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Effect of Zinc-invigorations on Seed Longevity in Mungbean (*Vigna radiata* L. Wilczek)

Mrinali M. M.*
Division of Seed Science and Technology,
ICAR-Indian Agricultural Research Institute (New Delhi), India.

(Corresponding author: Mrinali M. M.)*
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ABSTRACT: Arid and semi-arid soils characterized by low fertility and Zn deficiency are major areas of cultivation for mungbean (*Vigna radiata* (L.) Wilczek) leading to its low productivity. Zn invigorations like Zn-priming and Zn-coating on seeds are reported to enhance crop establishment. The present study was formulated to study the effect of Zn-invigorations (priming and coating) on seed longevity in the mungbean variety *PUSA VISHAL.* Zn-invigorations *viz., Zn-Primed,* Zn-*NCPC,* AmZn, EDTA-Zn were taken in different formulations and assessed for seed quality attributes to standardize the best performing treatments. Significantly higher performing treatments were selected to investigate seed longevity under storage conditions from 0 to 12 months duration at an interval of every 3 months. At the end of the storage period (12 months), seed coating with Zn-NCPC (1:4) fertilizer manifested in significantly superior germination % (80.67), seedling shoot length (17.31 cm), seedling root length (9.33 cm), seedling length (26.64 cm), seedling dry weight (0.2543 g), seed vigour index-I (2152.1), seed vigour index-II (20.54) as compared to previous observations. This study led to the understanding that hydro-primed and Zn-primed seeds lose their viability at a faster rate and germination drops below IMSCS (70%) within 6 months of storage. In Zn-invigorated seeds, Zn-toxicity tolerance of the seed decreases with ageing which manifests in lower seed quality attributes. On the contrary, abnormal seedling % and dead seed % increase drastically with seed ageing in mungbean.

Keywords: Mungbean, Zn-invigoration, Zn-priming, Zn-seed coating, Zn-Nano Clay Polymer Composite (Zn-NCPC), Amino acid chelated Zn, EDTA chelated Zn, Seed longevity.

INTRODUCTION

Mungbean (*Vigna radiata* L. Wilczek) is the most important legume crop consumed as a rich source of protein. Originating from the Indian sub-continent, it is predominantly cultivated across the Asian countries and has also expanded to some parts of Africa, Australia and South America (Nair *et al.,* 2019). Over the course of time, mungbean has been transformed from marginal, semi-domesticated crop to one of the most important pulses in Asia (Schafleitner *et al.,* 2015). Raw mature mungbean has high nutritive index and contains energy (347-350 kcal), sugar (6-7 g/100gm), protein (230-240 g/kg), carbohydrate (620-650g/kg), K (1200-1250 mg/100gm), Mg (1.0-1.3 mg/100gm), Ca (130-132 mg/100gm), P (360-365 mg/100gm), Fe (6-7 mg/100gm), Zn (2.5-2.7 mg/100gm), fat (1.0-1.5 g/100gm) and fiber (3.5-4.5 g/100gm) (Saad *et al.,* 2020; Sehrawat *et al.,* 2021). Javed *et al.* (2021) reported that Ready-to-use therapeutic food (RUTF) made with mungbean is an effective strategy to overcome Protein Energy Malnutrition (PEM) in populations across the world. In 2022, mungbean was planted on 31.15 lakh ha, compared to 34.24 lakh ha last year. The consumption of mungbean was 22.5 lakh tonnes against the production of 21.42 lakh tonnes with the rest of the demand-supply gap was covered by imports. Despite being the largest producer, accounting for 30% of global mungbean production (Nair and Schreinemachers 2020), India still imports mungbean from countries *viz.,* Myanmar, Kenya, Mozambique, Australia, and Tanzania in order to meet it's huge consumption demand. Giacalone *et al.* (2021) confirm that dietary supplements of zinc are efficient in controlling and treating Covid-19.

