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Effect of titanium dioxide (TiO_2) nanoparticles on the storability of onion (*Allium cepa* L.) seeds under ambient condition

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ABSTRACT

TiO_2 nanoparticles are highly stable, eco-friendly in nature, having low cost, act as a photo catalyst also having antimicrobial properties. Considering the effect of TiO_2 nanoparticles on seeds, a study was conducted during March 2022 to June 2022 at Department of Genetics and Plant Breeding, SHUATS, Prayagraj (U.P). In this study onion seeds of variety Nasik Red N-53 were collected to investigate the effect of TiO_2 nanoparticles on the seedling characters as well as on the biochemical characters under storage in ambient conditions. Onion seeds were treated with different concentration of TiO_2 nanoparticles (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130 and 140 ppm) along with control and stored in two containers; viz. tin container (C_1) and aluminum foil pouch (C_2). All the seedling parameters were evaluated every month during storage. The experiment was conducted in factorial CRD with 4 replications. The experimental result showed that the storage containers influenced the seedling characters of onion. Seeds stored in aluminum foil pouch (C_2) exhibited highest germination per cent (52.93 %), speed of germination (3.76), root length (2.27 cm), shoot length (4.11 cm), seedling length (6.38 cm), fresh weight (0.176 gm), dry weight (0.0205 gm), seed density (1.025 gm/cm^3), dehydrogenase activity (0.213 OD/g mL), catalase activity (0.0220 nmol/min/mg protein) and exhibited lowest moisture per cent (8.05 %) and lowest electrical conductivity (0.970 dS/m) as compared to tin container at the end of 3 months of storage. Seed treated with TiO_2 nanoparticles @40ppm (T_4) for 2 hours performed better in terms of seedling parameters; viz. germination per cent (58.5 %), speed of germination (4.20), root length (3.06 cm), shoot length (4.58 cm), seedling length (7.64 cm), fresh weight (0.222 gm), dry weight (0.0259 gm), seed density (1.056 gm/cm^3), dehydrogenase activity (0.337 OD/g mL), catalase activity (0.0375 nmol/min/mg protein) and recorded lowest moisture per cent (8.04 %) and lowest electrical conductivity (0.951 dS/m) as compared to control after 3 months of storage. The study concluded that seed treated with TiO_2 @40 ppm and stored in aluminum foil pouch can be used to expand the storability of onion seeds under ambient condition.

Introduction

Onion (*Allium cepa* L.) is one of the important vegetable crops that belongs to the family Amaryllidaceae. It is a cross pollinated crop having diploid chromosome number (2n = 16). It also known as the bulb onion or common onion, which is the most widely cultivated species of the genus *Allium* (Carl Linnaeus). Onion grows mainly in rabi season. It belongs to the biennial crop and requires two seasons for the production of seeds. Bulbs are produced in first year and stalks are grown, and seed are developed in second season. It is a long-day plant. The size of bulb and seedling

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length is affected by the day length but for seed production the day length has no influence. During early development of the bulb and during early growth of seed stalk the crop requires cool climate. To get high quality of bulbs, quality seeds are required at appropriate time. Loss of vigour in onion seeds due to moisture, relative humidity (RH) and temperature shifting, is the reason of poor storage life of the seeds. Seed deterioration mainly depends on the storage conditions of the seeds. If controlled storage facility is not possible then proper storage container must use to slow the deterioration. Rigid plastic container cannot absorb moisture, so they do not deteriorate and able to store seeds for long time (Flatman, 1977). Aluminum foil pouches and metal cans are most economical for packing small quantities like flower and vegetable hybrid seeds etc. (Khan *et al.,* 2018).

Nanotechnology is a connecting field between life sciences, material sciences and information technology. Among the advances in science, nanotechnology is visualized as a rapidly developing field that has the potential to improve agriculture and the food system (Mohanraj and Chen, 2006.). A nanoparticle is a small particle whose size is ranging between 1 and 100 nano-meters, undetectable to the human eyes. It poses high surface to volume ratio could be a reason for its reactivity, the ability to pierce the cell membranes and regulating biochemical activity of the seeds (Dubchak *et al.,* 2010). Seed priming method particularly nano-priming is more effective due to its small size and unique physiochemical property. Plant species differs physiologically so their uptake of nanoparticles and the effects of different concentration of nanoparticle on them may differs from plant to plant. Researchers have found that nanoparticle seed treatment could improve the seedling character (Singh *et al.,* 2012), induce growth and development of plants (Khater, 2014), increase the yield potential (Mathew *et al.,* 2021) and improve the storage life of seeds (Das and Dutta. 2022). Titanium dioxide (TiO_2) nanoparticles are the most common nanoparticles frequently used in diversified fields but there are less reviews on the effect of TiO_2 nanoparticles on plants compared to animals. TiO_2 act as a photo catalyst thus it helps in activating the photo reactions and helps in carbohydrate metabolism (Daood *et al*., 1998). It was found to give resistant to some bacteria, fungi and other organisms (Navarro *et al*., 2008) and it was reported in promoting the cell division at lower concentrations (Badiyeh *et al*., 2017). Some previous research concluded that nanosized TiO_2 at lower concentration could promote the seed germination in wheatgrass (Azimi *et al*., 2013) and in *Cannabis sativa* L. (Feizi and Javedanipour, 2021). Although the effect of nano priming with TiO_2 at different concentrations on onion seed germination is rarely reported but it is definite that use of nanoparticles can be one of the ways to retain the vigour and viability during storage by preventing the losses due to biotic and abiotic stress. Titanium dioxide (TiO_2) nanoparticles (NPs) are known for high stability and low costs, environmental-friendly in nature and found to be safe for human.

On the basis of above context, the study was conducted to find out the effect of different storage containers and TiO_2 nanoparticles treatments on the storage life of the onion seeds.

Material and Methods

Experimental site: The current study was conducted in a factorial CRD with four replications and the experiment was conducted at Seed Testing Laboratory (Notified by Govt. of Uttar Pradesh), Department of Genetics and Plant Breeding, Naini Agricultural Institute (NAI) and the preparation of nanoparticle solutions was done at Biochemistry laboratory, Department of Biochemistry & Biochemical Engineering, Sam Higginbottom University of Agriculture, Technology & Sciences Prayagraj (U.P.) during March 2022 to June 2022.

Source of seeds and TiO_2 nanoparticles: The seeds of onion variety Nasik Red N-53 were collected from Department of Genetics and Plant Breeding. The TiO_2 nanoparticle was purchased from Saveer Matrixnano Private Limited, Greater Noida, Uttar Pradesh with a purity of ≥98% and particle size of (50-80nm).

Preparation of TiO_2 nanoparticle solution: The required concentration of nanoparticles was prepared for the experiment as per the procedures given by Hao *et al*., 2016.

Seed treatment and preparation of seeds for storage: After recording the initial seed quality parameters, seeds of onion variety Nasik red N-53 were soaked in different concentration of nanoparticle solution (T_1:10ppm, T_2:20 ppm, T_3:30 ppm, T_4:40 ppm, T_5:50 ppm, T_6:60 ppm, T_7:70 ppm, T_8:80 ppm, T_9:90 ppm, T_{10}:100 ppm, T_{11}:110 ppm, T_{12}:120 ppm, T_{13}:130 ppm and T_{14}:140 ppm) for 2 hours along with T_0:Control (untreated) and then seeds were dried over night to safe moisture limit and then was packed in two containers viz. tin container (C_1) and aluminum foil pouch (C_2) and then stored under ambient condition (25 ± 3°c) with 95% RH in Seed Testing Laboratory. Seed parameters were observed every month during storage up to 3 months.

