



Enhancing Chickpea Seed Quality: Impact of Genotype Selection and Storage Conditions

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ABSTRACT

Background: Chickpea (*Cicer arietinum* L.), a vital cool-season legume, faces challenges in seed storage due to environmental factors affecting biochemical stability.

Methods: This study assessed the response of eight chickpea genotypes to different storage containers and environmental conditions over twelve months. Seeds were stored under ambient and refrigerated conditions in six types of containers and key biochemical parameters-protein content, carbohydrate content and electrical conductivity-were evaluated.

Result: Digvijay (V₅) and ICCV-191611 (V₆) exhibited superior protein and carbohydrate stability, while Bidisha (V₂) and BG-3043 (V₄) were more prone to deterioration. Refrigerated storage (T₆) and 700-gauge polythene packets (T₅) effectively maintained seed quality, minimizing protein and carbohydrate losses while reducing electrical conductivity. Cloth bags (T₁) and brown paper packets (T₃) resulted in the highest deterioration. These findings highlight the importance of genotype selection and optimized storage strategies for enhancing chickpea seed longevity and quality.

Key words: Carbohydrate, Chickpea, Genotypes, Protein, Storage.

INTRODUCTION

Chickpea (*Cicer arietinum* L.), a self-pollinated crop belonging to the subfamily *Papilionaceae* within the *Fabaceae* family, plays a significant role in global agriculture. Known for its adaptability to diverse climatic conditions, low production costs and contribution to nitrogen fixation, chickpea is a crucial legume in crop rotation systems. Despite its ability to thrive in a wide range of environments, chickpea cultivation faces challenges when exposed to low temperatures. As Cani (2009) highlighted, chickpea is not only vital for food security but also for sustaining agricultural ecosystems.

A critical aspect of chickpea production is seed quality, which directly affects both germination and storability. Several factors influence seed storage potential, including the pre-storage history, seed maturity and environmental conditions during pre- and post-harvest stages (Mahesha *et al.*, 2001, Ahmad *et al.*, 2014). Premature harvested seeds exhibit poor storage characteristics and reduced viability, making them less suitable for long-term storage (Rao *et al.*, 2023). In contrast, seeds harvested at physiological maturity-when they reach peak viability and vigour-offer the best chance for successful storage. The timing of harvest, which is influenced by both genetic traits and environmental factors, plays a key role in ensuring high-quality seeds (Singh, 1995; Raghu *et al.*, 2016).

Seed quality testing involves evaluating key attributes such as seed size, vigour, viability, germination rate and nutritional content, along with electrical conductivity (Ray, 2022). Furthermore, seed characteristics can be influenced by the specific location within the plant from which the seeds are harvested.

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Given the importance of seed quality in ensuring optimal crop performance, the present study aims to investigate the impact of genotype selection and storage conditions on chickpea seed quality. This research seeks to assess how different chickpea genotypes respond to varying storage containers and environmental conditions. The rationale behind this study is to identify strategies that will enhance both seed quality and storage potential, contributing to improved chickpea production and ensuring its availability for both immediate use and long-term preservation. By understanding the relationship between genotype, seed maturation and storage conditions, this study will provide valuable insights into optimizing chickpea seed storage techniques for better agricultural sustainability.

MATERIALS AND METHODS

Seeds from eight chickpea genotypes-Anuradha (V_1), Bidisha (V_2), Bidhan-1 (V_3), BG-3043 (V_4), Digvijay (V_5), GNG-2299 (V_6), ICCV-191609 (V_7) and ICCV-191611 (V_8)-were utilized. After harvest, seeds were cleaned thoroughly and sun-dried to approximately 8% moisture content. Seeds of each genotype were stored under ambient and refrigerated conditions in six types of storage containers: Cloth bags (T_1), aluminium foil pouches (T_2), brown paper packets (T_3), glass containers (T_4), 700-gauge polythene packets for ambient conditions (T_5) and 700-gauge polythene packets for refrigerated conditions (T_6 , 4-5°C). The study was set up using a two-factor complete randomized design (CRD) analysis with three replications. Laboratory experiments were conducted during April, 2022 to March, 2023 at the seed testing laboratory, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India. Seed samples were collected at bi-monthly intervals over twelve months, resulting in six evaluations from each replication. For biochemical estimation, seeds were thoroughly cleaned, oven-dried and ground into fine powder, where 100 mg of seed powder per sample was taken for protein and carbohydrate analysis. Seed protein content was determined using Lowry *et al.* (1951), based on the reaction of peptide bonds with copper under alkaline conditions (Biuret reaction), followed by reduction of the Folin-Ciocalteu reagent by aromatic amino acids, producing a blue colour measured spectrophotometrically. Carbohydrate

contents of the seeds were measured using Hedge (1962) method, involving hydrolysing carbohydrates to simple sugars, which react with anthrone reagent in acidic medium to form a green coloured complex. The intensity of the colour, read spectrophotometrically, is proportional to carbohydrate content. Electrical conductivity (EC), indicative of membrane stability, was measured to assess the physiological status of the seeds.