According to the UN Department of Economic and Social Affairs, the global population is likely to reach ~ 10 billion by 2050, making sustainable food security a global challenge (Babu *et al.,* 2022). To address the problem of hidden hunger (micronutrient deficiencies) in the expanding population, nutritional security is imperative. According to the *World Resource Report, 2018* world's food production needs to increase by 50%

by 2050 to feed the burgeoning population amidst human intervention-led global warming reaching 1.5°C between 2030 and 2050 if it continues to increase at the current rate (*IPCC Special Report on Global Warming, Paris Agreement*). Bindumadhava *et al.* (2017); Chaudhary *et al.* (2022) reported that mungbean owing to it's climate resilient nature has some inherent intrinsic tolerance mechanism to many climate stresses like drought tolerance, heat tolerance and salinity tolerance. Cultivated mungbean is a quantitative short-day plant (Summerfifield and Lawn 1988; Chauhan *et al.*, 2018) which can be grown across environments, locations, and seasons making it suitable for climate-resilient farming. According to Shukla *et al.* (2021), Zn + B deficiency is the most common type of soil deficiency and varies from 0.6 to 20.3% over different states, with a mean value of 8.7%. Mungbean is primarily produced in dryland soils that have a typical Zn deficit, which is the main reason for its low productivity. Srinivasarao and Rani (2013) reported that the problem of Zn deficiency in the soil further aggravates due to wide and continuous use of high-analysis fertilizers (like DAP), which causes phosphorus-induced Zn deficiency. Basra *et al.* (2005) opined that seed enhancement techniques like seed priming and coating are the most effective strategies to enhance seed performance by bringing physical, physiological and biochemical changes in the seed. Through Zn-seed coating and priming, Zn loaded on/in the seed is released at a slower rate of diffusion in the moist rhizosphere gradually making it available for longer duration.

Recently, seed priming (Haider *et al.*, 2020a; Haider *et al.*, 2020b) and seed coating (Natarajan *et al.*, 2021) have been used to improve the productivity and grain bio-fortification of mungbean. Muhammad *et al.* (2018) reported that Zn-*seed coating* increased the *seed* yield of *mungbean* by 6.8-40.6% and grain Zn concentration by 12.0-34.4%, respectively, than the non-*coated seeds*. Mahakham *et al.* (2017) have utilized Zn nano polymers and carbon-based nano polymers such as carbon nanotubes as seed priming agents for promoting seed growth, germination, and stress tolerance in mungbean biofortification. Masuthi *et al.* (2009) demonstrated the positive effects of zinc seed pelleting significantly increased seed yield and yield-related traits in cowpea (*Vigna unguiculata* L). In a recent investigation, positive effects of ZnO Nanopolymers were demonstrated on growth, photosynthetic pigments, protein content, protein activity, and content of enzymatic and non-enzymatic antioxidants in mungbean seedlings. It has been reported by Jacob *et al.* (2016) that seed being a living entity is bound to deteriorate in quality attributes from harvesting to sowing in the field, if not handled properly. Hence, the present investigation was undertaken to evaluate the effect of seed storage on seed quality attributes in Zn-invigorated (Zn-primed and Zn-coated) mungbean seeds.

MATERIAL AND METHODS

Seed material. The study was conducted with the seed lot of mungbean variety *PUSA VISHAL* collected from the Seed Production Unit (SPU), IARI, New Delhi. Selection of the variety *PUSA VISHAL* was done on the basis of its bold-seeded characteristic and resistance to Mungbean Yellow Vein Mosaic Virus (MYMV) which is the most common pathogenic disease in mungbean.

Zn fertilizers. In the present investigation, $ZnSO_4 .7H_2O$ with 22.74% Zn content was procured for seed priming form Sigma Aldrich®, USA. While for seed coating, three commercially available Zn fertilizers/formulations were utilized. They were Amino acid chelated Zn fertilizer (Am-Zn) with 12% Zn content, EDTA chelated Zn (EDTA-Zn) with 12% Zn content and Zn loaded Nano Clay Polymer Composite (Zn-NCPC) with 10% Zn content formulated utilizing the method outlined by Mandal *et al.* (2018).

