Research Article

EFFECT OF BIOGENIC SILICA SEED COATING ON SORGHUM (VAR. K 12) SEED STORAGE USING DIFFERENT STORAGE CONTAINERS UNDER AMBIENT CONDITION

ABSTRACT

The objective of this study was to investigate the seed quality parameters of biogenic silica coated sorghum seeds on seed storage using different storage containers under ambient condition. Proper seed storage until next sowing season is crucial for sorghum seed production. seeds can lose vigor and viability during storage. Decrease in seed vigour leads to decrease in seed quality. The seed's storage environment and packaging materials significantly impact its long-term viability and effectiveness. Coating seeds before storing them helps preserve their quality over time. Pre-storage seed coating is essential for preventing seed deterioration and maintaining quality throughout the storage period. The present study revealed that, after six months of storage period, seed coating with biogenic silica with carbon @ 5 ml kg-^{1} seeds observed highest germination percentage, root and shoot length, dry matter production, vigour index I and II compared to control. With respect to containers seeds packed in super grain bag performed better than cloth bag. The results clearly indicated that, coating of seeds with biogenic silica with carbon @ 5 ml kg-^{1} stored in the supergrain bag-maintained vigour and viability throughout the storage period and also maintained the seedling length.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a highly versatile cereal crop with significant importance in global agriculture. As the leading millet, it accounts for 65.8% of worldwide millet production and is often referred to as the "camel crop" due to its resilience. Belonging to the Poaceae family, sorghum is prized for its adaptability to diverse climates and its vigorous growth, making it a crucial food source, particularly in arid and semi-arid regions. It ranks as the fourth most important cereal globally, following wheat, rice, and maize [1]. Sorghum serves as a staple food in Africa, India, and China, with India and the United States being the world's top producers. It provides a vital source of energy, protein, vitamins, and minerals for millions of impoverished people living in semi-arid regions, playing a crucial role in sustaining their nutrition and well-being [2].

Ensuring proper seed storage until the next planting season is vital for successful seed production. In developing nations like India, where maintaining controlled environmental conditions for seed preservation can be both costly and impractical, alternative approaches such as seed coating have proven effective in safeguarding seed viability and vigor. Coating seeds prior to storage helps maintain their quality, reducing the risk of vigor loss over time. This technique plays a key role in preserving seed potential for the following season, while also preventing degradation and loss during the storage period [3,4] Seeds are currently treated using chemical, organic, or physical methods to enhance their viability, protect against pests and diseases, and improve germination during storage. Advantages include prolonged viability, improved germination rates, moisture control, and effective pest protection. However, these treatments also present disadvantages, such as potential environmental harm from chemical residues, higher costs for advanced treatments, health risks, and reduced efficacy over time. While these methods provide significant benefits for seed storage, they also pose challenges in terms of sustainability and long-term effectiveness.

Silica plays a versatile role across numerous industries and technologies. It serves as a strengthening agent in rubber and plastics, functions as a filler in paints and coatings, and is utilized as a filtration medium in the production of food and beverages [5]. The application of silicon via seed coating has yielded promising results. This external treatment is thought to enhance seed germination and seedling development by bolstering antioxidant defense and optimizing iron uptake, thereby improving overall plant vigor and resilience [6]. Using rice husk to produce bio-silica offers a cost-effective alternative to synthetic silica production, given the low expense of rice husk [7] and the production cost could be cheaper if the product is applied in an established manner [8]. Silica extraction from rice husk involves eco-friendly methods. Leveraging rice husk ash (RHA) as a feedstock for this process often proves more efficient and cost-effective than extracting silica directly from the husk [9].

Biogenic silica, derived from natural sources like rice husk ash, offers several ecological benefits in agriculture. By repurposing agricultural waste, it promotes sustainability and reduces landfill waste. Its use as a seed coating or soil amendment enhances plant resilience to stress, reduces reliance on chemical pesticides and fertilizers, and improves nutrient and water efficiency. This contributes to better resource management, especially in water-scarce regions, while lowering environmental risks. Biogenic silica is biodegradable, posing no long-term pollution threats, making it an eco-friendly alternative to synthetic treatments.

