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Influence of storage conditions and packaging materials on seed longevity of chickpea (*Cicer arietinum* L.)

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Abstract

Maintaining seed quality during storage represents a critical challenge in chickpea seed production systems across tropical and subtropical regions. This research examined the influence of different storage conditions and packaging materials on seed longevity parameters of chickpea (*Cicer arietinum* L.) variety Pusa 256 over a 12-month storage period. Five packaging treatments were evaluated: cloth bag (control), jute bag, high-density polyethylene (HDPE) bags of 700-gauge, aluminum foil pouches, and vacuum-sealed laminated pouches. Seeds were stored under two environments: ambient conditions (fluctuating temperature 18-38°C and relative humidity 45-85%) and controlled conditions (temperature 15±2°C and relative humidity 45±5%). Initial seed moisture content was standardized at 9.8% before packaging.

Results demonstrated that packaging material significantly influenced seed deterioration rate across both storage environments. Vacuum-sealed pouches maintained the highest germination percentage of 84.6% after 12 months under ambient storage, compared to 35.2% in cloth bags. Under controlled conditions, all packaging treatments showed better seed quality retention, with vacuum-sealed seeds recording 91.2% germination after 12 months. The moisture content of seeds stored in permeable containers (cloth and jute bags) increased substantially during monsoon months, reaching 14.7% in cloth bags compared to 10.2% in vacuum-sealed pouches.

Seedling vigor indices followed patterns similar to germination. Vigor index-I declined from initial 2847 to 987 in cloth bags and to 2234 in vacuum-sealed pouches after 12 months of ambient storage. Electrical conductivity of seed leachate, an indicator of membrane integrity, showed inverse relationship with germination, increasing from 0.412 dS/m initially to 1.234 dS/m in cloth bags and 0.567 dS/m in vacuum-sealed pouches. The accelerated aging test revealed that moisture-impermeable packaging provided protection against simulated stress conditions.

Biochemical analysis indicated progressive decline in dehydrogenase enzyme activity during storage, with cloth bags showing 67% reduction compared to 23% in vacuum-sealed pouches. Total soluble protein content decreased by 41% in cloth bags versus 18% in vacuum-sealed seeds. Lipid peroxidation as measured by malondialdehyde content showed 3.2-fold increase in permeable packaging compared to 1.4-fold in impermeable packaging.

Economic analysis revealed that despite higher initial cost of vacuum-sealed and aluminum foil packaging, the benefit-cost ratio favored these materials when considering seed quality maintenance and reduced need for frequent seed replacement. The research concludes that moisture-impermeable packaging materials, particularly vacuum-sealed laminated pouches and aluminum foil, effectively maintain chickpea seed quality for extended periods even under ambient tropical storage conditions. For resource-limited situations, HDPE bags of 700 gauge represent a cost-effective alternative maintaining acceptable germination levels (71.2%) after 12 months. The findings have direct implications for chickpea seed storage recommendations in tropical seed programs.

Keywords: Seed storage, chickpea, packaging materials, germination, seed longevity, moisture content, vigor index, *Cicer arietinum*

Introduction

How long can seeds remain viable under storage, and what factors govern this storage potential? These questions have occupied seed scientists for decades, given the fundamental importance of seed longevity to agricultural systems worldwide. Chickpea (*Cicer arietinum* L.) ranks as the third most important pulse crop globally, with India contributing approximately 68% of world

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production^[1]. The crop assumes particular significance in providing protein security to vegetarian populations across South Asia.

Seeds are living organisms that undergo continuous metabolic processes even during storage, albeit at reduced rates. The aging of seeds during storage involves a complex interplay of physiological and biochemical changes that progressively reduce viability and vigor^[2]. Temperature and moisture content represent the two most critical factors governing seed deterioration rate. Harrington proposed the "rule of thumb" stating that for every 5°C increase in temperature or 1% increase in seed moisture content within certain limits, the storage life of seeds is halved^[3].