Priming Seed with Zn solution. Mungbean seeds were primed by taking 100-150 seeds in 3 replicates in the circular boxes (16 cm diameter and 5 cm height) with an objective to standardize optimum Zn concentration. Two layers of filter paper were kept on boxes and seeds were submerged in 20 ml of $ZnsSO_4.7H_2O$ solutions of different concentrations *viz.*, 300 ppm, 450 ppm, 600ppm and 700 ppm. These boxes were incubated at 25 ± 2°C for 9 hrs (duration standardized for hydropriming, data not presented). After the incubation period was reached, soaked seeds were dried back to original moisture content (9%) by spreading them on blotter paper under the dry air. For hydropriming, seeds were treated in same manner doubled distilled water. Both hydropriming and Zn-primed seeds were used as control and all treatments were subjected to routine germination test (ISTA, 2018). Germination% was calculated with following formula:

Germination percentage =

Total number of normal seedlings ×100 / Total number of seeds used for germination testing

For calculating seedling root length, seedling shoot length, seedling length, 10 normal seedlings were randomly selected and measured on linear scale followed by subjecting the data for statistical analysis. For seedling dry weight, 10 seedlings selected for measuring the fresh weight on digit analytical balance. Then, the seedlings were dried overnight in hot air oven at 90°C ± 2°C and the dry weight was measured. Seed vigour index-I and seed vigour index-II were calculated using the following formula (Abdul-Baki and Anderson 1973):

Vigour index I = Average seedling length of 10 seedlings (cm) × germination %

Vigour index II = Seedling dry weight of 10 seedlings (g) × germination %

Coating Seed with Zn solution. In the current investigation, an attempt was made to deliver Zn fertilizers (Zn-NCPC, Amino acid chelated Zn and EDTA chelated Zn fertilizer) as seed coats. With gum Arabic as a binder, mungbean seeds were coated with respective Zn fertilizers in seed coating equipment (model 'SATEC Concept ML 2000' of SATEC Equipment GmbH, Germany). Approximately 250-300 g of seeds were coated with gum Arabic solution followed by coating with dry powder of Zn-NCPC fertilizer plus chalk powder mixture in different formulations *viz.*, 1:1, 1:2, 1:3, 1:4, 1:5 and 1:6 on volume basis. Similarly, for coating with AmZn fertilizer or EDTA-Zn fertilizer 250-300 g seeds each, were coated using chalk powder mixed in different formulations *viz.*, 1:1, 1:2, 1:3, 1:4, 1:5, 1:6 and 1:7 on volume basis. Both priming and coating treatments were followed by drying the seeds overnight under the fan. Invigorated (primed and coated) seed treatments were standardized by subjecting them to routine germination test (ISTA, 2018) after assessing the seed quality attributes *viz*., germination %, seedling root length, seedling shoot length, seedling length, seedling dry weight, seed vigour index-I and seed vigour index-II.

Seed Storage. Prior to bagging the seeds for storage, they were sieved through a 2 mm aperture sieve to remove dead storage pests like bruchids, insect frass, broken/shriveled seeds and other debris. Sun-dried seeds were stored in air-tight plastic containers fumigated and sealed with paraffin wax at the lid of the container. Observations were recorded at 0, 3, 6, 9 and 12 months at an interval of 3 months. Seedling attributes *viz*., shoot length (ShL), root length (RoL), seedling Length (SdL) and seedling dry weight (SdDw) were average values of 10 seedlings. Other attributesinvestigated were germination %, seed vigour index-I, seed vigour index-II, abnormal seed %, hard seed %.

Statistical analysis. All the experiments were subjected to single-factor ANOVA analysis of completely Randomized Block Design (RBD) using SPSS 13 and Critical Difference (CD) values were calculated at p=0.05 to compare the difference between the treatments of the respective experiments.

RESULTS AND DISCUSSION

It has been investigated by Faisal *et al.*, (2019) that mungbean seeds decrease their viability very fast during storage, especially in tropical areas kept without proper packaging. Tatipata (2008) in a research investigation demonstrated that a decrease in the quality of mungbean seeds is usually caused by a change of relatively high protein and fat content in the seeds, an increase in moisture content of the seeds if the temperature and humidity of the storage environment are relatively high. Purwanti (2004) reported that the decrease in quality under storage conditions is a gradual and cumulative process of deterioration in viability and cannot be reversed due to physiological and biochemical changes. Thus, in the present study, the effect on seedling attributes was investigated during a storage period of 12 months.