RESULTS AND DISCUSSION

Seed protein content (mg g^{-1}) at different stages of storage

The data analysis (Table 1) reveals significant differences among genotypes at each storage interval, as indicated by the critical difference (CD at 0.01) values being consistently higher than the corresponding standard error of the mean (SEm). This confirms that the observed variation in performance across genotypes is statistically significant at 1% level. Notably, genotype V_5 maintained significantly higher values throughout all storage periods, indicating superior storability, while V_2 and V_4 consistently recorded the lowest values, signifying poor seed quality retention over time. The increasing CD values from 0.307 at 2 months to 0.954 at 12 months further suggest that genotype differences become more pronounced with prolonged storage, emphasizing the importance of selecting genotypes with stable performance over time for long-term seed viability.

Table 1: Variation in protein content (mg g^{-1}) of the genotypes over the period of storage.

Genotype mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
V_1	19.38	18.50	16.79	14.94	12.77	9.93
V_2	17.18	16.46	15.27	13.34	11.28	8.47
V_3	18.96	18.52	17.08	15.12	13.15	10.23
V_4	18.19	17.32	16.07	14.05	11.86	8.96
V_5	20.91	20.43	18.75	16.74	14.55	11.78
V_6	19.04	18.55	16.86	14.75	12.43	9.69
V_7	20.56	19.40	17.28	15.34	13.12	10.32
V_8	20.57	19.79	17.95	15.84	13.77	10.79
SEm ($\pm$)	0.109	0.225	0.245	0.223	0.270	0.339
CD (0.01)	0.307	0.632	0.688	0.627	0.758	0.954

Table 2: Variation in seed protein content (mg g^{-1}) under various storage condition.

Treatment mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
T_1	16.97	15.53	13.57	11.77	9.17	5.88
T_2	19.37	18.52	17.40	15.35	13.17	10.36
T_3	17.63	17.22	16.11	13.96	11.08	7.77
T_4	19.83	19.42	17.55	15.51	13.78	10.70
T_5	20.78	20.02	18.46	16.48	14.55	11.87
T_6	21.50	21.02	18.95	17.03	15.45	13.54
SEm ($\pm$)	0.094	0.195	0.212	0.193	0.233	0.294
CD (0.01)	0.266	0.548	0.596	0.543	0.656	0.826

Table 3: Variation in protein content (mg g⁻¹) due to the interaction of treatment and genotype over the period of storage.