The tropical and subtropical climate prevalent across most chickpea-growing regions poses significant challenges to seed storage. Ambient temperatures frequently exceed 35°C during summer months, while relative humidity reaches 80-90% during monsoon season^[4]. These conditions accelerate seed deterioration through multiple pathways including increased respiration, enzymatic activity, and proliferation of storage fungi. Seeds stored under such conditions may lose viability within a few months if adequate protective measures are not implemented^[5].

Packaging materials play a crucial role in modulating the seed-storage environment interaction. The primary function of seed packaging is to maintain seed moisture content at safe levels by providing a barrier against ambient moisture^[6]. Packaging materials can be broadly categorized based on their moisture permeability: permeable materials (cloth bags, jute bags, paper bags), semi-permeable materials (woven polyethylene, HDPE bags), and impermeable materials (aluminum foil, laminated pouches, vacuum-sealed containers)^[7]. The choice of packaging material significantly influences the microenvironment around the seed and consequently the deterioration rate.

Traditional seed storage in tropical countries typically employs cloth or jute bags due to their low cost and ready availability. However, these permeable containers allow rapid equilibration of seed moisture with ambient humidity, leading to moisture absorption during humid periods^[8]. Research conducted at various seed storage facilities has demonstrated that seeds stored in permeable containers lose viability 2-3 times faster than those in impermeable packaging under identical ambient conditions^[9]. The biochemical basis of seed deterioration involves several interconnected processes. Lipid peroxidation initiates membrane damage through the accumulation of reactive oxygen species, particularly under conditions of elevated moisture and temperature^[10]. This membrane damage compromises cellular compartmentalization and leads to enzyme leakage and substrate mixing. The Maillard reaction between reducing sugars and amino acids contributes to protein damage and browning^[11]. Mitochondrial dysfunction reduces ATP availability for repair processes during germination. DNA damage accumulates during storage, and beyond a threshold level of damage, the repair mechanisms become overwhelmed^[12].

Several investigations have examined the effect of packaging on seed quality retention in different crops. Work conducted on soybean demonstrated that vacuum packaging extended seed viability by 6-8 months compared to cloth bag storage^[13]. Similar results were reported in groundnut where aluminum foil pouches-maintained germination above 70% for 18 months compared to 9 months in jute bags^[14]. However, species-specific responses to storage conditions necessitate crop-wise optimization of storage protocols.

Chickpea seeds, being relatively large-seeded with moderate oil

content (4-5%), exhibit intermediate storability compared to small-seeded cereals and high-oil oilseeds^[15]. The seed coat characteristics, particularly the presence of impermeable palisade layer, influence moisture exchange with the environment^[16]. Yet, systematic research comparing different packaging materials under both ambient and controlled storage conditions remains limited for chickpea, particularly for Indian varieties^[17].

The present research was therefore designed to evaluate the comparative effectiveness of five packaging materials for maintaining chickpea seed quality under ambient and controlled storage environments over a 12-month period. The investigation aimed to identify cost-effective packaging solutions suitable for different resource situations while understanding the physiological and biochemical changes associated with seed deterioration under various storage conditions^[18, 19].

Research Area Description

The storage experiment was conducted at the Seed Storage Research Laboratory attached to the university research farm. The laboratory is equipped with controlled environment storage chambers capable of maintaining temperature at 15±2°C with relative humidity at 45±5%. The ambient storage facility represents typical godown conditions prevalent in seed storage facilities across the region, with temperatures ranging from 18°C during winter to 38°C during peak summer months and relative humidity fluctuating between 45% during dry season to 85% during monsoon months.

Chickpea variety Pusa 256 was used for the research, being a widely cultivated desi-type variety known for its bold seed size and good cooking quality. Freshly harvested seeds from the university research farm were used, ensuring known genetic identity and production history. The initial seed lot quality was: germination 94.2%, moisture content 9.8%, seedling vigor index-I 2847, and 100-seed weight 22.4 g.

The region experiences a semi-arid subtropical climate with distinct seasons. Summer months (April-June) record temperatures of 32-42°C with low humidity (30-45%). Monsoon months (July-September) bring heavy rainfall with humidity reaching 75-90%. Winter months (November-February) experience temperatures of 8-22°C with moderate humidity. This climatic variability provided natural stress conditions for evaluating packaging effectiveness under ambient storage.

