs @1000 ppm, N₃= AgNPs @ 1500 ppm, N₄= FeNPs @500 ppm, N₅= FeNPs @1000 ppm, N₆=FeNPs @ 1500 ppm, N₇= without nanoparticle treatment (control)

A gradual reduction in seed quality parameters were observed with the increase in storage period was noticed across all treatments. From the FeNPs 500ppm (N₄) (70.2 %) treated seeds maintained above 70 per cent

germination percentage meeting the minimum germination requirement prescribed as per Minimum Seed Certification Standards (IMSCS) (Anon., 2013d) up to four months. However it's physiological and mechanical

mechanisms are still poorly understood with respect to storage potentiality of seed.

In this present investigation to enhanced storability in nanoparticles seed treatment may be due possible resonance as a phenomenon which enhances seed germination performance and vigour. Further, nanoparticles seed treatment reduced conductivity of leachate through rearranging the membrane content and leadings to increase the water absorption and ionic currents in the seeds. The present findings are in accordance with Vashisth and Nagarajan (2009) in maize and reported that treating of seed to nanoparticles seed treatment reversed the extend of the deterioration caused by ageing as attributed by higher germination per cent, seedling length and seedling dry weight. Similar observation was also made by Girishet *al.* (2011) in cotton and Anon, (2013b) in pea.

The probable reason for the enhanced germination due to the nano size of particles allow them to penetrate through seed coat easily and hence, provided better absorption and utilization of these particles by seeds. The beneficial effect of the these NPs in improving the germination and production of essential biomolecules as well as essential nutrients required for plant growth and are important components of various enzymes which are responsible for driving many metabolic reaction (Senthilkumar, 2011).

Interaction effect between seed lots (V) and nanoparticles (N) seed treatment ($V \times N$) was found to be non-significant for all the seed quality parameters studied throughout storage period of ten months. However, decrease in seed quality parameters except electrical conductivity values with increase in storage period was noticed in all the treatment combination.

In general higher seed germination (90.75 %), root length (17.85 cm), shoot length (14.64

cm), seedling length (32.49 cm), seedling dry weight (1.127 g), seedling vigour index (2890), lower electrical conductivity (0.43 dS m^{-1}) were seen in the treatment combination of high vigour seed lot with FeNP500 ppm (V_1N_4) compared to untreated low vigour seed lot (V_2N_7) (59.50 %, 15.39 cm, 11.06 cm, 26.45 cm, 1.026 g, 1433.03, and 0.59 dS m^{-1}) at the end of ten months of storage period.

From the FeNP 500 ppm (N_4) (70 %) treated seeds maintained above 70 per cent germination percentage meeting the minimum germination requirement prescribed as per Indian Minimum Seed Certification Standards (IMSCS) (Anon., 2013d) up to eight months.

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