Treatment ×	Storage duration					
Genotype	2 months	4 months	6 months	8 months	10 months	12 months
T ₁ V ₁	15.29	13.36	11.88	10.85	8.53	5.38
T ₁ V ₂	14.07	12.93	11.07	9.78	7.25	4.44
T ₁ V ₃	17.12	16.63	14.35	12.61	9.87	6.79
T ₁ V ₄	15.06	13.04	11.79	9.91	7.31	4.16
T ₁ V ₅	18.86	18.67	16.10	14.07	11.77	8.63
T ₁ V ₆	16.36	15.54	13.77	11.41	8.76	5.35
T ₁ V ₇	19.48	16.95	14.60	12.40	9.67	6.06
T ₁ V ₈	19.54	17.09	15.00	13.10	10.22	6.25
T ₂ V ₁	20.07	19.13	17.90	15.72	13.57	10.40
T ₂ V ₂	18.29	17.05	16.30	14.41	12.17	9.32
T ₂ V ₃	18.40	17.85	16.29	13.99	12.99	9.96
T ₂ V ₄	18.40	17.14	16.52	14.38	12.17	9.44
T ₂ V ₅	20.26	19.78	18.66	16.80	14.34	11.69
T ₂ V ₆	18.99	18.50	16.92	14.94	12.43	9.74
T ₂ V ₇	19.95	18.69	17.66	15.99	13.37	10.84
T ₂ V ₈	20.61	20.05	18.94	16.59	14.31	11.46
T ₃ V ₁	16.55	16.25	15.62	13.59	10.63	7.32
T ₃ V ₂	14.32	14.12	13.31	11.47	8.79	5.57
T ₃ V ₃	17.55	17.38	16.75	14.87	11.74	8.71
T ₃ V ₄	16.09	15.61	14.74	12.77	9.73	6.42
T ₃ V ₅	19.51	18.92	17.59	15.65	12.63	9.26
T ₃ V ₆	17.57	17.30	16.47	13.77	10.74	7.60
T ₃ V ₇	19.59	18.75	16.61	14.19	11.61	7.92
T ₃ V ₈	19.89	19.45	17.76	15.34	12.76	9.34
T ₄ V ₁	20.11	19.37	17.00	15.06	13.01	10.13
T ₄ V ₂	17.41	17.03	16.31	14.10	12.38	9.34
T ₄ V ₃	19.00	18.75	17.79	15.74	14.07	10.92
T ₄ V ₄	19.55	19.16	17.83	15.94	13.82	10.41
T ₄ V ₅	21.77	21.25	19.11	17.05	15.20	12.23
T ₄ V ₆	19.79	19.46	17.43	15.34	13.60	10.37
T ₄ V ₇	20.48	20.03	17.01	15.19	13.68	10.89
T ₄ V ₈	20.52	20.30	17.92	15.67	14.45	11.34
T ₅ V ₁	22.06	21.18	19.08	17.18	15.28	12.66
T ₅ V ₂	18.84	18.05	16.93	14.82	12.94	10.16
T ₅ V ₃	20.72	20.01	18.92	16.80	15.02	11.55
T ₅ V ₄	19.84	19.13	17.58	15.46	13.64	11.11
T ₅ V ₅	22.09	21.31	20.12	17.99	16.00	13.36
T ₅ V ₆	20.40	19.96	18.29	16.30	14.35	11.93
T ₅ V ₇	21.67	20.34	18.43	16.71	14.58	12.20
T ₅ V ₈	20.59	20.16	18.34	16.58	14.56	12.01
T ₆ V ₁	22.22	21.68	19.29	17.25	15.62	13.69
T ₆ V ₂	20.13	19.60	17.69	15.47	14.13	11.97
T ₆ V ₃	20.94	20.52	18.40	16.70	15.19	13.45
T ₆ V ₄	20.23	19.83	17.98	15.86	14.46	12.21
T ₆ V ₅	22.99	22.66	20.93	18.89	17.38	15.50
T ₆ V ₆	21.10	20.51	18.27	16.75	14.71	13.17
T ₆ V ₇	22.17	21.65	19.35	17.56	15.83	13.98
T ₆ V ₈	22.25	21.68	19.71	17.75	16.31	14.34
SEm (±)	0.267	0.551	0.599	0.546	0.660	0.831
CD (0.01)	0.751	1.549	NS	NS	NS	NS

The treatment-wise data (Table 2) demonstrates statistically significant differences in performance across all storage intervals, as the critical difference at 1% (CD/0.01) consistently exceeds the standard error of the mean (SEm), confirming the reliability of observed treatment effects. Among all treatments, T_6 consistently recorded the highest values throughout the 12-month storage period, significantly outperforming others and indicating superior effectiveness in maintaining seed quality. In contrast, T_1 showed the lowest performance at every interval, suggesting poor storability. The distinction among treatments becomes more evident over time, with increasing CD values from 0.266 at 2 months to 0.826 at 12 months, reinforcing that treatment effects on storability become more pronounced during extended storage. These findings highlight T_6 as the most effective treatment for preserving seed quality over long-term storage.

The interaction effect between treatment and genotype (Table 3) shows statistically significant differences at 2 and 4 months after storage, as the critical difference at 1% (CD/0.01) exceeds the standard error of the mean (SEm) at these time points, indicating that the treatment-genotype combinations significantly influenced the trait during early storage. However, from 6 months onward, the differences become statistically non-significant (NS), suggesting that the effect of specific treatment-genotype combinations diminishes over time, likely due to progressive uniform deterioration across all combinations. Notably, the highest-

performing combinations across time include T_6V_5 , T_6V_8 and T_6V_1 , all of which consistently retained superior values, whereas T_1V_2 and T_1V_4 exhibited the lowest values, especially by 12 months. These results emphasize that while certain treatment-genotype interactions initially confer storage advantages, their distinctiveness may wane with prolonged storage duration.

Seed carbohydrate content (mg g⁻¹) at different stages of storage

The genotype mean data (Table 4) across six storage durations reveals statistically significant differences among genotypes at all time points, as the critical difference at 1% (CD/0.01) consistently exceeds the standard error of the mean (SEm). This indicates that the genotypes differ significantly in their ability to maintain the trait under study-likely seed viability or vigour-over time. Genotypes V_5 , V_8 and V_7 consistently maintained higher mean values, particularly V_8 , which performed best at later stages (e.g., 12 months: 5.79), suggesting superior storability. In contrast, V_4 showed the lowest values throughout the storage duration, with a drastic decline to 3.34 at 12 months, indicating poor seed longevity. The significant differences highlight the importance of genotype selection for enhancing storage performance and long-term seed quality maintenance.