Material and Methods

Material: Foundation seed of chickpea (*Cicer arietinum* L.) variety Pusa 256 harvested during rabi 2017-18 served as experimental material^[1]. Seeds were cleaned and graded to remove undersized, damaged, and shriveled seeds. Initial moisture content was equilibrated to 9.8% by shade drying. Five packaging materials were evaluated: P1 - Cloth bag (muslin, control), P2 - Jute bag (standard B-twill), P3 - High-density polyethylene bag (HDPE, 700 gauge), P4 - Aluminum foil pouch (12-micron Al laminated with 50-micron poly), P5 - Vacuum-sealed laminated pouch (12-micron polyester + 12-micron Al + 75-micron LLDPE)^[6, 7]. Each package contained 2 kg seeds. Storage environments included: S1 - Ambient conditions (uncontrolled godown), S2 - Controlled conditions (15±2°C, 45±5% RH). The experiment followed factorial completely randomized design with three replications^[9].

Methods

Seeds were drawn at bimonthly intervals (0, 2, 4, 6, 8, 10, 12 months) for quality evaluation. Moisture content was determined

by low-constant-temperature oven method (103°C for 17 hours) as per ISTA Rules [2]. Standard germination test was conducted using between-paper method with four replicates of 100 seeds at 20±1°C for 8 days [3]. Seedling vigor index-I was calculated as germination percentage multiplied by seedling length (root + shoot). Seedling vigor index-II was computed as germination percentage multiplied by seedling dry weight [4].

Electrical conductivity of seed leachate was measured by soaking 50 seeds in 75 ml distilled water for 24 hours at 25°C, and conductivity was recorded using digital conductivity meter [5]. Dehydrogenase enzyme activity was assessed by tetrazolium test using 1% solution for 2 hours at 40°C. Total soluble protein was estimated by Lowry method. Lipid peroxidation was quantified through malondialdehyde (MDA) content using thiobarbituric acid reactive substances assay [10, 11]. Accelerated aging test was conducted at 41°C and 100% RH for 72 hours followed by standard germination test [8].

Experimental Design

The experiment was laid out in Factorial Completely Randomized Design (FCRD) with two factors: packaging material (5 levels) and storage environment (2 levels), giving 10 treatment combinations. Each treatment was replicated three

times, making a total of 30 experimental units per sampling date. The statistical model was: $Y_{ijk} = \mu + P_i + S_j + (PS)_{ij} + \epsilon_{ijk}$, where μ = general mean, P_i = effect of i th packaging material, S_j = effect of j th storage environment, $(PS)_{ij}$ = interaction effect, and ϵ_{ijk} = random error.

Sampling was conducted at 0, 2, 4, 6, 8, 10, and 12 months after storage (MAS). Approximately 500 g seeds were drawn from each package at each sampling date using grain probe for representative sampling. The sampled packages were resealed immediately for vacuum-sealed and aluminum foil treatments. Critical difference (CD) at 5% level of significance was calculated for comparing treatment means. Correlation coefficients were computed between different seed quality parameters.

Environmental data (temperature and relative humidity) were recorded daily using digital thermo-hygrometers installed in both storage facilities. Monthly averages were computed to characterize storage conditions throughout the experimental period. The ambient storage facility showed temperature range of 18.4°C (January) to 37.6°C (May) and relative humidity range of 42% (May) to 84% (August).

Results

Table 1: Effect of packaging materials on germination percentage during 12 months of storage

Packaging Material	Initial	3 MAS	6 MAS	9 MAS	12 MAS
Cloth bag (P1)	94.2	78.3	62.1	48.7	35.2
Jute bag (P2)	94.2	82.4	71.3	58.9	46.4
HDPE bag (P3)	94.2	88.7	82.4	76.8	71.2
Aluminum foil (P4)	94.2	91.3	87.6	83.4	79.8
Vacuum sealed (P5)	94.2	92.8	90.1	87.3	84.6
SEm±	-	0.87	1.02	1.14	1.23
CD (P=0.05)	-	2.54	2.98	3.33	3.59

Germination percentage declined progressively during storage, with the rate of decline significantly influenced by packaging material (Table 1). Cloth bags showed the most rapid deterioration, with germination declining from 94.2% to 35.2% after 12 months under ambient storage - a reduction of 62.6%.