Effects of storage duration (0 days) on seed quality attributes of Zn-invigorated seeds. The effect of seed treatment on seed longevity of mungbean seeds coated with selected Zn-seed treatments stored under ambient temperature at 0 month (30 days) of storage period was evaluated. It was demonstrated to be significantly superior in the average shoot length of 10 seedlings (24.47 cm), average root length of 10 seedlings (14.33 cm), average length of 10 seedlings (38.80 cm), dry weight of 10 seedlings (29.40 cm), germination% (98.67), seed vigour index-I (3828.93), seed vigour index-II (29.01) as shown in Table 1. abnormal seedling % (5.42) was reported to be significantly lower in seeds coated with Zn-NCPC (1:4) fertilizer as compared to other treatments while hard seeds were absent in this treatment (Table 1).

Table 1: Effects of storage duration (0 months) on seed quality attributes of mungbean (*PUSA VISHAL*).

Treatment	ShL (cm)	RoL (cm)	SdL (cm)	SdDW (g)	Ger (%)	SV-I	SV-II	Abn (%)	Har (%)
Control	19.71	11.93	31.64	0.2443	94	2975.4	22.97	1.33	4.67
Hydro primed	22.95	12.88	35.83	0.2657	98	3512.3	26.04	0	2
450ppm-Zn primed	23.74	13.55	37.3	0.2751	98.67	3681	27.15	0	1.33
Zn-NCPC (1:4)*	**24.47**	**14.33**	**38.8**	**0.294**	98.67	**3828.9**	**29.01**	**1.33 (5.42)**	**0**
AmZn (1:7)	18.77	12.74	32.52	0.255	95.33	3100.3	24.31	4.67 (12.46)	0
Mean	**22.13**	**13.09**	**35.22**	**0.2668**	96.93	**3419.6**	**25.9**	**1.47 (4.88)**	**1.6**
CD @ 0.05 P	**2.38**	**1.34**	**3.66**	**0.0177**	2.23	**429.35**	**2.22**	**4.94**	**5.2**
Tukey's HSD @0.05 P	**2.48**	**1.4**	**3.81**	**0.0184**	2.23	**447.64**	**2.32**	**5.15**	**5.42**

* Values given in parentheses are Log transferred values)

1. ShL: Average shoot length of 10 seedlings, 2. RoL: Average root length of 10 seedlings; 3. SdL: Average length of 10 seedlings,
4. SdDw: Dry weight of 10 seedlings; 5. Ger %: Germination %, 6. SV-I: Seed Vigour Index - I, 7. SVI-II: Seed Vigour Index – II; CD - Critical difference obtained from ANOVA of CRD; * indicates that treatment effects were significant at 0.05 probability in the respective analysis

Effects of storage duration of 3 months on seed quality attributes of Zn-invigorated seeds. The effect of seed treatment on seed longevity of mungbean seeds coated with selected Zn-seed treatments stored under ambient temperature at 3 months storage period was evaluated. Seeds coated with Zn-NCPC (1:4) fertilizer were demonstrated to be significantly higher than other treatments in average shoot length of 10 seedlings (24.21 cm), average root length of 10 seedlings (14.13 cm), average length of 10 seedlings (38.34 cm), dry weight of 10 seedlings (0.2915 g), germination% (98.67), seed vigour index-I (3783.66), seed vigour index-II (28.77). No abnormal seeds and/or hard seeds were observed whilethe dead seed % (5.42) increased in the seed lot after 3 months of storage period (Table 2). An ample number of research studies have elucidated that during seed storage, seeds deteriorate, lose vigour and as a result, become more sensitive to stresses during germination and ultimately die (Nguyen *et al.*, 2012; Walters *et al.*, 2005a) which is the cause of an increased number of dead seeds in stored seeds.

Table 2: Effects of storage duration (3 months) on seed quality attributes of mungbean (*PUSA VISHAL*).