The treatment-wise analysis (Table 5) across storage durations demonstrates statistically significant differences at all time points, as the critical difference at 1% (CD/0.01)

Table 4: Variation in carbohydrate content (mg g⁻¹) of the genotypes over the period of storage.

Genotype mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
V_1	16.01	13.73	11.51	9.35	6.79	3.69
V_2	17.80	15.44	13.17	11.02	8.52	5.38
V_3	17.37	15.09	12.79	10.71	8.15	5.05
V_4	14.06	12.50	10.10	8.55	6.13	3.34
V_5	18.11	15.83	13.57	11.46	8.90	5.48
V_6	17.68	15.34	13.03	11.15	8.46	5.36
V_7	17.81	15.53	13.24	11.23	8.59	5.66
V_8	17.98	16.08	13.44	11.48	8.88	5.79
SEm (±)	0.144	0.160	0.182	0.217	0.236	0.308
CD (0.01)	0.406	0.449	0.512	0.610	0.663	0.613

Table 5: Variation in seed carbohydrate content (mg g⁻¹) under various storage condition.

Treatment mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
T_1	16.62	13.84	11.31	9.04	6.61	4.06
T_2	16.80	14.57	12.25	10.28	7.73	4.31
T_3	16.69	14.35	11.81	9.64	6.90	4.21
T_4	17.09	15.10	13.20	11.08	8.55	5.20
T_5	17.38	15.57	12.92	11.42	8.87	5.54
T_6	18.03	16.23	14.15	12.25	9.67	6.49
SEm (±)	0.125	0.138	0.158	0.188	0.204	0.267
CD (0.01)	0.352	0.389	0.444	0.528	0.574	0.531

Table 6: Variation in carbohydrate content (mg g⁻¹) due to the interaction of treatment and genotype over the period of storage.

Treatment ×	Storage duration					
Genotype	2 months	4 months	6 months	8 months	10 months	12 months
T ₁ V ₁	15.49	12.54	10.09	7.67	5.18	2.66
T ₁ V ₂	17.27	14.23	11.78	9.53	6.89	4.44
T ₁ V ₃	17.23	14.28	11.82	9.41	6.92	4.40
T ₁ V ₄	13.24	11.28	8.70	7.12	5.31	2.51
T ₁ V ₅	17.51	14.56	12.11	9.69	7.20	4.59
T ₁ V ₆	17.35	14.47	11.90	9.45	7.04	4.52
T ₁ V ₇	17.42	14.46	12.01	9.66	7.11	4.64
T ₁ V ₈	17.47	14.88	12.06	9.78	7.24	4.68
T ₂ V ₁	15.75	13.37	11.12	9.03	6.43	3.00
T ₂ V ₂	17.55	15.07	12.81	10.67	8.15	4.42
T ₂ V ₃	17.04	14.66	12.40	10.32	7.71	4.29
T ₂ V ₄	13.53	12.15	9.77	8.18	6.06	3.28
T ₂ V ₅	17.87	15.50	13.24	11.16	8.55	4.78
T ₂ V ₆	17.38	14.97	12.65	10.83	8.06	4.64
T ₂ V ₇	17.52	15.15	12.89	10.88	8.20	4.98
T ₂ V ₈	17.72	15.72	13.09	11.14	8.68	5.13
T ₃ V ₁	15.65	13.14	10.68	8.40	5.60	2.93
T ₃ V ₂	17.45	14.87	12.41	10.03	7.32	4.67
T ₃ V ₃	16.93	14.43	11.96	9.68	6.88	4.22
T ₃ V ₄	13.43	11.92	9.33	7.55	5.44	2.60
T ₃ V ₅	17.77	15.26	12.80	10.52	7.72	4.70
T ₃ V ₆	17.28	14.68	12.21	10.20	7.23	4.56
T ₃ V ₇	17.42	14.91	12.45	10.27	7.37	4.90
T ₃ V ₈	17.62	15.60	12.65	10.51	7.63	5.05
T ₄ V ₁	16.04	13.90	12.40	9.83	7.38	3.93
T ₄ V ₂	17.84	15.63	13.76	11.46	9.10	5.67
T ₄ V ₃	17.33	15.18	13.16	11.12	8.66	5.22
T ₄ V ₄	13.82	12.68	10.72	8.98	6.14	3.58
T ₄ V ₅	18.16	16.02	14.20	11.95	9.50	5.70
T ₄ V ₆	17.67	15.42	13.57	11.63	9.01	5.56
T ₄ V ₇	17.81	15.67	13.72	11.67	9.15	5.90
T ₄ V ₈	18.01	16.28	14.07	11.96	9.44	6.05
T ₅ V ₁	16.34	14.37	11.79	10.17	7.63	4.27
T ₅ V ₂	18.14	16.08	13.51	11.81	9.37	6.01
T ₅ V ₃	17.62	15.65	13.07	11.46	8.92	5.56
T ₅ V ₄	14.12	13.15	10.44	9.32	6.87	3.89
T ₅ V ₅	18.46	16.49	13.91	12.30	9.76	6.05
T ₅ V ₆	17.97	15.90	13.32	11.97	9.27	5.91
T ₅ V ₇	18.11	16.14	13.56	12.02	9.41	6.25
T ₅ V ₈	18.31	16.79	13.76	12.31	9.72	6.40
T ₆ V ₁	16.77	15.05	13.02	10.99	8.54	5.31
T ₆ V ₂	18.57	16.77	14.74	12.62	10.28	7.05
T ₆ V ₃	18.06	16.34	14.31	12.28	9.83	6.60
T ₆ V ₄	16.22	13.83	11.67	10.14	6.99	4.19
T ₆ V ₅	18.90	17.17	15.14	13.11	10.66	7.09
T ₆ V ₆	18.41	16.59	14.55	12.79	10.17	6.95
T ₆ V ₇	18.55	16.82	14.79	12.86	10.31	7.29
T ₆ V ₈	18.75	17.24	14.99	13.19	10.58	7.44
SEm (±)	0.354	0.391	0.446	0.531	0.577	0.755
CD (0.01)	NS	NS	NS	NS	NS	NS