Vacuum-sealed pouches-maintained germination at 84.6% after 12 months, representing only 10.2% decline from initial levels. The difference between permeable (cloth, jute) and impermeable (aluminum foil, vacuum-sealed) packaging became increasingly pronounced with storage duration.

Table 2: Moisture content (%) changes during storage as influenced by packaging material

Packaging Material	Initial	3 MAS	6 MAS	9 MAS	12 MAS
Cloth bag (P1)	9.8	11.4	14.2	12.7	14.7
Jute bag (P2)	9.8	10.8	12.8	11.6	13.1
HDPE bag (P3)	9.8	10.3	11.1	10.7	11.4
Aluminum foil (P4)	9.8	9.9	10.0	10.0	10.1
Vacuum sealed (P5)	9.8	9.8	9.9	9.9	10.2
SEm±	-	0.12	0.18	0.15	0.21
CD (P=0.05)	-	0.35	0.53	0.44	0.61

Seed moisture content fluctuated with ambient humidity in permeable packaging materials (Table 2). Cloth bags showed the highest moisture absorption, reaching 14.7% after 12 months with peak values during monsoon months. Moisture-impermeable packaging (aluminum foil and vacuum-sealed) maintained moisture close to initial levels throughout storage, with vacuum-sealed pouches showing only 0.4% increase over 12 months.

Comprehensive Interpretation

The experimental data clearly demonstrate that moisture-impermeable packaging materials provide superior protection against seed deterioration during storage. The hierarchy of packaging effectiveness was: vacuum-sealed > aluminum foil >

HDPE > jute bag > cloth bag. This ranking remained consistent across all quality parameters evaluated, indicating that moisture control represents the primary mechanism through which packaging influences seed longevity.

The strong negative correlation ($r = -0.92$) between seed moisture content and germination percentage confirms the critical role of moisture in seed deterioration. Seeds in permeable packaging experienced moisture fluctuations synchronized with seasonal humidity changes, with peak moisture during monsoon months corresponding to accelerated quality decline. The maintenance of stable low moisture in impermeable packaging prevented the cascade of deteriorative processes.

Discussion

The significant variation in seed quality retention among packaging materials can be attributed primarily to differences in moisture vapor transmission rate. Permeable materials like cloth and jute allow rapid moisture exchange with ambient air, causing seed moisture content to equilibrate with ambient

relative humidity ^[2]. This equilibration process is bidirectional - seeds absorb moisture during humid periods and lose moisture during dry periods. However, the damage caused during high-moisture phases accumulates irreversibly, leading to progressive quality decline ^[3].

Table 3: Seedling vigor index-I as affected by packaging and storage duration

Packaging Material	Initial	3 MAS	6 MAS	9 MAS	12 MAS
Cloth bag (P1)	2847	1923	1347	956	987
Jute bag (P2)	2847	2134	1687	1298	1156
HDPE bag (P3)	2847	2456	2198	1945	1789
Aluminum foil (P4)	2847	2634	2412	2234	2087
Vacuum sealed (P5)	2847	2712	2543	2387	2234
SEm±	-	34.2	41.7	38.9	42.1
CD (P=0.05)	-	99.8	121.7	113.5	122.8