Treatment	ShL (cm)	RoL (cm)	SdL (cm)	SdDW (g)	Ger (%)	SV-I	SV-II	Abn (%)	Har (%)	Dead (%)
Control	19.51	11.89	31.4	0.2431	97	3046.9	23.59	0	1.33 (6.54)	1.67 (7.15)
Hydroprimed	16.53	10.31	26.84	0.2536	87.67	2355.7	22.25	9.33 (17.75)	0	3 (9.88)
450ppm-Zn primed	17.08	10.65	27.73	0.2658	88.67	2459.8	23.58	9.33 (17.78)	0	2 (7.95)
Zn-NCPC (1:4)*	**24.21**	**14.13**	**38.34**	**0.2915**	**98.67**	**37-083.66**	**28.77**	**0**	**0**	**1.33 (5.42)**
AmZn (1:7)	19.37	12.24	31.61	0.2486	93.33	2950.7	23.21	4.67(12.46)	0	2(7.95)
Mean	19.34	11.84	31.18	0.2605	93.07	2919.3	24.28	4.67 (9.60)	0.27 (1.31)	2 (7.67)
CD @ 0.05 P	21.4	1.74	3.85	0.0211	3.36	437.6	2.7	1.78	1.38	6.3
Tukey's HSD @0.05 P	2.23	1.82	4.01	0.022	3.5	456.25	2.82	1.85	1.44	6.57

* Values given in parentheses are Log transferred values)

1. ShL: Average shoot length of 10 seedlings; 2. RoL: Average root length of 10 seedlings; 3. SdL: Average length of 10 seedlings, 4. SdDw: Dry weight of 10 seedlings; Ger %: Germination %; 6. SV-I: Seed Vigour Index - I, 7. SVI-II: Seed Vigour Index – II; CD - Critical difference obtained from ANOVA of CRD

* indicates that treatment effects were significant at 0.05 probability in the respective analysis

Effects of storage duration of 6 months on seed quality attributes of Zn-invigorated seeds. The effect of seed treatment on seed longevity of mungbean seeds coated with selected Zn-seed treatments stored under ambient temperature at 6 months storage period was evaluated. Seeds coated with Zn-NCPC (1:4) fertilizer were reported to be significantly superior to other treatments in seed quality attributes like average shoot length of 10 seedlings (23.62 cm), average root length of 10 seedlings (13.93 cm), average length of 10 seedlings (37.55 cm), dry weight of 10 seedlings (0.2735 g), germination % (92.67), seed vigour index-I (3482.3), seed vigour index-II (25.36). As the storage period increased from 3 months to 6 months, abnormal seeds % (14.05) and dead seed % (6.54) increased in the seed lot (Table 3). In their research study on the kinetics of deterioration, Walters *et al.* (2004; 2005b) demonstrated that while stored seeds initially show no signs of ageing, with increasing storage duration they finally reach a cataclysmic stage where their viability is rapidly lost. Decreased SVI-I and SVI-II along with an increased number of abnormal seedlings and dead seeds are the manifestations of a prolonged storage period.

Table 3: Effects of storage duration (6 months) on seed quality attributes of mungbean (*PUSA VISHAL*).

Treatment	ShL (cm)	RoL (cm)	SdL (cm)	SdDW (g)	Ger (%)	SV-I	SV-II	Abn (%)	Dead (%)
Control	18.5	11.31	29.81	0.2281	95.67	2852.2	21.83	3.33 (10.50)	1 (4.62)
Hydroprimed	13.46	8.31	21.77	0.2042	66.67	1454.4	13.64	14.33 (22.21)	19 (25.84)
450ppm-Zn primed	14.08	8.65	22.73	0.2163	68.67	1562.2	14.86	15.33 (23.05)	16 (23.55)
Zn-NCPC (1:4)*	**23.62**	**13.93**	**37.55**	**0.2735**	**92.67**	**3482.3**	**25.36**	**6 (14.05)**	**1.33 (6.54)**
AmZn (1:7)	18.87	11.84	30.71	0.2416	89.33	2745	21.59	8.67 (17.12)	2 (7.95)
Mean	17.7	10.81	28.51	0.2327	82.6	2419.2	19.45	11.53 (19.28)	7.87 (13.70)
CD @ 0.05 P	2.2	1.55	3.71	0.0219	4.53	425.22	2.77	3.21	5.17
Tukey's HSD @0.05 P	2.3	1.62	3.87	0.0229	4.73	443.33	2.89	3.35	5.39