is consistently greater than the standard error of the mean (SEm), confirming the reliability of treatment effects. Among the treatments, T_6 consistently outperformed the others, maintaining the highest values from 2 to 12 months, with a notable value of 6.49 at the end of the storage period, indicating superior efficacy in preserving seed quality. Conversely, T_1 consistently recorded the lowest values, particularly after prolonged storage, suggesting it was the least effective treatment. The growing differences among treatments over time, as reflected in increasing CD values, emphasize the long-term impact of effective storage treatments, highlighting T_6 as the most promising for sustaining seed viability and vigour over extended periods.

The analysis of the interaction effects between treatments and genotypes (Table 6) on seedling vigour index over a 12-month storage period reveals no statistically significant differences, as indicated by the absence of a critical difference (CD) at the 1% level across all storage intervals. Despite observable numerical variation in seedling vigour index values among the 48 treatment $\times$ genotype combinations, the lack of significance suggests that these differences are not statistically reliable and could be due to random variation. This indicates that the combined effect of treatment and genotype does not contribute meaningfully to variation in seedling vigour index under storage conditions, emphasizing the dominant role of main effects (treatment or genotype alone) rather than their interaction in determining storability traits.

Electrical conductivity ($\mu\text{S cm}^{-1} \text{g}^{-1}$) of seeds at different stages of storage

The analysis of genotype means (Table 7) for electrical conductivity (EC) over a 12-month storage period indicates statistically significant differences among genotypes at each time point, as the calculated critical difference (CD) at the 1% level exceeds the Standard Error of Mean (SEm) throughout. Genotypes V_2 , V_4 and V_6 consistently recorded higher EC values, indicating greater membrane deterioration and, consequently, reduced seed vigour during storage. In contrast, genotypes V_5 , V_8 and V_7 maintained comparatively lower EC values, suggesting better seed membrane integrity and storability. The significant differences highlight the genetic variability in seed quality deterioration patterns, with EC values steadily increasing across storage durations for all genotypes, reflecting the typical aging-related loss of membrane stability.

The data on treatment means (Table 8) for electrical conductivity (EC) across storage durations reveals statistically significant differences among treatments at all time points, as the critical difference (CD) at the 1% level exceeds the corresponding standard error of mean (SEm). Notably, treatment T_1 consistently exhibited the highest EC values throughout the storage period, indicating the greatest level of seed membrane deterioration and reduced vigour. Conversely, treatments T_5 and T_6 showed significantly lower EC values, reflecting better membrane integrity and higher storability potential. Among them, T_6 emerged as

Table 7: Variation in electrical conductivity ($\mu\text{S cm}^{-1} \text{g}^{-1}$) of the genotypes over the period of storage.