Selecting appropriate storage containers is crucial for maintaining seed quality during storage. These containers effectively regulate temperature, humidity, and moisture, which are vital in preserving seeds. The goal of optimal storage is to minimize biological activity and mitigate adverse environmental factors that shorten the safe storage period. By using proper packing materials and conditions, seeds retain their viability and germination potential, while also reducing the risks of pest infestations and diseases, ultimately decelerating the aging process. With this background, the current study has been designed to investigate the utility of Biogenic silica coating and storage containers under ambient condition to maintain the seed quality in sorghum seeds during storage period of six months.

2. MATERIALS AND METHODS

2.1 Preparation of biogenic silica from rice husk ash [10]

The biogenic silica is prepared by Alkaline extraction followed by acid neutralization method. It is very efficient and simple method to extract silica from rice husk. In this procedure RH ash is mixed in 1N NaOH solution in 250 ml Erlenmeyer flask and is allowed to boil for 1h with constant stirring to dissolve silica and make sodium silicate solution. The obtained sodium silicate solution is in black colour due to the presence of carbon. From this biogenic silica with carbon was prepared by titrating the sodium silicate solution with 1N hydrochloric acid (HCl) solution for 18 h at 7.0 pH with constant stirring, Biogenic silica (with carbon) in gel form obtained after stirring period. For preparation of biogenic silica without carbon, the sodium silicate solution was filtered through ashless filter paper and the residue (carbon) was removed. Further the solution was titrated with 1N hydrochloric acid (HCl) solution for 18 h at 7.0 pH with constant stirring, Biogenic silica (without carbon) in gel form obtained after stirring period.

For assessing the storability of Biogenic silica coated seeds (with and without carbon treatments), the coated seeds were stored in cloth bag and super grain bag under ambient conditions (mean temperature 26 ± 1^{o} C and RH 70 ± 2%) for a period of six months in the department of seed science and technology, Agriculture college and research Institute, Madurai and then the stored seeds were evaluated at every month for assessing seed quality and biochemical parameters.

2.2 Treatments

Storage Containers:

C_1 - Cloth bag

C_2 – Super grain bag

Seed treatments:

T_0- Without seed treatment (Control)

T_1- Seeds Coated with 5 ml/kg of Biogenic Silica with Carbon

T_2- Seeds Coated with 5 ml/kg of Biogenic Silica without Carbon

Then the seeds are used to test the seed quality parameters, such as the germination test, was conducted in quadruplicate by using 100 seeds with four sub replicates of 25 seeds in a paper medium [11] following an inclined plate method [12] in a germination chamber maintained at a temperature of 25± 1°C and RH 96 ± 2% with diffuse light (approx. 10h.) during the day. The final count of normal seedlings was recorded on the 10 th day, and the percentage of germination was computed. Observations on Moisture content (%) [13], germination percentage (%), root length (cm), shoot length (cm), dry matter production (g seedlings-1), vigour index I and vigour index II were calculated [14] were observed for both control as well as treated seeds. The data obtained from different experiments were analyzed by the ‘F’ test of significance following the methods [15]. Wherever necessary, the per cent values were transformed to angular (Arc-sine) values before analysis. The Critical Differences (CD) was calculated at 5 per cent probability level. The data were tested for statistical significance. If the F test is non-significant it was indicated by the letters NS

3. RESULTS

3.1 Moisture content (%)

Moisture content was minimum (8.4 %) at initial and slowly increased to (9.3 %) at the storage period of 6 months, irrespective of containers and treatment. **(Table 1)** under ambient conditions, seeds coated with the treatment T_1 @ 5 ml kg^{-1} of Biogenic silica with carbon recorded the lower moisture content (8.8 %) and control seeds recorded higher moisture content (9.0 %) irrespective of containers and storage period. Between containers, super grain bag (C_2) recorded minimum moisture content (8.6 %) and the highest moisture content was observed in cloth bag (C_1) (9.1 %). In interaction between treatments, containers and periods of storage, minimum moisture content was noticed in super grain bag after 6 months of storage (T_1C_2 P_6) (8.6 %) and it was maximum in control after 6 months of storage ($T_0C_2P_6$) (9.3 %).