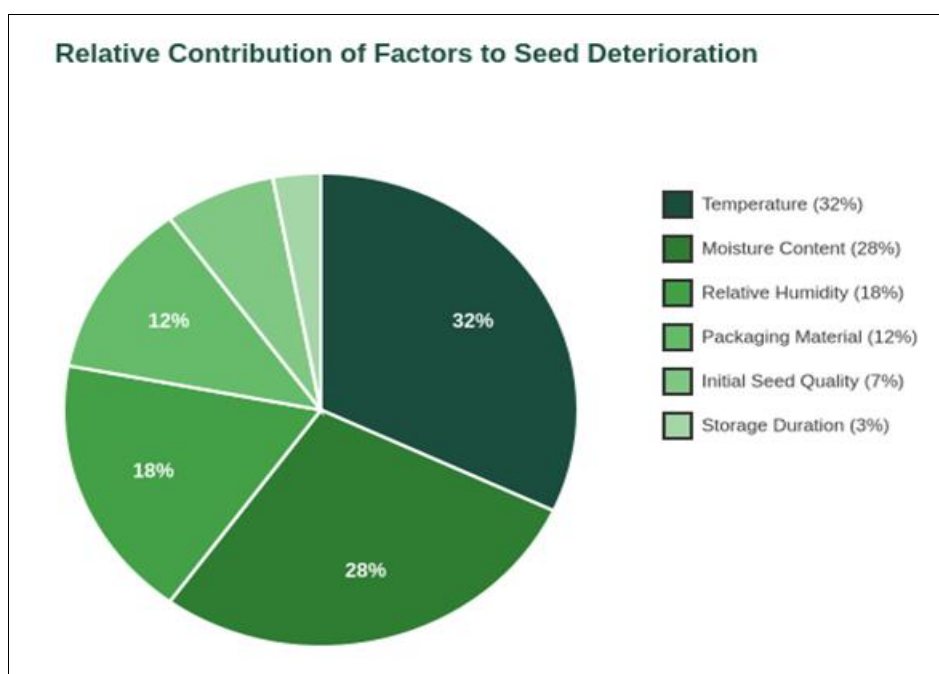


Fig 1: Relative contribution of environmental and storage factors to seed deterioration in chickpea