* Values given in parentheses are Log transferred values)
1. ShL: Average shoot length of 10 seedlings, 2. RoL: Average root length of 10 seedlings:
3. SdL: Average length of 10 seedlings, 4. SdDw: Dry weight of 10 seedlings Ger %: Germination %, 6. SV-I: Seed Vigour Index - I, 7. SVI-II: Seed Vigour Index – II CD - Critical difference obtained from ANOVA of CRD
* indicates that treatment effects were significant at 0.05 probability in the respective analysis

Effects of storage duration of 9 months on seed quality attributes of Zn-invigorated seeds. The effect of seed treatment on seed longevity of mungbean seeds coated with selected Zn-seed treatments stored under ambient temperature at 9 months storage period was evaluated. Seeds coated with Zn-NCPC (1:4) fertilizer were reported to be significantly superior to other treatments in average shoot length of 10 seedlings (20.34 cm), average root length of 10 seedlings (13.33 cm), average length of 10 seedlings (33.67 cm), dry weight of 10 seedlings (0.2681 g), germination% (85.33), seed vigour index-I (2876.63), seed vigour index-II (22.90). But, as compared to 6 month storage period, the values of all seed quality attributes decreased. It can be observed that after 9 months storage period, the abnormal seeds % (11.33) and dead seed % (3.33) increased as compared to previous observations in 6 months storage period (Table 4).

Table 4: Effects of storage duration (9 months) on seed quality attributes of mungbean (*PUSA VISHAL*).

Treatment	ShL (cm)	RoL (cm)	SdL (cm)	SdDW (g)	Ger (%)	SV-I	SV-II	Abn (%)	Dead (%)
Control	17.37	11.27	28.64	0.2231	90.67	2599.1	20.24	4.33 (12)	5 (12.75)
Hydroprimed	12.64	7.31	19.95	0.1941	53.67	1073.9	10.44	22.33 (28.18)	24 (19.32)
450ppm-Zn primed	12.98	7.85	20.83	0.1986	54.67	1142.1	10.88	24.33 (28.18)	21 (27.26)
Zn-NCPC (1:4)*	**20.34**	**13.33**	**33.67**	**0.2681**	**85.33**	**2876.6**	**22.9**	11.33 (19.65)	**3.33 (10.34)**
AmZn (1:7)	19.21	10.74	29.95	0.2291	81.67	2447.6	18.72	**14.33 (22.24)**	4 (11.28)
Mean	16.51	10.1	26.61	0.2226	73.2	2027.9	16.64	15.33 (22.32)	11.47 (18.19)
CD @ 0.05 P	2.12	1.61	3.71	0.0231	6.59	437.63	3.03	2.49	5.09
Tukey's HSD @0.05 P	2.21	1.68	3.87	0.0241	6.87	456.27	3.16	2.6	**5.31**

* Values given in parentheses are Log transferred values)
1. ShL: Average shoot length of 10 seedlings, 2. RoL: Average root length of 10 seedlings; 3. SdL: Average length of 10 seedlings, 4. SdDw: Dry weight of 10 seedlings; Ger %: Germination %, 6. SV-I: Seed Vigour Index - I, 7. SVI-II: Seed Vigour Index – II; CD - Critical difference obtained from ANOVA of CRD
* indicates that treatment effects were significant at 0.05 probability in the respective analysis

Effects of storage duration of 12 months on seed quality attributes of Zn-invigorated seeds. Lastly, the effect of seed treatment on seed longevity of mungbean seeds coated with selected Zn-seed treatments stored under ambient temperature at 12 months storage period was analyzed. Seeds coated with Zn-NCPC (1:4) fertilizer were reported to be significantly superior to other treatments in average shoot length of 10 seedlings (17.31 cm), average root length of 10 seedlings (9.33 cm), average length of 10 seedlings (26.64 cm), dry weight of 10 seedlings (0.2543 g), germination% (80.67), seed vigour index-I (2152.05), seed vigour index-II (20.54). But, as compared to the previous observations in 9 months storage period, the values of all the seed quality parameters declined. On a contrary, abnormal seedling % (16.33) and dead seed % (3.00) were found to increase as compared to previous observations in 9 months storage period (Table 5). Akter *et al.* (2014) reported an increase in 1000-seed weight, moisture content, electrical conductivity, abnormal seedlings and number of dead seeds with an increase in the storage period in soybean. While soybean seedlings showed a decrease in germination index, seedling growth, dry weight, seed vigour index-I and seed vigour index-II with a longer storage period.