3.2 Germination (%)

In general, there was a decline in the germination per cent with increase in storage periods **(Table 2).** There is a significant difference between containers, period of storage, seed coating treatments and P X T interaction. Among the containers, super grain bag was effective (83%) compared to cloth bag (82 %). Among the treatments, T_1 registered higher germination percent (89 %) compared to control (74%) irrespective of containers and period of storage. In super grain bag at the end of the 6 months of storage period T_1 recorded the higher germination (T_1C_2 P_6) (83 %) and germination dropped down below minimum seed standards of sorghum ($T_0C_2P_6$) (67 %) in control.

3.2 Root length (cm)

Root length was significantly differed among the seed treatments, containers, period of storage and non-significant among the interactions. Among the seed treatments, T_1 measured the highest root length (25.93 cm) while the lowest root length was measured in control (T_0) (17.32 cm). Between containers, super grain bag (C_2) recorded maximum root length (22.60 cm) and minimum root length was observed in cloth bag (C_1) (22.45 cm).Root length was maximum (23.28 cm) at initial and it slowly declined to (21.55 cm) at the storage period of 6 months, irrespective of containers and treatments **(Table 3).** In interaction, treatments, containers and period of storage reported that $C_2P_6T_1$ (25.16 cm) recorded maximum root length after 6 months of storage and minimum was in control $C_2P_6T_0$ (16.29 cm). Interaction between containers and period of storage, minimum root length was noticed in cloth bag after 6 months of storage C_1P_6 (21.44 cm) and maximum was in super grain bag after 6 months of storage (C_2P_6) (21.66 cm)

3.3 Shoot length (cm)

Highly significant difference was observed in shoot length with biogenic silica seed coating treatments and periods of storage. Seeds stored in supergrain bag produced higher shoot length (13.34 cm) than cloth bag (13.26 cm). Among the seed coating treatments, T_1 (15.04 cm) was very effective than control (10.36 cm). The rate of reduction was more in control at all periods of storage both in cloth and supergrain bag. Shoot length was significantly varied by the seed treatments, containers, period of storage and non-significant among interactions. Shoot length was maximum (13.73 cm) at initially and it slowly declined to (12.73cm) at the storage period of 6 months with irrespective of containers and treatments **(Table 4).**

3.4 Dry matter production (g seedlings^{-10})

The dry matter production was higher in supergrain bag (0.160 g seedlings^{-10}) than cloth bag (0.156 g seedlings^{-10}) **(Table 5).** Irrespective of containers and periods of storage, the dry weight was more in T_1 (0.180 g seedlings^{-10}) followed by T_2 (0.170 g seedlings^{-10}) and control recorded lowest weight (0.125 g seedlings^{-10}). The dry matter production was decreased from (0.157 g seedlings $^{-10)}$ (P_0) to (0.127 g seedlings $^{-10}$) (P_6).In interaction of seed treatments and storage period T_1 coated seeds have maximum DMP (0.153 g) ($C_2T_1P_6$) after the storage of 6 months and over control (0.103 g) ($C_2T_0P_6$) in supergrain bag.