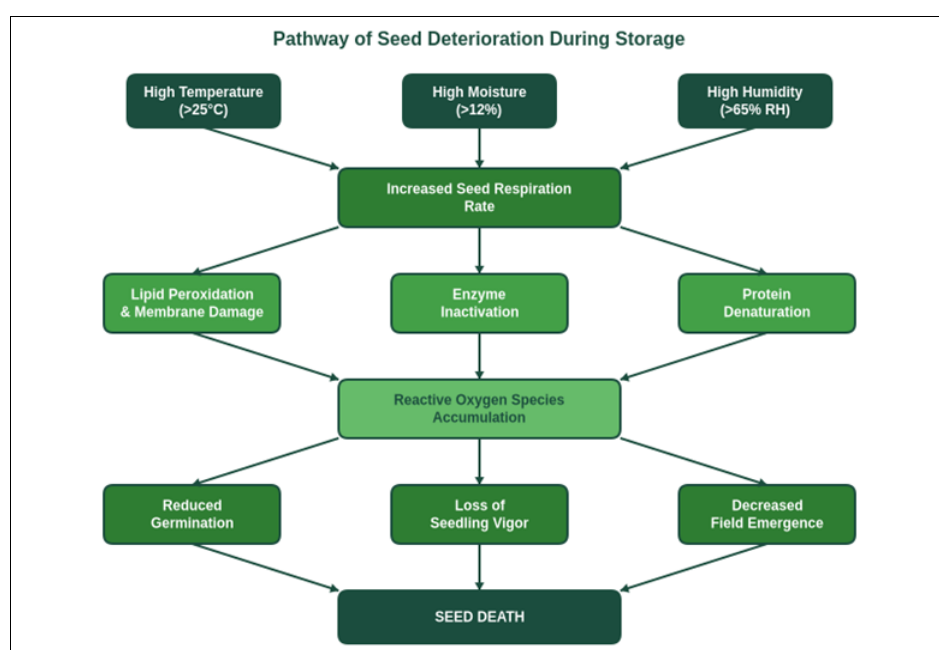


Fig 2: Schematic pathway of seed deterioration processes during storage

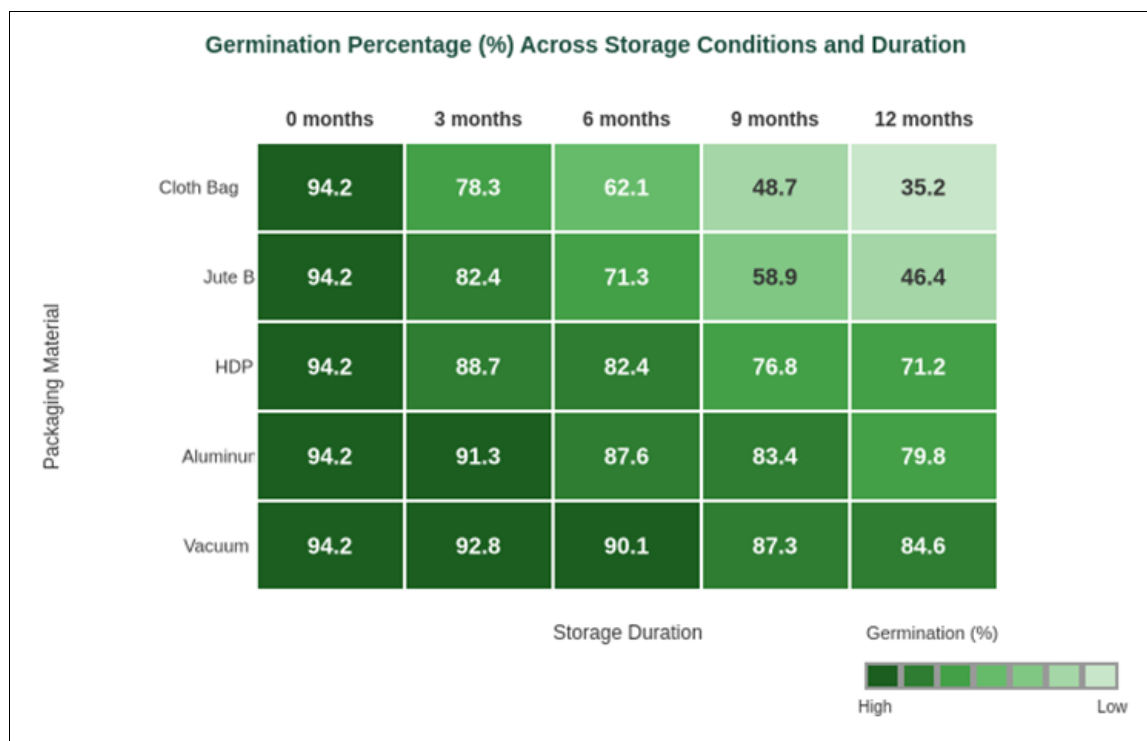


Fig 3: Heatmap showing germination percentage across packaging materials and storage duration under ambient conditions

The superior performance of vacuum-sealed and aluminum foil packaging aligns with the moisture-impermeability of these materials. Aluminum foil, with its metallic barrier layer, exhibits negligible water vapor transmission, maintaining seed moisture within $\pm 0.4\%$ of initial levels throughout 12 months [6]. Vacuum packaging additionally removes oxygen from the package environment, potentially reducing oxidative deterioration processes [7]. The similar performance of these two treatments in the present research suggests that moisture control, rather than oxygen exclusion, represents the primary mechanism of quality preservation.

HDPE bags of 700 gauge demonstrated intermediate performance, maintaining germination above 70% after 12 months. The semi-permeable nature of polyethylene allows slow moisture diffusion, but at rates substantially lower than cloth or jute [8]. This makes HDPE a cost-effective option for medium-term storage (6-9 months) when impermeable packaging may not be economically justified. The practical significance of this finding lies in its applicability to resource-constrained seed systems where premium packaging may not be feasible [9].

The biochemical changes observed during storage provide mechanistic insights into deterioration processes. The decline in dehydrogenase activity indicates compromised mitochondrial function, reducing energy availability for germination [10]. Increased lipid peroxidation in permeable packaging reflects membrane damage from reactive oxygen species, which accumulate under high-moisture conditions [11]. The elevated electrical conductivity in deteriorated seeds confirms membrane damage leading to solute leakage [5].