The observations recorded during storage are

1. **Germination per cent**: It was measured using Top of Paper methods as per ISTA, 2015. It was calculated by the formula

$$\textbf{Germination (\%)} = \frac{\text{Number of seed germinated}}{\text{Number of seed placed}} \times 100$$

2. **Speed of germination***:* It was measured by the formula given by Magurie, 1962. Speed of germination was calculated using formula:

$$SG = \frac{X_1}{Y_1} + \frac{X_2 - X_1}{Y_2} + \ldots\ldots \frac{X_n - X_{n-1}}{Y_n}$$

X_1= Number of seeds germinated on first count; X_n= Number of seeds germinated on final count; Y_1= No of days from sowing to 1st count; Y_n= No of days from sowing to final count

3. **Moisture per cent**: Seed moisture content was determined by low constant oven method as per ISTA, 2015.

4. Root length (cm): 10 healthy seedlings from each replication were selected randomly on the 12th day and their root length was measured from the tip of the primary root to the base of hypocotyl (ISTA, 2015).

5. Shoot length (cm): 10 random seedlings selected for root length measurement. The shoot length was measured from the tip of the primary leaf to the base of the hypocotyls (ISTA, 2015).

6. Seedling length (cm): Seedling length was calculated by adding root and shoot length.

7. Fresh weight (gm): 10 healthy seedlings were picked randomly from each replication and the fresh weight of the seedlings was measured with the help of electronic balance (ISTA, 2015).

8. Dry weight (gm): It was measured using the methods given by ISTA, 2015.

9. Electrical conductivity: It was measured by the procedures of Brar *et al*., (2019) and it was expressed in dS/m.

10. Seed density (gm/cm^3): It was measured by the formula = (weight of the seed) / (volume of the seeds).

11. Dehydrogenase activity: DHA was measured as per the procedure given by Brar *et al*., (2019) using 0.5% tetrazolium solution. The absorbance was recorded at 480 nm in a spectrophotometer, and enzymatic activity was expressed as OD/g mL (Brar *et al*., 2019). The 200 mg flour prepared was soaked in 5 mL of 0.5% tetrazolium chloride solution at 38°C for 3-4 h and followed by centrifugation for 3 minutes at 10,000 rpm and the supernatant was discarded. The formazan from the sediment was extracted with 10 mL acetone and left for 16 h then followed by centrifugation and absorbance of the solution was recorded at 480 nm using spectrophotometer.

12. Catalase activity: The extraction process was used following protocol of Dhindsa *et al.,* (1981). The catalase activity was determined using following protocol of Aebi *et al.,* (1984). The reaction mixture was comprised of 0.1ml enzyme extract, 1.50ml phosphate buffer (50mM, pH 7.0) and 0.10ml H_2O_2 (10mM) with the final volume made to 3ml with distilled water. Soon after addition of H_2O_2 to the reaction mixture, decrease in the absorbance was noted at 240nm using spectrophotometer for one min at an interval of 15 seconds. The activity of catalase was expressed as nmol/min/mg protein (Brar *et al*., 2019)

Statistical analysis: All the data were analyzed by factorial CRD and the mean was subjected to the critical difference at 5 % level of significance, and the data was analyzed using OPSTAT software.

Results and Discussion

Effect of storage containers on seedling parameters: The storage containers significantly influenced the seed quality parameters after 3 months of storage. The study revealed that seeds stored in aluminum foil pouch (C_2) performed better than tin container (C_1) during the storage period. Reduction of germination per cent was observed in both containers but lowest reduction was found in aluminum foil pouch (66% to 52.93%) compared to tin container (66% to 50.53%) (Table 1).

Table 1. Influence of storage containers and seed treatments on germination per cent, speed of germination, moisture per cent and root length of onion seeds during storage

Containers (C)	Germination percent				Speed of germination				Moisture per cent				Root length (cm)			
	Initial	Months after storage			Initial	Months after storage			Initial	Months after storage			Initial	Months after storage		
		1	2	3		1	2	3		1	2	3		1	2	3
C_1	66.00	57.73	54.47	50.53	4.834	3.930	3.762	3.520	7.80	8.07	8.09	8.24	3.95	2.41	2.29	2.18
C_2		**58.07**	**56.57**	**52.93**		**4.057**	**3.909**	**3.765**		**8.00**	**8.03**	**8.05**		**2.54**	**2.44**	**2.27**
Mean		57.90	55.52	51.73		3.993	3.835	3.642		8.03	8.06	8.15		2.48	2.37	2.22
S.Em. (±)		0.55	0.35	0.20		0.040	0.040	0.010		0.01	0.01	0.01		0.06	0.04	0.01
S.Ed. (±)		0.78	0.50	0.29		0.050	0.060	0.010		0.01	0.01	0.01		0.08	0.05	0.01
CD @ 5%		NS	0.99	0.57		0.110	0.110	0.020		0.03	0.02	0.02		NS	0.10	0.02
Treatments (T)																
T_0	66.00	58.75	54.75	50.75	4.834	3.966	3.749	3.583	7.80	8.15	8.21	8.30	3.95	2.98	2.75	2.47
T_1		61.00	58.75	54.50		4.103	3.998	3.847		8.00	8.04	8.15		3.17	2.83	2.67
T_2		63.50	60.50	56.00		4.256	4.138	3.932		7.98	8.01	8.13		3.36	3.05	2.82
T_3		64.00	61.50	57.00		4.577	4.335	4.125		7.95	7.94	8.06		3.44	3.26	2.98
T_4		**64.25**	**62.25**	**58.50**		**4.620**	**4.540**	**4.209**		**7.91**	**7.90**	**8.04**		**3.53**	**3.31**	**3.07**
T_5		61.75	59.75	56.50		4.552	4.305	4.094		8.03	8.04	8.10		3.00	3.17	2.96
T_6		59.00	57.00	55.00		4.124	3.846	3.810		8.06	8.09	8.19		2.51	2.85	2.68
T_7		58.75	55.75	52.50		3.988	3.923	3.688		8.03	8.05	8.15		2.60	2.39	2.41
T_8		57.25	54.25	49.75		3.806	3.768	3.642		8.05	8.04	8.16		2.15	1.89	2.02
T_9		54.75	52.50	50.00		3.774	3.649	3.455		8.03	8.06	8.14		1.92	1.79	1.70
T_{10}		56.25	52.50	50.25		3.633	3.568	3.354		8.03	8.06	8.11		1.77	1.67	1.58
T_{11}		56.25	50.75	47.50		3.786	3.478	3.287		8.08	8.14	8.16		1.70	1.84	1.56
T_{12}		51.75	52.00	46.25		3.648	3.464	3.246		8.04	8.10	8.15		1.77	1.59	1.54
T_{13}		49.75	50.50	46.25		3.390	3.405	3.220		8.10	8.10	8.20		1.66	1.55	1.47
T_{14}		51.50	50.00	45.25		3.678	3.367	3.146		8.08	8.09	8.19		1.59	1.55	1.44
Mean		57.90	55.52	51.73		3.993	3.835	3.642		8.03	8.06	8.15		2.48	2.37	2.22
S.Em. (±)		1.50	0.96	0.56		0.100	0.110	0.020		0.03	0.02	0.02		0.15	0.10	0.02
S.Ed. (±)		2.12	1.36	0.79		0.150	0.150	0.030		0.04	0.03	0.03		0.21	0.14	0.03
CD @ 5%		4.22	2.71	1.56		0.290	0.300	0.070		0.07	0.06	0.06		0.43	0.28	0.05