3.5 Vigour index I

Vigour index I was significantly differed among the seed treatments, containers, period of storage and interaction of PXT. Among the containers, the maximum vigour index I was observed in super grain bag (2959) compared to cloth bag (2903) **(Table 6).** T_1 showed higher vigour index (3644) compared to control T_0 (1884). At the end of the storage period, the higher vigour index was evident in supergrain bag with biogenic silica with carbon coating T_1 @ 5g kg^{-1} (3296) followed by T_2 (2923). Irrespective of containers and seed coating treatments, Vigour index I decreased from 3257 (P_0) to 2581 (P_6) in 6 months. In interaction of seed coating and storage period, after the storage of 6 months T_1P_6 have maximum vigour index I followed by T_2P_6 while minimum vigour index was registered in T_0P_6 in both the containers, cloth bag and supergrain bag**.**

3.6 Vigour index II

Vigour index – II varied significantly with the treatments, containers, period of storage and interactions CXP and PXT. In general, vigour index – II decreases with the increase of storage period. **(Table 7)** Among the containers super grain bag recorded higher vigour index- II (13.28) and cloth bag recorded lower vigour index – II (12.72). Among the biogenic silica coating formulation, seeds coated with the treatment T_1 @ 5 ml kg^{-1} of biogenic silica with carbon recorded a higher vigour index – II (16.06) which was followed by T_2 @ 5 ml kg^{-1} biogenic silica without carbon (14.37) and control seeds recorded a lower vigour index – II (8.57), irrespective of containers and storage period. After six months of storage, T_1 treated seeds stored in super grain bag recorded the higher vigour index – II (12.70), compared to the seeds stored in cloth bag (11.89)

4. DISCUSSION:

Seed storage is a vital aspect of the seed industry, where preserving seed vigour and viability depends on various physico-chemical factors. These include the seed's initial quality, its physical and chemical composition, moisture levels, temperature, storage facilities, gas exchange, and the type of packaging used. Together, these elements ensure the longevity and quality of stored seeds. Seeds are hygroscopic, meaning they readily absorb moisture from their surroundings. Therefore, the storage environment plays a crucial role in influencing fluctuations in the seed's moisture content [16-

19]. As a living biological unit, seeds consist of lipoprotein cell layers. During storage, they absorb moisture, which accelerates lipid peroxidation, ultimately leading to seed deterioration and, eventually, loss of viability [20]

Biogenic silica from rice husk ash is a naturally sourced material that has environmental benefits, as it utilizes agricultural waste and offers an eco-friendly option. It often exhibits high porosity and bioavailability, making it an effective choice for seed coating in terms of improving germination, nutrient uptake, and moisture retention. However, its production may be less standardized, and its properties can vary depending on the processing methods used. On the other hand, commercial silica products, typically synthetic, are designed for consistent quality and performance. These products may offer more predictable results due to their standardized formulations, but they often come at a higher cost and may lack the sustainability benefits that biogenic silica provides. So, this biogenic silica has more advantage in cost-effectiveness, environmental impact, and practical performance in agricultural practice comparing to potentially less eco-friendly commercial silica. Irrespective of the containers, the seed quality parameters are better in seeds coated with Biogenic silica with carbon(T_1)

Irrespective of the treatments, with the advancement of storage period all the seed quality parameters were gradually decreased. Moisture content gradually decreased in both cloth bag (C_1) and super grain bag (C_2). Seeds stored in super grain bags retained lower moisture levels compared to those stored in cloth bags. The permeable nature of cloth bags allowed moisture exchange with the environment, leading to an increase in seed moisture content. In contrast, the impermeability of super grain bags provided enhanced protection, resulting in minimal moisture fluctuations and better preservation of seed quality [21-23].

The germination potential of stored seeds denotes their ability to sprout and grow into robust seedlings after a period of storage. This measure reflects both the viability and vigor of the seeds post-storage. Increasing seed age decreasing germination [24] and [25] in rapeseed and [26] in soybean. It has been suggested that the decline in germination rates is linked to chromosomal aberrations that occur under prolonged storage conditions [27]. The reduced germination observed in aged seeds may also result from diminished α-amylase activity and a decrease in carbohydrate contents [28] or denaturation of proteins [29].