Genotype mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
V_1	0.178	0.196	0.229	0.264	0.326	0.462
V_2	0.206	0.223	0.256	0.292	0.354	0.490
V_3	0.175	0.192	0.225	0.261	0.322	0.459
V_4	0.197	0.215	0.248	0.283	0.345	0.482
V_5	0.146	0.163	0.196	0.232	0.293	0.430
V_6	0.196	0.213	0.246	0.282	0.344	0.480
V_7	0.170	0.188	0.221	0.258	0.320	0.454
V_8	0.162	0.179	0.213	0.250	0.311	0.446
SEm ($\pm$)	0.003	0.005	0.008	0.013	0.009	0.012
CD (0.01)	0.008	0.014	0.024	0.036	0.025	0.035

Table 8: Variation in electrical conductivity ($\mu\text{S cm}^{-1} \text{g}^{-1}$) under various storage condition.

Treatment mean	Storage duration					
	2 months	4 months	6 months	8 months	10 months	12 months
T_1	0.194	0.215	0.251	0.289	0.351	0.505
T_2	0.177	0.195	0.228	0.264	0.325	0.460
T_3	0.191	0.211	0.246	0.283	0.345	0.484
T_4	0.176	0.192	0.224	0.259	0.321	0.454
T_5	0.169	0.184	0.216	0.250	0.312	0.442
T_6	0.166	0.180	0.210	0.246	0.307	0.431
SEm ($\pm$)	0.002	0.004	0.007	0.011	0.008	0.011
CD (0.01)	0.007	0.012	0.020	0.031	0.022	0.030

Table 9: Variation in electrical conductivity ($\mu\text{S cm}^{-1} \text{g}^{-1}$) due to the interaction of treatment and genotype over the period of storage.

Treatment ×	Storage duration					
Genotype	2 months	4 months	6 months	8 months	10 months	12 months
T ₁ V ₁	0.201	0.222	0.258	0.297	0.359	0.512
T ₁ V ₂	0.226	0.247	0.284	0.322	0.384	0.537
T ₁ V ₃	0.194	0.215	0.252	0.290	0.352	0.505
T ₁ V ₄	0.213	0.234	0.271	0.309	0.371	0.524
T ₁ V ₅	0.153	0.173	0.210	0.248	0.310	0.463
T ₁ V ₆	0.208	0.229	0.265	0.304	0.366	0.519
T ₁ V ₇	0.187	0.208	0.245	0.283	0.345	0.498
T ₁ V ₈	0.166	0.187	0.224	0.262	0.324	0.477
T ₂ V ₁	0.173	0.191	0.225	0.260	0.322	0.457
T ₂ V ₂	0.204	0.222	0.256	0.291	0.353	0.488
T ₂ V ₃	0.170	0.187	0.221	0.256	0.318	0.453
T ₂ V ₄	0.192	0.210	0.244	0.279	0.341	0.476
T ₂ V ₅	0.149	0.166	0.200	0.235	0.297	0.432
T ₂ V ₆	0.203	0.220	0.254	0.289	0.351	0.486
T ₂ V ₇	0.164	0.182	0.216	0.251	0.313	0.448
T ₂ V ₈	0.159	0.176	0.210	0.245	0.307	0.442
T ₃ V ₁	0.173	0.210	0.245	0.282	0.344	0.483
T ₃ V ₂	0.204	0.238	0.273	0.310	0.372	0.511
T ₃ V ₃	0.170	0.209	0.244	0.281	0.343	0.482
T ₃ V ₄	0.192	0.228	0.264	0.301	0.363	0.502
T ₃ V ₅	0.149	0.170	0.206	0.243	0.304	0.444
T ₃ V ₆	0.203	0.226	0.261	0.298	0.360	0.499
T ₃ V ₇	0.164	0.205	0.240	0.277	0.339	0.478
T ₃ V ₈	0.159	0.200	0.236	0.273	0.334	0.474
T ₄ V ₁	0.190	0.189	0.221	0.256	0.318	0.451
T ₄ V ₂	0.218	0.218	0.250	0.285	0.347	0.480
T ₄ V ₃	0.189	0.186	0.218	0.253	0.314	0.448
T ₄ V ₄	0.209	0.213	0.245	0.280	0.342	0.475
T ₄ V ₅	0.151	0.161	0.193	0.228	0.289	0.423
T ₄ V ₆	0.206	0.209	0.241	0.276	0.338	0.471
T ₄ V ₇	0.185	0.182	0.214	0.249	0.311	0.444
T ₄ V ₈	0.181	0.178	0.211	0.245	0.307	0.440
T ₅ V ₁	0.173	0.184	0.215	0.250	0.311	0.442
T ₅ V ₂	0.202	0.207	0.239	0.273	0.335	0.466
T ₅ V ₃	0.169	0.179	0.210	0.244	0.306	0.437
T ₅ V ₄	0.197	0.204	0.236	0.270	0.332	0.462
T ₅ V ₅	0.144	0.156	0.188	0.222	0.284	0.414
T ₅ V ₆	0.193	0.200	0.232	0.266	0.328	0.458
T ₅ V ₇	0.166	0.174	0.206	0.240	0.302	0.432
T ₅ V ₈	0.162	0.168	0.199	0.233	0.295	0.426
T ₆ V ₁	0.168	0.176	0.207	0.240	0.301	0.428
T ₆ V ₂	0.192	0.205	0.235	0.268	0.330	0.456
T ₆ V ₃	0.163	0.175	0.206	0.239	0.300	0.427
T ₆ V ₄	0.189	0.198	0.229	0.262	0.323	0.450
T ₆ V ₅	0.141	0.150	0.180	0.213	0.275	0.401
T ₆ V ₆	0.185	0.194	0.225	0.258	0.319	0.446
T ₆ V ₇	0.159	0.172	0.202	0.247	0.308	0.423
T ₆ V ₈	0.152	0.165	0.195	0.239	0.301	0.416
SEm (±)	0.007	0.012	0.021	0.031	0.022	0.030
CD (0.01)	NS	NS	NS	NS	NS	NS