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140ppm

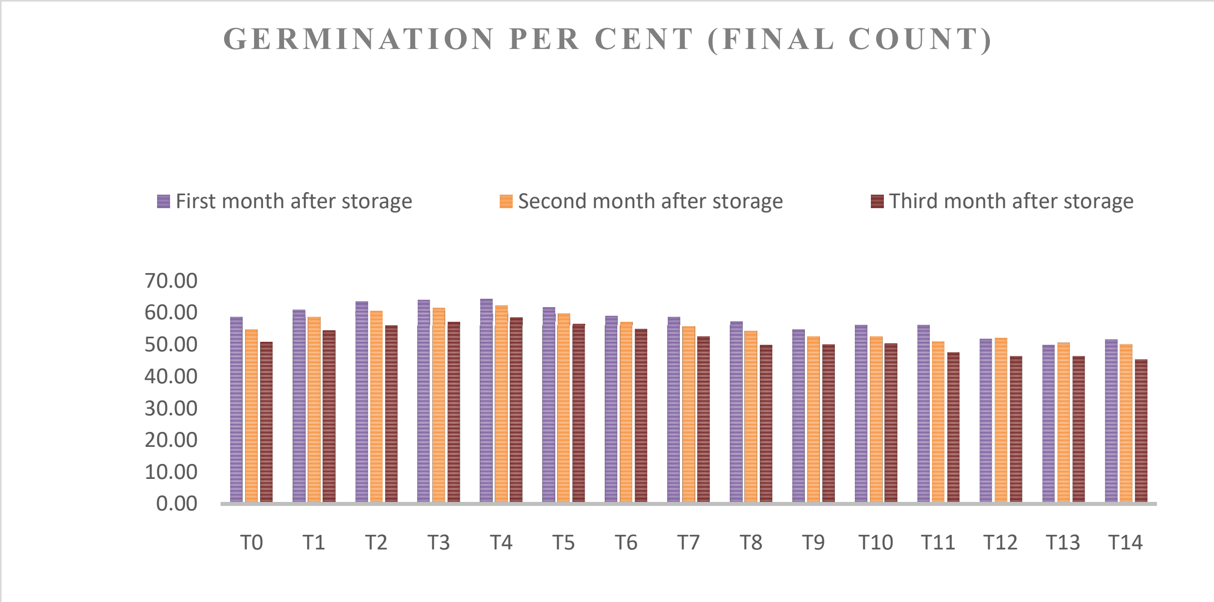

Figure 1. Effect of seed treatments on germination per cent (Final count) in onion variety Nasik Red N-53 during seed storage

Similar results were found by (Khan *et al*., 2018), (Rolston *et al*., 2012), (Kandil *et al*., 2013) reported that aluminum foil pouch performed slightly better due to its moisture vapour proof nature, so seed deterioration was slow whereas tin container is moisture proof in nature (not vapour proof) (Monira *et al*., 2012) so the deterioration was slightly on higher side. The initial speed of germination of the onion seed was 4.834 but with the advancement of the storage period it was decreased to 3.520 in tin container (C_1) and 3.765 in aluminum foil pouch (C_2). Initial moisture content before storage was 7.80% but it was increased with the increasing storage period. The inclination was lower in the seeds stored in aluminum foil pouch (7.80% to 8.05%) due its moisture vapour proof nature, so it does not absorb moisture from surroundings whereas slightly higher inclination was found in tin container (7.80% to 8.24%) (Kandil *et al*., 2013) (Table 1). Initial root length (Table 1), shoot length (Table 3) and seedling length (Table 2) was declined with the advancement of storage period. Aluminum foil pouch recorded lowest declination in root length (3.95 cm to 2.27 cm), shoot length (5.47 cm to 4.12 cm) and seedling length (9.42 cm to 6.39 cm) as compare to tin container. Alike evident was reported by Hunje *et al*., (2007). The initial fresh weight and dry weight was declined with increasing storage period. Lowest reduction in fresh weight (0.256 gm to 0.176 gm) and dry weight (0.0335 gm to 0.0205 gm) was found with the seeds stored in aluminum foil pouch (C_2) compared to tin container (C_1) (Table 2). An increasing trend was found in electrical conductivity during storage period. The enhancement was less in aluminum foil pouch (0.848 dS/mto 0.970 dS/m) compared to tin container (0.848 dS/mto 0.990 dS/m) (Table 3). Alike evident of electrical conductivity was reported by Hunje *et al*., (2007), concluded that seeds stored in aluminum foil pouch continued to maintain the membrane integrity by reducing physiological and biochemical process thus improve the storage life of the seeds. The initial seed density was 1.077 gm/cm^3 which decreased to 1.025 gm/cm^3 in aluminum foil pouch and 1.016 gm/cm^3 in tin container at the end of the storage period (Table 3). The initial dehydrogenase and catalase activity was 0.446 OD/g mL and 0.0625 nmol/min/mg proteinbut it declined with the advancement of storage period. Although the declination was minimum in aluminum foil pouch (C_2) over tin container (C_1) (Table 3).

Table 2. Influence of storage containers and seed treatments on shoot length, seedling length, fresh weight and dry weight of onion seeds during storage