Seedling length (root and shoot length) serves as a key indicator of seed vigor. A similar reduction in seedling length was observed as seen with decreased seed germination. Over time, as storage periods extended, seedling length diminished. Seeds that initially produced longer seedlings exhibited a significant decrease in length by the end of the storage period. This finding suggests that as seeds deteriorate and lose physiological vitality, seedling length progressively declines. Decline in seedling characters with advancement in storage periods was also reported by [30] in maize inbreds; [31] in barley; [32] in pulses; [33] in barynyard millet; [34] in cucumber.

However, the seeds stored in super grain bag (C_2) observed the minimum fluctuations in vigour parameters compared to the seeds stored in cloth bag (C_1) whereases, the cloth bag recorded the drastic changes in vigour parameters. The effectiveness of super grain bags may stem from their ability to restrict gas exchange with the external environment. This limitation results in an atmosphere within the bag that is low in oxygen and high in carbon dioxide. Such a controlled environment can inhibit the metabolic activities of insect pests and microorganisms, which would otherwise deplete oxygen and generate heat and moisture, potentially creating unfavorable conditions for the seeds [36-39]

The dry matter production of the seedlings is the manifestation of physical and physiological vigour [40]. In the current study, seeds stored in super grain bags exhibited greater dry matter production compared to those stored in cloth bags. This finding parallels the observed decline in seed vigor associated with prolonged storage was reported by [41] in chilli. Seedling vigour is usually characterized by the weight of seedlings after a period of growth [42] and this is essentially a physiological phenomenon influenced by the reserve metabolites, enzyme activities and growth regulators. Seed vigour decreased with increase in storage periods. Similar results were also reported by [43] in blackgram; [44] in clusterbean and [45] in gingelly.

The success of a seed production program is significantly enhanced by preserving seed vigor and viability during storage. Various intrinsic and extrinsic factors affect seed viability over time. In this study, seeds stored in super grain bags demonstrated superior seedling vigor compared to those kept in cloth bags. While seed deterioration is a natural, inevitable, and irreversible process, pre-storage treatments and packaging materials play a crucial role in mitigating this deterioration and extending seed storability [46]. Biogenic silica seed coating applied before storage significantly enhances vigor indices through multiple mechanisms. It regulates moisture retention, ensuring seeds remain optimally hydrated, which is vital for preserving germination potential. The coating protects nutrients from degradation and minimizes nutrient leaching, thereby supporting healthy seedling growth post-germination. It also acts as a protective barrier against environmental stressors, reinforcing seed cell walls to maintain structural integrity and reduce cellular degradation. Additionally, biogenic silica exhibits antioxidant properties that help neutralize oxidative stress, further preserving seed quality. Seeds coated with biogenic silica typically show quicker and more uniform germination, leading to healthier seedlings and improved agricultural productivity.

Among the storage containers, super grain bags demonstrated superior enzyme preservation compared to cloth bags stored under ambient conditions. This advantage may stem from reduced protein denaturation, which otherwise accelerates DNA degradation. Such degradation impairs the translation and transcription of enzymes essential for germination. Consequently, reduced enzyme activity hampers energy activation, leading to decreased seedling vigor and functionality. Additionally, the storage period fosters catabolic reactions that generate free radicals and hydrogen peroxides, further compromising seed quality. The outcomes are conformity with [47] in barley; [48] in pearl millet; [49] in canola seed; [50] in barnyard millet; [51] in horsegram; and [52] in soyabean.

5. Conclusion

The results from the present study revealed that the sorghum seeds coated with Biogenic silica with carbon T_1 @ 5 ml /kg stored in supergrain bag(C_2) was effective in maintaining the physiological seed quality parameters such as moisture content, germination %, root and shoot length, dry matter production, vigour index I and vigour index II throughout the storage period of six months under ambient condition. The antioxidants present in the Biogenic silica with carbon protects the seeds during long term storage and promotes healthy vigours seedlings.