the most effective in preserving seed quality, with the lowest EC across all durations. The consistent and significant variation underscores the influence of storage treatments on seed deterioration dynamics and highlights T_6 as the most promising treatment for maintaining seed quality during long-term storage.

The analysis of Treatment $\times$ Genotype interaction data for electrical conductivity (Table 9) over 12 months of storage reveals no statistically significant differences at the 1% level ($CD > SEM$) across all time intervals, as indicated by the non-significant (NS) critical difference values. This suggests that while variations in EC values exist among different genotype and treatment combinations, these variations are not substantial enough to be considered statistically significant. Therefore, the interaction effect between storage treatments and genotypes on seed membrane deterioration was not pronounced. The trend across the dataset still shows that certain combinations (such as T_1V_2 , T_1V_4 and T_1V_6) consistently exhibited higher EC values, while others like T_6V_5 , T_6V_8 and T_5V_5 maintained lower EC levels, indicating comparatively better seed storability. However, these observations remain descriptive and not statistically validated at the 1% level due to the lack of significant interaction effects.

Agarwal, (1987) noticed that protease activity was elevated in chickpea and mung bean seeds when they aged naturally or artificially. According to Ebone *et al.* (2019), the downregulation of antioxidant enzymes, including glutathione peroxidase (GPX), ascorbate peroxidase (APX), catalase (CAT) and superoxide dismutase (SOD), is the initial step in the aging process of seeds. The down-regulation and decrease in scavenging antioxidant activity resulted in the depression of the antioxidant enzyme system (Yin *et al.*, 2014). Reduced antioxidant activity can cause soluble protein degradation and decreased enzyme activity, as noted by Pukacka (2007), who also reported an increase in reactive oxygen species (ROS) during storage. Similar type of result was obtained in Bengal gram by Laxman *et al.* (2017) in terms of carbohydrate content, where they found that total carbohydrate decreased with storage time. Satasiya *et al.* (2020) and Chakraborty *et al.* (2024) in Chickpea also found similar type of result as well as corroborate with the findings.

The loss of leachate includes sugars, amino acids, fatty acids, proteins, enzymes and inorganic ions (K^+ , Ca^{+2} , Mg^{+2} , Na^+ and Mn^{+2}) and the test evaluates that the higher amount of ion as well as electrolyte leakage from the seeds resulting higher chances of degradation of seeds. Those genotypes and the containers measured higher amount of electrical conductivity are more prone to higher electrolyte leakage from the seeds compared to the seeds of other genotypes and containers. Beedi *et al.* (2018) observed similar type of result in kabuli chickpea. They further noted that, damage to the membrane system could be repaired and protected against such changes by primed treatment as indicated by low electrical conductivity of seed leachate and protective action

of primed chemicals could presumably have extended the viability of seeds. Dias *et al.* (2004) also revealed that seed soaking in water effectively controlled the leakage of electrolytes, sugars and amino acids from the seeds.