	Shoot length (cm)				Seedling length (cm)				Fresh weight (gm)				Dry weight (gm)			
Containers (C)	**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**		
		1	2	3		1	2	3		1	2	3		1	2	3
C_1	5.47	4.80	4.34	3.96	9.42	7.21	6.62	6.13	0.256	0.218	0.210	0.167	0.0335	0.0252	0.0243	0.0195
C_2		**4.96**	**4.45**	**4.12**		**7.50**	**6.89**	**6.39**		**0.227**	**0.218**	**0.176**		**0.0264**	**0.0251**	**0.0205**
Mean		4.88	4.39	4.04		7.36	6.76	6.26		0.223	0.214	0.171		0.0258	0.0247	0.0200
S.Em. (±)		0.01	0.01	0.01		0.06	0.04	0.01		0.001	0.002	0.000		0.0001	0.0003	0.0001
S.Ed. (±)		0.01	0.01	0.01		0.08	0.05	0.02		0.002	0.003	0.001		0.0002	0.0004	0.0001
CD @ 5%		0.02	0.03	0.02		0.15	0.11	0.03		0.004	0.007	0.001		0.0004	0.0008	0.0002
Treatments (T)																
T_0	5.47	4.84	4.48	4.06	9.42	7.82	7.23	6.53	0.256	0.219	0.196	0.165	0.0335	0.0254	0.0225	0.0194
T_1		5.14	4.75	4.34		8.32	7.58	7.01		0.224	0.214	0.183		0.0260	0.0248	0.0214
T_2		5.16	4.77	4.44		8.52	7.81	7.26		0.227	0.219	0.190		0.0264	0.0253	0.0223
T_3		5.22	4.86	4.52		8.66	8.12	7.50		0.246	0.242	0.209		0.0285	0.0281	0.0245
T_4		**5.27**	**4.97**	**4.58**		**8.79**	**8.29**	**7.65**		**0.260**	**0.245**	**0.222**		**0.0303**	**0.0289**	**0.0259**
T_5		5.00	4.72	4.48		8.00	7.88	7.45		0.246	0.235	0.208		0.0284	0.0274	0.0243
T_6		4.94	4.63	4.30		7.44	7.47	6.98		0.245	0.237	0.194		0.0281	0.0273	0.0228
T_7		4.91	4.52	4.20		7.51	6.91	6.61		0.240	0.234	0.184		0.0274	0.0270	0.0214
T_8		4.88	4.49	4.04		7.03	6.39	6.06		0.230	0.213	0.162		0.0268	0.0248	0.0189
T_9		4.77	4.34	3.86		6.69	6.13	5.57		0.217	0.227	0.154		0.0250	0.0264	0.0180
T_{10}		4.66	4.24	3.65		6.43	5.91	5.23		0.207	0.201	0.144		0.0239	0.0233	0.0170
T_{11}		4.62	3.94	3.62		6.32	5.78	5.18		0.201	0.192	0.146		0.0233	0.0223	0.0169
T_{12}		4.64	3.95	3.50		6.40	5.53	5.04		0.199	0.192	0.141		0.0231	0.0221	0.0163
T_{13}		4.60	3.65	3.52		6.26	5.20	4.99		0.196	0.186	0.135		0.0226	0.0209	0.0158
T_{14}		4.57	3.61	3.42		6.15	5.16	4.86		0.185	0.175	0.132		0.0215	0.0196	0.0151
Mean		4.88	4.39	4.04		7.36	6.76	6.26		0.223	0.214	0.171		0.0258	0.0247	0.0200
S.Em. (±)		0.02	0.02	0.02		0.15	0.11	0.03		0.004	0.007	0.001		0.0004	0.0008	0.0002
S.Ed. (±)		0.03	0.03	0.03		0.21	0.15	0.04		0.006	0.010	0.002		0.0010	0.0011	0.0003
CD @ 5%		0.05	0.07	0.06		0.42	0.30	0.08		0.012	0.021	0.004		0.0012	0.0022	0.0006

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140ppm

Table 3. Influence of storage containers and seed treatments on electrical conductivity, seed density, dehydrogenase activity and catalase activity of onion seeds during storage.

	Electrical conductivity (dS/m)				Seed density (gm/cm^3)				Dehydrogenase activity (OD/g mL)				Catalase activity (nmol/min/mg protein)			
Containers (C)	**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**		
		1	2	3		1	2	3		1	2	3		1	2	3
C_1	0.848	0.962	0.978	0.990	1.077	1.038	1.029	1.016	0.446	0.243	0.209	0.197	0.0625	0.0271	0.0226	0.0191
C_2		**0.938**	**0.947**	**0.970**		**1.042**	**1.033**	**1.025**		**0.256**	**0.229**	**0.213**		**0.0311**	**0.0245**	**0.0220**
Mean		0.950	0.962	0.980		1.040	1.031	1.021		0.250	0.219	0.205		0.0291	0.0235	0.0206
S.Em. (±)		0.002	0.003	0.001		0.001	0.001	0.001		0.006	0.001	0.001		0.001	0.0001	0.0001
S.Ed. (±)		0.003	0.005	0.001		0.002	0.001	0.002		0.008	0.001	0.001		0.001	0.0001	0.0001
CD @ 5%		0.006	0.010	0.002		0.003	0.003	0.003		NS	0.002	0.002		0.002	0.001	0.001
Treatments (T)																
T_0		0.984	1.014	1.077		1.018	1.010	0.990		0.292	0.223	0.209		0.0164	0.0131	0.0114
T_1		0.962	0.959	0.982		1.031	1.021	1.011		0.320	0.272	0.255		0.0243	0.0206	0.0168
T_2		0.955	0.956	0.970		1.051	1.039	1.028		0.354	0.320	0.298		0.0285	0.0246	0.0224
T_3		0.939	0.948	0.961		1.060	1.048	1.043		0.383	0.337	0.318		0.0424	0.0377	0.0338
T_4		**0.913**	**0.934**	**0.951**		**1.075**	**1.066**	**1.056**		**0.399**	**0.365**	**0.337**		**0.0572**	**0.0436**	**0.0375**
T_5		0.944	0.952	0.963		1.052	1.045	1.039		0.378	0.335	0.316		0.0417	0.0373	0.0309
T_6		0.950	0.956	0.974		1.039	1.033	1.030		0.339	0.265	0.251		0.0295	0.0261	0.0233
T_7		0.960	0.967	0.978		1.038	1.027	1.023		0.270	0.234	0.218		0.0282	0.0215	0.0195
T_8	0.848	0.954	0.968	0.980	1.077	1.028	1.022	1.019	0.446	0.201	0.217	0.195	0.0625	0.0240	0.0195	0.0176
T_9		0.950	0.955	0.980		1.032	1.028	1.019		0.175	0.136	0.134		0.0281	0.0213	0.0190
T_{10}		0.951	0.956	0.985		1.031	1.031	1.018		0.135	0.129	0.122		0.0260	0.0188	0.0173
T_{11}		0.949	0.960	0.969		1.032	1.039	1.019		0.139	0.118	0.116		0.0248	0.0207	0.0163
T_{12}		0.945	0.967	0.976		1.038	1.026	1.013		0.126	0.113	0.106		0.0218	0.0199	0.0155
T_{13}		0.948	0.976	0.973		1.037	1.021	1.004		0.115	0.110	0.103		0.0250	0.0142	0.0140
T_{14}		0.949	0.967	0.982		1.040	1.016	0.999		0.115	0.109	0.096		0.0184	0.0137	0.0133
Mean		0.950	0.962	0.980		1.040	1.031	1.021		0.250	0.219	0.205		0.0291	0.0235	0.0206
S.Em. (±)		0.006	0.01	0.002		0.003	0.003	0.003		0.016	0.002	0.002		0.002	0.001	0.001
S.Ed. (±)		0.009	0.013	0.003		0.004	0.004	0.004		0.023	0.003	0.002		0.003	0.001	0.001
CD @ 5%		0.018	0.027	0.006		0.009	0.008	0.008		0.046	0.005	0.005		0.006	0.003	0.002

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140ppm

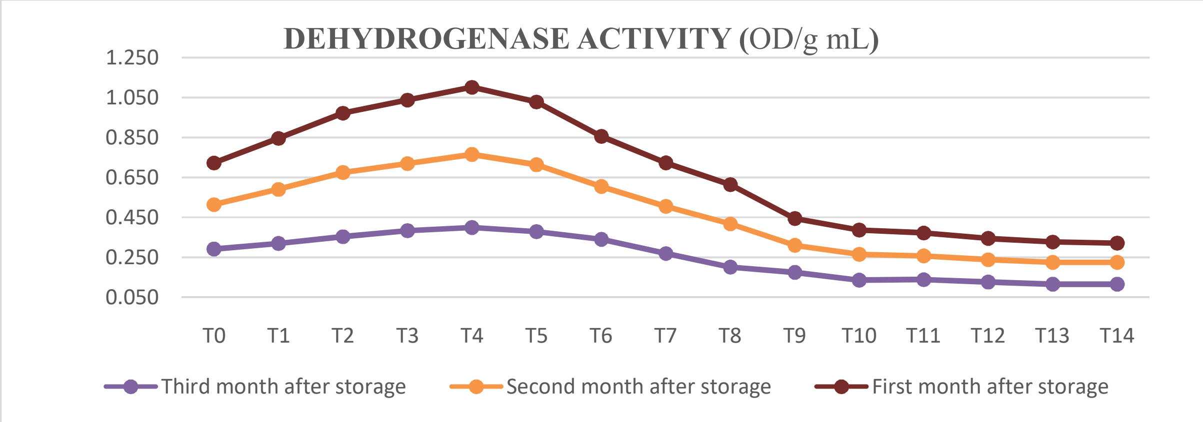

Figure 2. Effect of seed treatments on dehydrogenase activity (OD/g mL) in onion variety Nasik Red N-53 during seed storage