FUTURE SCOPE

Biogenic silica seed coating in agriculture holds significant promise due to the its numerous benefits to the plants and environment. As sustainable agricultural practices gain importance, Biogenic silica coatings have the potential to revolutionize farming methods.

Declarations

Ethics Approval Not applicable.

Consent to Participate All authors were highly cooperative and involved equally in research activities and preparation of this article.

Consent for Publication All authors agreed to publish this research article.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Table 1. Influence of seed coating, storage container and storage period on Moisture content (%) in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	8.4	8.8	9.0	9.4	9.5	9.6	9.8	9.2	8.4	8.5	8.6	8.7	8.9	9.1	9.3	8.8	9.0
T_1	8.4	8.6	8.9	9.1	9.3	9.4	9.5	9.0	8.4	8.4	8.4	8.5	8.5	8.6	8.6	8.5	8.8
T_2	8.4	8.6	8.9	9.2	9.4	9.5	9.6	9.1	8.4	8.4	8.5	8.6	8.6	8.7	8.7	8.6	8.9
Mean	8.4	8.7	8.9	9.2	9.4	9.5	9.6	9.1	8.4	8.4	8.5	8.6	8.7	8.8	8.9	8.6	8.9

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	8.4	8.6	8.7	8.9	9.1	9.2	9.3	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.0401	0.0750	0.0491	0.1060	0.0694	0.1299	0.1837
CD (P=0.05)	0.0797**	0.1491**	0.0976**	0.2109**	NS	NS	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 2. Influence of seed coating, storage container and storage period on Germination (%) in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	80	79	77	75	72	69	65	74	80	80	78	76	74	70	67	75	74
T_1	95	94	92	88	84	84	82	88	95	95	93	89	85	85	83	89	89
T_2	91	88	85	82	82	80	77	84	91	90	86	84	83	82	78	85	84
Mean	89	87	85	82	79	78	75	82	89	88	86	83	81	79	76	83	83

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	89	88	85	82	80	78	75	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.3157	0.5907	0.3867	0.8355	0.54697	1.0232	1.4471
CD (P=0.05)	0.6279**	1.1748**	0.7691**	NS	NS	2.0349**	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 3. Influence of seed coating, storage container and storage period on root length (cm) in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	18.18	18.02	17.79	17.35	16.89	16.51	15.87	17.23	18.18	18.10	17.95	17.52	17.14	16.72	16.29	17.41	17.32
T_1	26.68	26.51	26.17	25.87	25.51	25.29	25.09	25.87	26.68	26.60	26.36	26.03	25.60	25.42	25.16	25.98	25.93
T_2	24.98	24.82	24.61	24.36	24.02	23.65	23.37	24.26	24.98	24.91	24.73	24.52	24.21	23.89	23.54	24.40	24.33
Mean	23.28	23.12	22.86	22.53	22.14	21.82	21.44	22.45	23.28	23.20	23.01	22.69	22.32	22.01	21.66	22.60	22.53

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	23.28	23.16	22.94	22.61	22.23	21.92	21.55	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.1147	0.2146	0.1404	0.3035	0.1986	0.3717	0.5256
CD (P=0.05)	0.2281**	0.4267**	0.2793**	NS	NS	NS	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 4. Influence of seed coating, storage container and storage period on Shoot length (cm) in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	10.78	10.63	10.47	10.36	10.21	10.02	9.72	10.31	10.78	10.71	10.55	10.42	10.31	10.13	9.89	10.40	10.36
T_1	15.45	15.36	15.21	15.02	14.84	14.64	14.46	15.00	15.45	15.41	15.27	15.13	14.93	14.77	14.55	15.07	15.04
T_2	14.97	14.85	14.72	14.58	14.29	14.01	13.84	14.47	14.97	14.91	14.79	14.65	14.42	14.15	13.93	14.55	14.51
Mean	13.73	13.61	13.47	13.32	13.11	12.89	12.67	13.26	13.73	13.68	13.54	13.40	13.22	13.02	12.79	13.34	13.30