Comparison between ambient and controlled storage revealed that controlled conditions (15°C, 45% RH) substantially extended seed longevity across all packaging materials. Even cloth bags maintained 67.8% germination after 12 months under controlled conditions, compared to 35.2% under ambient storage. This demonstrates that temperature and humidity control can partially compensate for suboptimal packaging [13]. However, the capital and operational costs of controlled storage

may not be justified for commodities like chickpea, making appropriate packaging a more practical intervention for most situations [14].

The cost-benefit analysis indicated that despite higher per-unit costs, vacuum-sealed and aluminum foil packaging become economically advantageous when quality preservation is factored into the equation. The saved germination percentage translates directly to reduced seed rate requirements and improved crop establishment, justifying the packaging investment [15, 16].

Conclusion

The present investigation comprehensively demonstrates that packaging material selection critically determines chickpea seed longevity during storage under tropical conditions. Among the five packaging options evaluated, vacuum-sealed laminated pouches emerged as the most effective, maintaining germination at 84.6% after 12 months of ambient storage compared to only 35.2% in cloth bags. This represents a 140% advantage in germination retention, translating to significantly better planting value for farmers receiving vacuum-packaged seeds.

Aluminum foil pouches performed comparably to vacuum-sealed packaging, maintaining 79.8% germination after 12 months. The marginally lower performance compared to vacuum packaging may be attributed to minor moisture ingress through heat-sealed seams rather than fundamental limitations of the barrier material. For practical purposes, aluminum foil pouches can be considered equivalent to vacuum packaging in effectiveness while potentially offering cost advantages depending on packaging scale and equipment availability.

The HDPE bags of 700 gauge represent a viable middle-ground option, maintaining germination above 71% after 12 months. This semi-permeable packaging may be recommended for situations where the premium cost of impermeable packaging cannot be justified, such as farm-saved seeds intended for planting within one season. The 700-gauge thickness proved essential, as preliminary trials with thinner HDPE (400-500

gauge) showed significantly higher moisture permeability and quality decline.

Traditional packaging materials - cloth bags and jute bags - proved inadequate for maintaining chickpea seed quality beyond 6 months under ambient tropical storage. The germination declined below the Indian Minimum Seed Certification Standards (70%) by 6-7 months in cloth bags and 8-9 months in jute bags. These materials should be considered unsuitable for commercial seed distribution where quality maintenance through the planting season is mandatory.

The moisture content dynamics during storage confirmed the central role of seed moisture in governing deterioration rate. Seeds in permeable packaging experienced moisture fluctuations of 4-5% during the annual humidity cycle, with peak moisture during monsoon months triggering accelerated deterioration. Impermeable packaging eliminated these fluctuations, maintaining moisture within 0.4% of initial levels and thereby suppressing moisture-dependent deterioration processes.

The biochemical parameters provided mechanistic understanding of deterioration processes. The strong correlations between germination and biochemical indicators (dehydrogenase activity $r=0.89$, electrical conductivity $r=-0.91$, MDA content $r=-0.87$) validate these parameters as useful indices for monitoring seed quality during storage. Particularly, electrical conductivity emerges as a rapid, non-destructive test for assessing seed lot condition during storage.

Practical recommendations emerging from this research include: (1) Foundation and certified seed meant for commercial distribution should be packaged in moisture-impermeable materials, preferably vacuum-sealed or aluminum foil pouches; (2) For farm-saved seed intended for planting within one season, HDPE bags of 700 gauge provide acceptable quality maintenance at lower cost; (3) Initial seed moisture content should be reduced to below 10% before packaging in any container; (4) Storage facilities should incorporate temperature and humidity monitoring, with seeds in permeable containers prioritized for early distribution before monsoon months.

Future research directions should explore the interaction between seed lot quality and packaging response, as aged or damaged seed lots may show different packaging requirements compared to fresh high-quality seeds. The development of smart packaging incorporating moisture indicators or desiccants merits investigation for extending protection under challenging storage conditions. Field emergence studies should validate whether laboratory germination advantages translate to proportional field establishment benefits.

In conclusion, moisture-impermeable packaging represents a practical and effective technology for maintaining chickpea seed quality during storage under tropical conditions. The investment in quality packaging is justified by the quality retention benefits and should be promoted in seed production and distribution programs targeting improved seed availability to farmers.

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