Effect of TiO_2 nanoparticle treatment on seedling parameters: A significant difference was observed for all the parameters of TiO_2 nanoparticle treated seeds. Germination per cent significantly reduced in all treatments from the initial to the end of the storage period. The lowest reduction trend was found in onion seeds treated with TiO_2 @40ppm (T_4) (66% to 58.50%) followed by TiO_2 @30ppm (T_3) and highest reduction was found in TiO_2 @140ppm (66% to 45.25%) (Table 1 and fig 1). The germination per cent was decreased in TiO_2 @80ppm and above concentration compared to the control. The reduction in germination per cent at higher concentrations might be due to the toxicity which affect the germination by reducing the water uptake (Eskandarinasab *et al.*, 2019). Alike evident was found by Azimi *et al.*, (2013) reported highest germination per cent (84%) in lower concentration of TiO_2 (40ppm) as compared to control in wheatgrass (*Agropyron desertorum*). The increase in the germination per cent at low concentration might be due to the photo sterilization and photo-generation of 'active oxygen like superoxide and hydroxide anions' which leads to increase of water and oxygen uptake by increasing the seed stress resistance and by promoting capsule penetration (Khot *et al.*, 2012) and by promoting activities of nitrate reductase enzyme and seed antioxidant system (Lu *et al.*, 2002). Similar reduction trend was found in speed of germination during storage period. The minimum decline in speed of germination was recorded withTiO_2 @ 40ppm (T_4) (4.834 to 4.209) followed by TiO_2 @30ppm (T_3) whereas maximum decline was found in TiO_2 @140ppm (4.834 to 3.146) (Table 1). It was found that speed of germination was significantly affected with TiO_2 nanoparticles at lower concentration (10ppm to 70ppm) which might be due to the increase in the cell division rate in the seed radicle meristem (Badiyeh *et al.*, 2017). Due to the hygroscopic nature of seeds, the initial moisture per cent was increased with the advancement of storage period. Seeds treated with TiO_2 @40ppm (T_4) recorded the lowest increase in moisture per cent (7.80% to8.04%) followed by TiO_2 @30ppm (T_3) whereas highest increase was recorded in control (T_0) (7.80% to 8.30%) (Table 1). Root, shoot and seedling length was significantly affected by TiO_2 nanoparticles, although the root, shoot and seedling length were decreased with the increasing storage period (Table 1 and Table 2). Application of TiO_2 @40ppm (T_4) recorded highest root length (3.07 cm), shoot length (4.58 cm) and seedling length (7.65 cm) at the end of the storage period. TiO_2 @80ppm and above concentration have showed reduction in root length, shoot length and seedling length which might be due to toxicity of TiO_2 nanoparticles (Azimi *et al.*, 2013). Feizi *et al.*, (2012) reported that seedling length is affected by lower concentrations of TiO_2 nanoparticles. Fresh weight and dry weight were significantly affected by TiO_2 nanoparticle treatment. The of storage period. The reduction was lower with TiO_2 @40ppm for fresh weight (0.256 gm to 0.222 gm) and for dry weight (0.0335 gm to 0.0259 gm) and followed by TiO_2 @30ppm. Use of TiO_2 @80ppm and above concentrations greatly reduced the fresh and dry weight, every month during storage (Table 2). Azimi *et al*., (2013) reported maximum fresh and dry weight at 40ppm of nano-TiO_2 and also reported alike decreasing trend in higher concentrations. Zhou *et al.,* (2022) stated that TiO_2 nanoparticles increase the fresh weight as compared to control. The downfall of fresh weight at higher concentration (100ppm) might be due to toxicity. Priya *et al.,* (2016) reported highest seedling dry weight at lower concentration of TiO_2 nanoparticles (20ppm, 40ppm) in cowpea might be due to the highest accumulation of dry matter content at lower concentration. Electrical conductivity was increased with the advancement of the storage period. At the end of the storage period lowest electrical conductivity (0.951 dS/m) was found at TiO_2 @40ppm (T_4) due to the less electrolyte leachate of seed coat at the particular concentration which shows less damage and more vigour but at the control (T_0) due to more damage of membrane, highest electrical conductivity (0.990 dS/m) was found (Table 3). A reduction trend was found in seed density with the advancement of the storage period. The lowest reduction was found with TiO_2 @40ppm (T_4) (1.077 gm/cm^3 to 1.075 gm/cm^3) followed by TiO_2 @30ppm (T_3) and the highest reduction was found in control (T_0) (1.077 gm/cm^{3}to 1.075 gm/cm^3) followed by TiO_2 @30ppm (T_3) and the highest reduction was found in control (T_0)(1.077 gm/cm^3 to 1.018 gm/cm^3). Shah *et al*., (2021) reported that TiO_2 nanoparticle priming significantly reduced the relative electrolyte leakages of the membrane in maize thus improve the storage. TiO_2 nanoparticle ensures the protections against the electrolyte leakages of membranes. The findings are similar with previous findings, stated that TiO_2 helps in maintaining membrane integrity (Mahmoodzadeh *et al*., 2013). Similar trend of reduction was found in dehydrogenase activity (OD value). The lowest decline was found in concentration TiO_2 @40ppm (0.446 to 0.337) followed by TiO_2 @30ppm as compared to control (Table 3 and figure 2). Dehydrogenase is a respiratory enzyme that is found in germinating seeds that catalases the food materials during respiration and yields energy to the growing seedling (Oikhena *et al*., 2013). With the increasing storage period the catalase activity was also declined. Highest catalase activity was found with TiO_2 @40ppm (T_4) (0.0375 nmol/min/mg protein) followed by TiO_2 @30ppm (T_3) over control (0.0114 nmol/min/mg protein) at the end of the storage period (Table 3 and figure 3). Catalase is an antioxidant enzyme that provides tolerance to the stress conditions (Kibinza *et al*., 2011) and its high presence in seeds indicates high seed quality (Bailly *et al*., 2001). It was suggested that priming with TiO_2 nanoparticles could improve the catalase activity in maize by scavenging reactive oxygen species (Mahmoodzadeh *et al*., 2013), (Shah *et al*., 2021). Sardar *et al*., (2021) reported an increase in catalase activity of coriander seeds treated with TiO_2 nanoparticles.