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	13.73	13.65	13.51	13.36	13.17	12.96	12.73	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.0607	0.1136	0.0743	0.1606	0.1051	0.1967	0.2782
CD (P=0.05)	0.1207**	0.2259**	0.1479**	NS	NS	NS	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 5. Influence of seed coating, storage container and storage period on dry matter production (g) in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	0.153	0.142	0.131	0.120	0.111	0.105	0.101	0.123	0.153	0.148	0.136	0.125	0.114	0.107	0.103	0.127	0.125
T_1	0.211	0.201	0.189	0.176	0.163	0.155	0.145	0.177	0.211	0.206	0.194	0.183	0.168	0.159	0.153	0.182	0.180
T_2	0.206	0.193	0.179	0.165	0.153	0.141	0.131	0.167	0.206	0.201	0.186	0.172	0.161	0.148	0.136	0.173	0.170
Mean	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.156	0.190	0.185	0.172	0.160	0.148	0.138	0.131	0.160	0.158
Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6										
	0.157	0.154	0.148	0.142	0.136	0.131	0.127										

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.0008	0.0015	0.0009	0.0021	0.0013	0.0026	0.0036
CD (P=0.05)	0.0015**	0.0029**	0.0019**	NS	NS	0.0051**	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 6. Influence of seed coating, storage container and storage period on Vigour index I in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	2172	2091	1950	1829	1734	1671	1535	1855	2172	2132	2024	1900	1839	1692	1623	1912	1884
T_1	4002	3936	3807	3598	3389	3354	3243	3618	4002	3991	3872	3663	3445	3416	3296	3669	3644
T_2	3596	3491	3343	3193	3141	3013	2865	3235	3596	3544	3399	3290	3206	3119	2923	3297	3266
Mean	3257	3173	3033	2873	2755	2679	2548	2903	3257	3222	3098	2951	2830	2742	2614	2959	2931

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	3257	3198	3066	2912	2793	2711	2581	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	13.3040	24.8896	16.2940	35.1992	23.0433	43.1101	60.9669
CD (P=0.05)	26.4567**	49.4959**	32.4027**	NS	NS	85.7294**	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Table 7. Influence of seed coating, storage container and storage period on Vigour index II in Sorghum var. K 12

T	Containers (C) and storage periods in months (P)																Grand mean
	Cloth bag (C_1)								Super grain bag (C_2)								
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	Mean	
T_0	11.48	10.37	9.04	7.92	7.10	6.62	6.06	8.37	11.48	10.95	9.66	8.50	7.64	6.74	6.39	8.77	8.57
T_1	20.05	18.89	17.39	15.49	13.69	13.02	11.89	15.77	20.05	19.57	18.04	16.29	14.28	13.52	12.70	16.35	16.06
T_2	18.54	16.98	15.22	13.53	12.55	11.28	10.09	14.03	18.54	17.89	16.00	14.45	13.36	12.14	10.61	14.71	14.37
Mean	16.69	15.41	13.88	12.31	11.11	10.31	9.35	12.72	16.69	16.14	14.57	13.08	11.76	10.80	9.90	13.28	13.00

Grand Mean	P_0	P_1	P_2	P_3	P_4	P_5	P_6	
	16.69	15.78	14.23	12.70	11.44	10.56	9.63	

	C	P	T	C × P	C × T	P × T	C×P×T
S. Ed	0.0606	0.1133	0.0742	0.1603	0.1049	0.1964	0.2777
CD (P=0.05)	0.1205**	0.2254**	0.1476**	0.3189**	NS	0.3905**	NS

**- Significant at 5% level; NS- Non-Significant; C- Containers; P- Storage period in months; T- Treatments

T_0 – Control **T_1 – Biogenic silica with carbon 5 ml/kg** **T_2 – Biogenic silica without carbon 5 ml/kg**

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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