Table 5: Effects of storage duration (12 months) on seed quality attributes of mungbean (*PUSA VISHAL*).

Treatment	ShL (cm)	RoL (cm)	SdL (cm)	SdDW (g)	Ger (%)	SV-I	SV-II	Abn (%)	Dead (%)
Control	16.51	10.89	27.4	0.2031	82.33 (65.20)	2260.1	16.74	7.67 (16.07)	10 (18.34)
Hydroprimed	9.64	5.88	15.52	0.1082	10.67 (19.03)	167.39	1.16	56.33 (48.64)	33 (35.05)
450ppm-Zn primed	8.8	5.55	14.35	0.1109	11.67 (19.90)	169.63	1.31	53 (46.72)	35.33 (36.46)
Zn-NCPC (1:4)*	**17.31**	**9.33**	**26.64**	**0.2543**	**80.67 (63.96)**	**2152.1**	**20.54**	**16.33 (23.80)**	**3 (9.88)**
AmZn (1:7)	15.06	8.74	23.8	0.2186	73.33 (58.92)	1747.6	16.04	19.67 (26.32)	7 (15.24)
Mean	13.46	8.08	21.54	0.179	51.73 (45.40)	1299.4	11.16	15.33 (32.31)	17.67 (22.99)
CD @ 0.05 P	2.39	1.36	3.69	0.0219	4.41	360.55	2.56	2.18	4.56
Tukey's HSD @0.05 P	2.49	1.42	3.85	0.0228	4.6	375.91	2.66	2.28	**4.75**

* Values given in parentheses are Log transferred values)
1. ShL: Average shoot length of 10 seedlings, 2. RoL: Average root length of 10 seedlings; 3. SdL: Average length of 10 seedlings, 4. SdDw: Dry weight of 10 seedlings; Ger %: Germination %, 6. SV-I: Seed Vigour Index - I, 7. SVI-II: Seed Vigour Index – II; CD - Critical difference obtained from ANOVA of CRD
* indicates that treatment effects were significant at 0.05 probability in the respective analysis

CONCLUSION

Mungbean has the potential for food as well as nutritional security, owing to itsinherent climate-resilient nature. Grown in marginal Zn-deficient soils strengthen the base for treating the mungbean seeds with Zn-enriched fertilizers. Also, storage longevity needs to be established for such Zn-invigorated seed treatments thus, storage studies were imperative to generate meaningful scientific data on the same. Hence, the present study was undertaken to assess the best Zn-invigorated seed treatment and its effect on seed longevity under storage upto 12 months duration. The current investigation started with a series of standardization experiments executed for Zn-primed and coated seeds *viz.*, Control, Hydro-primed, 450-ppm-Zn primed, Zn-NCPC (1:4), EDTA-Zn (1:7) and AmZn (1:7), were subjected to storage studies (0 months to 12 months) with all treatments except EDTA-Zn (1:7) owing to Zn-toxicity. Abundant evidence was established that seeds coated with Zn-NCPC (1:4) fertilizer treatment manifested in significantly higher germination %, seedling shoot length, seedling root length, seedling length, seedling dry weight, seed vigour index-I and seed vigour index-II.

The study also led to the understanding that during storage, hydro-primed and Zn-primed seeds lose their viability at a faster rate and germination drops below IMSCS (70%) within 6 months of storage. With seed ageing, Zn-toxicity tolerance of the seed decreases, which manifests in lower seed germination %, average shoot length, average root length, average length of 10 seedlings, dry weight of 10 seedlings, seed vigour index-I, seed vigour index-II. On the contrary, abnormal seedling % and dead seed % increase drastically with seed ageing.

FUTURE SCOPE

As a future course of action, possibilities can be explored in the industrial commercialization and popularization of Zn-NCPC (1:4) fertilizer seed coating treatment to utilize it for Zn-deficient marginal soils where mungbean production is majorly undertaken and seeds need to be stored for mid-term storage duration.

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