Interaction effect of storage containers and seed treatment on seedling parameters: Interaction effect due to the storage container and seed treatment was significant only after third month of storage except for the first count per cent, dry weight, seed density and catalase activity. All the seed quality parameters declined with the advancement of storage period except for electrical conductivity and moisture per cent. After 3 months of storage, the seeds treated with TiO_2 @40ppm and stored in aluminum foil pouch (C_2T_4) recorded highest germination per cent (60%) followed by seed treated with TiO_2 @30ppm and stored in aluminum foil pouch (C_2T_3) (Table 4). The same treatment combination (C_2T_4) also recorded highest speed of germination (4.358), root length (3.12 cm) (Table 5), shoot length (4.65 cm) and seedling length (7.77 cm) (Table 5) at the end of the storage period due to fast germination, cell division at radicle meristem region and root-shoot elongation. The seeds treated with TiO_2 @40ppm and stored in aluminum foil pouch (C_2T_4) recorded lowest moisture per cent (7.90%) whereas highest moisture per cent (8.40%) was recorded with untreated seeds stored in tin container (C_1T_0) after 3 months of storage (Table 4). The same treatment combination (C_2T_4) recorded highest fresh weight (0.227 gm) and dry weight (0.0265 gm) followed by the combination C_2T_3 and the lowest was recorded in the combination of seed treatment with TiO_2 @140ppm and tin container (C_1T_{14}) at the end of the storage period. Lowest electrical conductivity (0.994 dS/m) was found in the combination C_2T_4 and followed by C_2T_3 and highest electrical conductivity (1.123 dS/m) was recorded with the combination C_1T_0 at the end of the storage period (Table 6).

Table 4. Influence of interaction of storage containers and seed treatment on germination per cent, speed of germination, moisture per cent and root length of onion seeds during storage

	Germination percent				Speed of germination				Moisture per cent				Root length (cm)			
Interaction	Initial	Months after storage			Initial	Months after storage			Initial	Months after storage			Initial	Months after storage		
(CXT)		1	2	3		1	2	3		1	2	3		1	2	3
C_1T_0	66.00	58.50	53.50	49.50	4.834	3.937	3.746	3.527	7.80	8.15	8.23	8.40	3.95	2.84	2.41	2.36
C_1T_1		61.50	58.50	54.00		4.034	3.861	3.749		8.03	8.05	8.25		2.90	2.54	2.61
C_1T_2		63.50	59.00	54.50		4.106	3.916	3.790		8.00	8.03	8.23		3.23	2.97	2.80
C_1T_3		64.00	60.50	55.50		4.548	4.232	3.961		7.98	7.95	8.20		3.35	3.17	2.92
C_1T_4		64.00	61.50	57.00		4.599	4.473	4.060		7.95	7.93	8.18		3.42	3.22	3.01
C_1T_5		61.00	58.00	55.00		4.507	4.201	3.904		8.10	8.13	8.23		3.08	3.12	2.91
C_1T_6		57.50	55.00	52.50		3.978	3.824	3.658		8.10	8.15	8.33		2.83	3.02	2.75
C_1T_7		57.00	53.50	50.50		3.870	3.851	3.484		8.05	8.08	8.23		2.58	2.52	2.44
C_1T_8		56.50	53.50	48.00		3.736	3.689	3.510		8.08	8.08	8.30		1.87	1.71	2.00
C_1T_9		53.00	51.50	49.50		3.697	3.617	3.277		8.05	8.10	8.25		1.69	1.68	1.57
C_1T_{10}		56.50	52.00	49.50		3.525	3.572	3.226		8.13	8.15	8.23		1.65	1.58	1.47
C_1T_{11}		57.50	50.00	45.50		3.741	3.462	3.189		8.13	8.18	8.20		1.65	1.81	1.51
C_1T_{12}		53.50	52.00	46.50		3.649	3.438	3.157		8.08	8.10	8.20		1.85	1.49	1.49
C_1T_{13}		50.50	49.50	45.50		3.322	3.337	3.184		8.15	8.15	8.25		1.69	1.50	1.43
C_1T_{14}		51.50	49.00	45.00		3.703	3.208	3.126		8.08	8.08	8.20		1.58	1.59	1.40
C_2T_0		59.00	56.00	52.00		3.996	3.753	3.639		8.15	8.20	8.20		3.13	3.09	2.59
C_2T_1		60.50	59.00	55.00		4.173	4.136	3.946		7.98	8.03	8.05		3.45	3.12	2.73
C_2T_2		63.50	62.00	57.50		4.406	4.361	4.073		7.95	8.00	8.03		3.49	3.13	2.83
C_2T_3		64.00	62.50	58.50		4.606	4.438	4.289		7.93	7.93	7.93		3.54	3.35	3.04
C_2T_4		**64.50**	**63.00**	**60.00**		**4.641**	**4.607**	**4.358**		**7.88**	**7.88**	**7.90**		**3.64**	**3.41**	**3.12**
C_2T_5		62.50	61.50	58.00		4.597	4.410	4.285		7.95	7.95	7.98		2.92	3.22	3.02
C_2T_6		60.50	59.00	57.50		4.270	3.867	3.962		8.03	8.03	8.05		2.19	2.68	2.61
C_2T_7		60.50	58.00	54.50		4.107	3.994	3.892		8.00	8.03	8.08		2.62	2.27	2.38
C_2T_8		58.00	55.00	51.50		3.875	3.846	3.774		8.03	8.00	8.03		2.43	2.07	2.05
C_2T_9		56.50	53.50	50.50		3.851	3.681	3.633		8.00	8.03	8.03		2.15	1.90	1.84
C_2T_{10}		56.00	53.00	51.00		3.740	3.564	3.482		7.93	7.98	8.00		1.89	1.77	1.69
C_2T_{11}		55.00	51.50	49.50		3.831	3.494	3.386		8.03	8.10	8.13		1.75	1.87	1.61
C_2T_{12}		50.00	52.00	46.00		3.648	3.490	3.336		8.00	8.10	8.10		1.68	1.69	1.59
C_2T_{13}		49.00	51.50	47.00		3.458	3.473	3.256		8.05	8.05	8.15		1.63	1.60	1.51
C_2T_{14}		51.50	51.00	45.50		3.653	3.526	3.165		8.08	8.10	8.18		1.60	1.50	1.48
Mean		57.90	55.52	51.73		3.993	3.835	3.642		8.03	8.06	8.15		2.48	2.37	2.22
S.Em. (±)		2.12	1.36	0.79		0.15	0.15	0.03		0.04	0.03	0.03		0.21	0.14	0.03
S.Ed. (±)		3.00	1.93	1.11		0.21	0.21	0.05		0.05	0.04	0.04		0.3	0.2	0.04
CD @ 5%		NS	NS	2.21		NS	NS	0.09		NS	0.08	0.09		NS	NS	0.07

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140ppm

Table 5. Influence of interaction of storage containers and seed treatments on shoot length, seedling length, fresh weight and dry weight of onion seeds during storage