CONCLUSION

Therefore, Digvijay (V_9) and ICCV-191611 (V_8) exhibited superior seed quality retention, while refrigerated storage (T_6) was most effective in preserving seed biochemical integrity, highlighting the importance of optimal genotype selection and storage conditions for maintaining seed viability and quality over time.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

- Agarwal, P. and Kharlukhi, L. (1987). Enzyme activities in seeds during storage. *Experimental Biology*. **25**: 719-722.
- Ahmad, S., Khulbe, R.K., Roy, D. (2014). Evaluation of mungbean (*Vigna radiata*) germplasm for pre-harvest sprouting tolerance. *Legume Research-An International Journal*. **37(3)**: 259-263. doi: 10.5958/j.0976-0571.37.3.039.
- Beedi, S., Macha, S., Gowda, B., Savitha, A.S., Kurnallikar, V. (2018). Effect of seed priming on germination percentage, shoot length, root length, seedling vigour index, moisture content and electrical conductivity in storage of kabuli chickpea cv., MNK-1 (*Cicer arietinum* L.). *Journal of Pharmacognosy and Phytochemistry*. **7(1)**: 2005-2010.
- Cani, H. and Toker, C. (2009). Evaluation of annual wild *Cicer* species for drought and heat resistance under field conditions. *Genetic Resources and Crop Evolution*. **56**: 1-6.
- Chakraborty, A., Bordolui, S.K., Nandi, D., Ray, J., Desetty, J.M.S. N.K.S.V., Rout, S. (2024). Estimation of biochemical changes in green gram (*Vigna radiata* L.) during storage. *Agricultural Research Journal*. **61(2)**: 248-256.
- Dias, D., Freitas, R.A., Dias, L., Olivera, M. (2004). Storage Potential of Cotton Seeds Predicted by Vigour Tests and Biochemical Assays. 27th ISTA Congress, Budapest, Hungary. 70.
- Ebone, L.A., Caverzan, A., Chavarria, G. (2019). Physiologic alterations in orthodox seeds due to deterioration processes. *Plant Physiology and Biochemistry*. **145**: 34-42.
- Hedge, J.E. and Hofreiter, B.T. (eds.) (1962). Carbohydrate Chemistry. Whistler, R.L. and Be Miller, J.N. Inc., Academic Press, New York.
- Laxman, J., Roopa, G., Dayal, A. (2017). Effect of treatment on seed storage and physiological characters of chickpea (*Cicer arietinum* L.). *Journal of Pharmacognosy and Phytochemistry*. **6(3)**: 689-692.

- Lowry, O.H., Rosebrough, N.J., Farr, A.L., Randall, R.J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry*. **193**: 265.
- Mahesha, C.R., Channaveeraswami, A.S., Kurdikeri, M.B., Shekhargouda, M., Merwade, M.N. (2001). Seed maturation studies in sunflower genotypes. *Seed Research*. **29(1)**: 95-97.
- Pukacka, S. and Rataiczak, E. (2007). Age-related biochemical changes during storage of beech (*Fagus sylvatica* L.). *Seed Science Research*. **17(1)**: 45-53.
- Raghu, B.N., Kumar, R.P., Gowda, B., Manjunatha, N., Alur, R.S. (2016). Post harvest seed quality of greengram as influenced by pre-harvest spray of insecticides. *Indian Journal of Agricultural Research*. **50(2)**: 113-116. doi: 10.18805/ijare.v50i2.9588.
- Rao P.S., Madhulley T.Y., Ankaiah R. (2023). Scanning electron microscopy and morpho-physiological features imparting differential tolerance to pre-harvest sprouting (PHS) in mungbean [*Vigna radiata* (L.) Wilczek]. *Legume Research*. **46(11)**: 1453-1459. doi: 10.18805/LR-4834.
- Ray, J. and Bordolui, S.K. (2022). Seed quality deterioration of tomato during storage: Effect of storing containers and condition. *Biological Forum-An International Journal*. **14(2)**: 327-334.
- Satasiya, R.M., Antala, D.K., Sojitra, M.A., Kothiya, A.V., Chauhan, P.M. (2020). Effect of packaging on storage behaviour of chickpea grain. *Journal of Pharmacognosy and Phytochemistry*. **10(1)**: 1575-1584.
- Singh, A.R. and Lachanna, A. (1995). Effect of dates of harvesting, drying and storage on seed quality of sorghum parental lines. *Seed Research*. **13**: 180-185.
- Yin, G., Xin, X., Song, C., Chen, X., Zhang, J., Wu, S., Li, R., Liu, X., Lu, X. (2014). Activity levels and expression of antioxidant enzymes in the ascorbate-glutathione cycle in artificially aged rice seed. *Plant Physiology and Biochemistry*. **80**: 1-9.