	Shoot length (cm)				Seedling length (cm)				Fresh weight (gm)				Dry weight (gm)			
Interaction	Initial	Months after storage			Initial	Months after storage			Initial	Months after storage			Initial	Months after storage		
CXT		1	2	3		1	2	3		1	2	3		1	2	3
C_1T_0	5.47	4.81	4.25	3.93	9.42	7.65	6.66	6.29	0.256	0.218	0.193	0.157	0.0335	0.0253	0.0223	0.0185
C_1T_1		5.04	4.55	4.25		7.93	7.09	6.86		0.221	0.210	0.179		0.0258	0.0243	0.0210
C_1T_2		5.06	4.58	4.37		8.29	7.55	7.17		0.223	0.216	0.187		0.0260	0.0250	0.0220
C_1T_3		5.11	4.64	4.44		8.47	7.81	7.36		0.240	0.238	0.205		0.0278	0.0278	0.0238
C_1T_4		5.15	4.77	4.52		8.56	7.99	7.53		0.258	0.243	0.217		0.0300	0.0283	0.0253
C_1T_5		5.02	4.58	4.42		8.10	7.69	7.32		0.240	0.235	0.204		0.0275	0.0275	0.0235
C_1T_6		4.84	4.56	4.20		7.67	7.58	6.95		0.240	0.240	0.192		0.0273	0.0275	0.0225
C_1T_7		4.83	4.56	4.07		7.40	7.08	6.51		0.232	0.235	0.178		0.0263	0.0273	0.0205
C_1T_8		4.81	4.55	3.92		6.68	6.27	5.91		0.233	0.202	0.154		0.0270	0.0233	0.0180
C_1T_9		4.72	4.54	3.83		6.40	6.22	5.39		0.207	0.228	0.146		0.0238	0.0263	0.0173
C_1T_{10}		4.57	4.49	3.61		6.22	6.07	5.08		0.199	0.197	0.138		0.0230	0.0228	0.0163
C_1T_{11}		4.54	3.92	3.58		6.18	5.73	5.10		0.194	0.182	0.144		0.0223	0.0210	0.0168
C_1T_{12}		4.55	3.99	3.40		6.40	5.48	4.89		0.198	0.182	0.140		0.0230	0.0210	0.0163
C_1T_{13}		4.51	3.57	3.47		6.20	5.07	4.90		0.194	0.177	0.133		0.0220	0.0205	0.0155
C_1T_{14}		4.48	3.53	3.34		6.06	5.12	4.74		0.179	0.168	0.130		0.0208	0.0193	0.0148
C_2T_0		4.86	4.72	4.18		7.99	7.81	6.77		0.221	0.199	0.173		0.0255	0.0228	0.0203
C_2T_1		5.25	4.96	4.44		8.70	8.07	7.17		0.226	0.219	0.188		0.0263	0.0253	0.0218
C_2T_2		5.27	4.96	4.52		8.76	8.08	7.35		0.231	0.222	0.193		0.0268	0.0255	0.0225
C_2T_3		5.33	5.09	4.60		8.86	8.44	7.64		0.253	0.246	0.214		0.0293	0.0285	0.0253
C_2T_4		**5.39**	**5.18**	**4.65**		**9.03**	**8.59**	**7.77**		**0.261**	**0.247**	**0.227**		**0.0305**	**0.0295**	**0.0265**
C_2T_5		4.98	4.86	4.55		7.90	8.07	7.57		0.252	0.235	0.213		0.0293	0.0273	0.0250
C_2T_6		5.03	4.69	4.40		7.22	7.37	7.01		0.251	0.234	0.196		0.0290	0.0270	0.0230
C_2T_7		4.99	4.48	4.34		7.61	6.75	6.72		0.248	0.233	0.191		0.0285	0.0268	0.0223
C_2T_8		4.96	4.43	4.17		7.39	6.51	6.22		0.227	0.224	0.170		0.0265	0.0263	0.0198
C_2T_9		4.83	4.14	3.90		6.98	6.04	5.74		0.226	0.226	0.162		0.0263	0.0265	0.0188
C_2T_{10}		4.76	3.98	3.69		6.64	5.75	5.37		0.215	0.205	0.151		0.0248	0.0238	0.0178
C_2T_{11}		4.71	3.96	3.67		6.46	5.83	5.27		0.209	0.203	0.148		0.0243	0.0235	0.0170
C_2T_{12}		4.73	3.91	3.60		6.41	5.59	5.19		0.200	0.201	0.142		0.0233	0.0233	0.0163
C_2T_{13}		4.69	3.73	3.57		6.32	5.34	5.08		0.199	0.195	0.136		0.0233	0.0213	0.0160
C_2T_{14}		4.66	3.70	3.49		6.25	5.20	4.97		0.192	0.183	0.134		0.0223	0.0200	0.0155
Mean		4.88	4.39	4.04		7.36	6.76	6.26		0.223	0.214	0.171		0.0258	0.0247	0.0200
S.Em. (±)		0.03	0.03	0.03		0.21	0.15	0.04		0.006	0.010	0.002		0.0010	0.0011	0.0003
S.Ed. (±)		0.04	0.05	0.05		0.30	0.21	0.06		0.008	0.015	0.003		0.0010	0.0016	0.0004
CD @ 5%		0.08	0.10	0.09		NS	0.42	0.12		NS	NS	0.005		NS	NS	NS

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140ppm

Table 6. Influence of interaction of storage containers and seed treatments on electrical conductivity, seed density, dehydrogenase activity and catalase activity of onion seeds during storage

	Electrical conductivity (dS/m)				Seed density (gm/cm^3)				Dehydrogenase activity (OD/g mL)				Catalase activity (nmol/min/mg protein)			
Interaction	**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**			**Initial**	**Months after storage**		
CXT		1	2	3		1	2	3		1	2	3		1	2	3
C_1T_0	0.848	0.983	1.030	1.123	1.077	1.017	1.008	0.983	0.446	0.286	0.215	0.201	0.0625	0.0145	0.0120	0.0100
C_1T_1		0.970	0.975	0.994		1.027	1.020	1.008		0.305	0.256	0.244		0.0198	0.0180	0.0143
C_1T_2		0.967	0.971	0.978		1.047	1.033	1.023		0.337	0.311	0.290		0.0263	0.0238	0.0215
C_1T_3		0.948	0.963	0.970		1.058	1.048	1.040		0.389	0.331	0.314		0.0393	0.0368	0.0318
C_1T_4		0.945	0.961	0.957		1.070	1.065	1.055		0.389	0.357	0.332		0.0545	0.0415	0.0360
C_1T_5		0.951	0.968	0.970		1.052	1.045	1.038		0.388	0.329	0.312		0.0383	0.0365	0.0288
C_1T_6		0.954	0.974	0.984		1.032	1.030	1.028		0.344	0.256	0.237		0.0253	0.0250	0.0210
C_1T_7		0.968	0.979	0.993		1.032	1.025	1.020		0.244	0.213	0.195		0.0250	0.0195	0.0178
C_1T_8		0.976	0.987	0.989		1.025	1.020	1.015		0.202	0.216	0.186		0.0270	0.0180	0.0165
C_1T_9		0.967	0.975	0.989		1.030	1.028	1.018		0.165	0.105	0.122		0.0303	0.0225	0.0170
C_1T_{10}		0.958	0.969	0.988		1.032	1.030	1.013		0.130	0.126	0.119		0.0253	0.0183	0.0165
C_1T_{11}		0.967	0.968	0.974		1.028	1.038	1.018		0.147	0.113	0.112		0.0190	0.0198	0.0148
C_1T_{12}		0.963	0.976	0.988		1.035	1.025	1.003		0.107	0.108	0.102		0.0200	0.0218	0.0145
C_1T_{13}		0.961	0.987	0.973		1.037	1.020	0.993		0.099	0.103	0.099		0.0253	0.0133	0.0130
C_1T_{14}		0.954	0.985	0.983		1.047	1.015	0.995		0.104	0.101	0.093		0.0165	0.0128	0.0128
C_2T_0		0.985	1.000	1.031		1.020	1.013	0.998		0.297	0.231	0.217		0.0183	0.0143	0.0128
C_2T_1		0.953	0.943	0.970		1.035	1.023	1.015		0.334	0.287	0.267		0.0290	0.0233	0.0193
C_2T_2		0.944	0.942	0.962		1.055	1.045	1.033		0.371	0.330	0.306		0.0308	0.0255	0.0233
C_2T_3		0.929	0.933	0.952		1.062	1.050	1.045		0.377	0.344	0.321		0.0455	0.0388	0.0358
C_2T_4		**0.882**	**0.908**	**0.944**		**1.080**	**1.068**	**1.058**		**0.409**	**0.374**	**0.343**		**0.0600**	**0.0458**	**0.0390**
C_2T_5		0.936	0.937	0.955		1.052	1.045	1.040		0.368	0.341	0.320		0.0453	0.0383	0.0330
C_2T_6		0.946	0.937	0.964		1.045	1.038	1.033		0.334	0.274	0.265		0.0338	0.0273	0.0255
C_2T_7		0.952	0.955	0.962		1.042	1.030	1.025		0.296	0.256	0.242		0.0315	0.0235	0.0213
C_2T_8		0.933	0.950	0.970		1.032	1.025	1.023		0.200	0.218	0.204		0.0210	0.0210	0.0188
C_2T_9		0.932	0.936	0.971		1.035	1.030	1.020		0.184	0.167	0.145		0.0260	0.0203	0.0210
C_2T_{10}		0.944	0.944	0.983		1.030	1.033	1.023		0.140	0.132	0.125		0.0268	0.0195	0.0180
C_2T_{11}		0.930	0.953	0.964		1.037	1.040	1.020		0.131	0.123	0.120		0.0305	0.0218	0.0178
C_2T_{12}		0.926	0.959	0.964		1.042	1.028	1.023		0.144	0.118	0.109		0.0238	0.0180	0.0165
C_2T_{13}		0.934	0.966	0.974		1.037	1.023	1.015		0.130	0.117	0.107		0.0248	0.0153	0.0150
C_2T_{14}		0.942	0.951	0.981		1.033	1.018	1.003		0.126	0.117	0.100		0.0203	0.0148	0.0138
Mean		0.950	0.963	0.980		1.040	1.032	1.021		0.249	0.219	0.205		0.0291	0.0235	0.0206
S.Em. (±)		0.009	0.013	0.003		0.004	0.004	0.004		0.023	0.003	0.002		0.003	0.001	0.001
S.Ed. (±)		0.013	0.019	0.004		0.006	0.006	0.006		0.032	0.004	0.003		0.004	0.002	0.001
CD @ 5%		NS	NS	0.008		NS	NS	NS		NS	0.008	0.007		NS	NS	NS

C_1= Tin container; C_2= Aluminum foil pouch; T_0= Control; T_1= TiO_2 @10ppm; T_2= TiO_2 @20ppm; T_3= TiO_2 @30ppm; T_4= TiO_2 @40ppm; T_5= TiO_2 @50ppm; T_6= TiO_2 @60ppm; T_7= TiO_2 @70ppm; T_8= TiO_2 @80ppm; T_9= TiO_2 @90ppm; T_{10}= TiO_2 @100ppm; T_{11}= TiO_2 @110ppm; T_{12}= TiO_2 @120ppm; T_{13}= TiO_2 @130ppm; T_{14}= TiO_2 @140

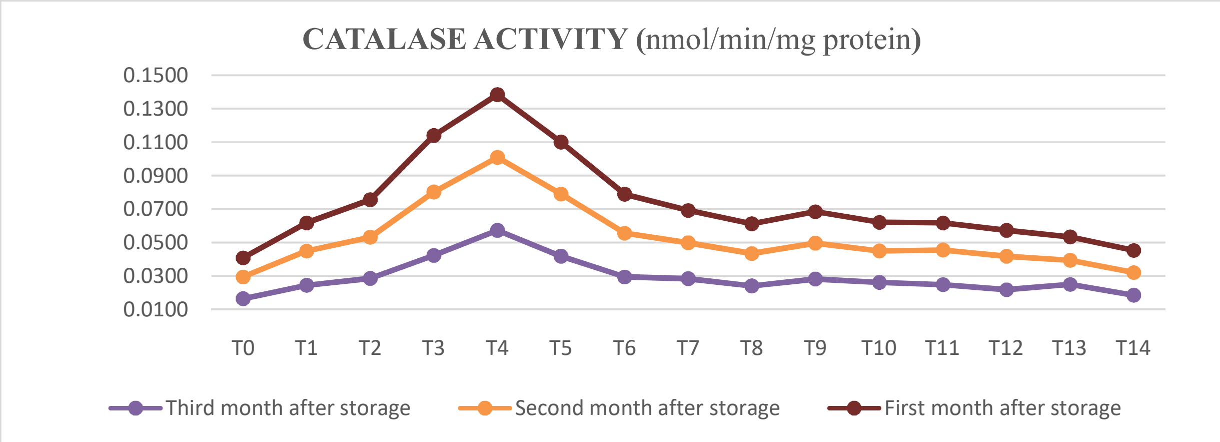

Figure 3. **Effect of seed treatments on catalase activity** (nmol/min/mg protein) **in onion variety Nasik Red N-53 during seed storage**

Similar treatment combination (C_2T_4) also exhibited highest seed density (1.058 gm/cm^3) followed by C_2T_3 after 3 months of storage and lowest seed density (0.983 gm/cm^3) was recorded with the treatment combination C_1T_0 at the end of the storage period. The combination C_2T_4 also recorded highest dehydrogenase activity (0.343 OD/g mL) and catalase activity (0.0390 nmol/min/mg protein) followed by C_2T_3 at the end of the storage period.

Conclusion

According to the current study, it is found that all the seedling parameters except electrical conductivity and moisture per cent expressed reduction trend with the advancement of storage period irrespective of storage containers and nano-TiO_2 seed treatment. It is concluded that seed treatment with TiO_2 nanoparticles have positive effect on seedling parameters as well as on the enzymatic activity (Dehydrogenase activity and catalase activity). Seed treatment with titanium dioxide (TiO_2) nanoparticles at lower concentration (10ppm to 70ppm) is beneficial for improving seedling parameters in onion and it is economically feasible. Among the containers, the seeds stored in aluminum foil pouch, exhibited highest seedling parameters and showed less damage of seeds (lowest moisture per cent and EC), so it performed well during the storage period. At the end of the storage period, it was found that the seeds treated with TiO_2 @40ppm and stored in aluminum foil pouch recorded highest seedling parameters and performed better in storage. So, this can be recommended for onion to improve seedling parameters and to extend the storage life of the seeds. These recommendations are based on three months experimentation and therefore further investigation is needed to arrive at valid recommendation.

Future prospects

In the field of agriculture, nanotechnology has been used to heighten the crop production with quality enrichment by improving farming systems. Low dose of nanoparticles can be assessed in order to encourage seed germination and seedling growth of different plant species. The potential of nanoparticles encourages a new green revolution with reduced farming risks. However, there are still huge gaps in our knowledge of the uptake capacity, permissible limit and the ecotoxicity of different nanoparticles on different crops. Therefore, further research is urgently needed to elucidate and develop potential.

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Conflict of interest

The authors declare that they have no conflict of interest.

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