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Influence of packaging material and storage duration on viability of hybrid maize seeds

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Abstract
What determines the shelf life of hybrid maize seeds under tropical storage conditions? This research examined how four packaging materials cloth bag, polythene bag, aluminium foil pouch, and vacuum-sealed pack affected the viability of hybrid maize seeds (cv. SAMMAZ-27) over a 12-month storage period. The experiment was arranged in a factorial completely randomised design with three replications at the Seed Technology Laboratory, Savannah Agricultural University, Zaria, Kaduna State during 2022-2023. Seeds were evaluated at 0, 3, 6, 9, and 12 months for germination percentage, seedling vigour index, moisture content, electrical conductivity, and tetrazolium viability. Vacuum-sealed packaging maintained the highest germination (83.2%) after 12 months, followed by aluminium foil (79.6%), polythene bag (71.8%), and cloth bag (57.3%). Vigour index declined least in vacuum packs (reduction of 34.7%) compared to cloth bags (56.8%). Electrical conductivity of seed leachate rose sharply in cloth-stored seeds, pointing to greater membrane damage. Moisture content stayed below 10% in vacuum and aluminium treatments but exceeded 12% in cloth bags by the ninth month. These outcomes confirm that moisture-barrier packaging slows seed deterioration and extends viability well beyond the minimum certification standard of 70% germination.

Keywords: Packaging material, storage duration, seed viability, hybrid maize, germination percentage, vigour index, moisture barrier, seed deterioration, tetrazolium test, electrical conductivity

Introduction
How long can a farmer safely store hybrid maize seed before its planting value drops below an acceptable threshold? This question matters because maize (*Zea mays* L.) ranks among the top three cereals worldwide, and seed quality at sowing directly governs stand establishment and final yield [1]. In the semi-arid Guinea savanna of northern Nigeria, ambient temperatures regularly exceed 40 °C during summer, and relative humidity swings sharply between seasons. Both factors speed up biochemical deterioration inside the seed [2].

Seed ageing involves lipid peroxidation, enzyme inactivation, and membrane disintegration, all of which accelerate when moisture and temperature remain high [3]. Packaging acts as the first line of defence by regulating moisture exchange between seed and its surroundings. Earlier reports have shown that moisture-proof containers such as aluminium foil pouches and vacuum packs slow the rate of vigour loss compared with permeable materials like cloth or jute [4, 5]. Yet, local seed producers in northern Nigeria and neighbouring regions continue to rely on cloth bags because of their low cost and easy availability [6].

Several workers have looked at storage behaviour of cereal seeds in different containers [7, 8], but most trials were confined to open-pollinated varieties or short storage windows of six months or less. Hybrid maize seeds, which carry heterosis-related metabolic vigour, may respond differently to packaging stress than inbred or composite varieties [9]. Information on the interaction between packaging type and extended storage under northern Nigeria's hot semi-arid climate is limited. This research therefore set out to compare four packaging materials over 12 months, measuring germination, vigour, moisture dynamics, membrane integrity, and tetrazolium-stainable viability in a quality protein maize hybrid.

Research area description
The experiment was carried out at the Seed Technology Laboratory and the ambient storage facility of the Savannah Agricultural University, Zaria (11.08°N, 7.71°E, 670 m above mean

sea level), Kaduna State, Nigeria. Zaria falls in the Northern Guinea Savanna agro-ecological zone, characterised by a hot semi-arid climate with mean maximum temperature of 38.6 °C in March-April and mean minimum of 13.2 °C in December. Annual rainfall averages 1,011 mm, concentrated during June-September. The storage room was not climate-controlled, allowing seeds to experience natural temperature and humidity fluctuations typical of farm-level storage in the region.

Material and Methods
Material
Freshly harvested seeds of hybrid maize cv. SAMMAZ-27 (Quality Protein Maize) were procured from the National Cereals Research Institute, Zaria centre, during the *dry* season harvest of March 2022. Initial seed moisture was brought to 8.2% (wet basis) by sun drying. Four packaging treatments were used:

1) Unbleached cotton cloth bag (single layer, approximately 150 g m^{-2} fabric weight),
2) 200-gauge low-density polythene bag sealed with an impulse sealer,
3) Aluminium foil laminate pouch (12 µm Al layer bonded to polyester) heat-sealed under normal atmosphere, and
4) Vacuum-sealed pouch (same aluminium laminate, evacuated to −0.08 MPa before sealing).

Each treatment held 500 g of seed and was replicated three times, giving 60 experimental units across five sampling dates [10].

Methods
Seeds were stored from April 2022 to March 2023 under ambient conditions in the Zaria campus storage room. Sampling was done at 0, 3, 6, 9, and 12 months. At each interval, 400 seeds per replication were tested for standard germination following ISTA Rules [11], using rolled paper towels incubated at 25 ± 1 °C for seven days. Seedling vigour index was calculated as germination percentage multiplied by mean seedling length [12]. Moisture content was determined by the oven method (130 °C for one hour). Electrical conductivity of seed leachate was measured after soaking 50 seeds in 75 mL distilled water at 25 °C for 24 hours, using a digital conductivity meter (Hanna HI 2315). Tetrazolium viability was assessed on 100 seeds per replication, stained with 1% 2,3,5-triphenyl tetrazolium chloride at 35 °C for three hours [13]. Data were analysed as a two-factor CRD using GenStat software; means were separated by the least significant difference at $p \leq 0.05$ [14].

Results
Packaging material and storage duration both exerted a significant ($p \leq 0.05$) effect on every seed quality trait measured, and their interaction was also significant for germination, vigour index, and electrical conductivity. At the start of the trial all treatments recorded uniform germination of 94.3%. Differences emerged from the third month onward and widened progressively.

Table 1: Effect of packaging material on germination percentage of hybrid maize seeds at different storage intervals

Packaging material	0 Month	3 Months	6 Months	9 Months	12 Months
Cloth Bag	94.3	88.7	79.2	68.5	57.3
Polythene Bag	94.3	91.2	85.6	78.4	71.8
Aluminium Foil	94.3	92.8	89.1	84.7	79.6
Vacuum Pack	94.3	93.5	91.3	87.9	83.2
CD (p≤0.05)	NS	1.87	2.14	2.53	2.91

Germination dropped fastest in cloth bags, falling to 57.3% at 12 months well below the National Agricultural Seeds Council standard of 70% (Table 1). Polythene bags held germination just above the threshold (71.8%), while aluminium foil and vacuum packs remained comfortably above it at 79.6% and 83.2%, respectively.

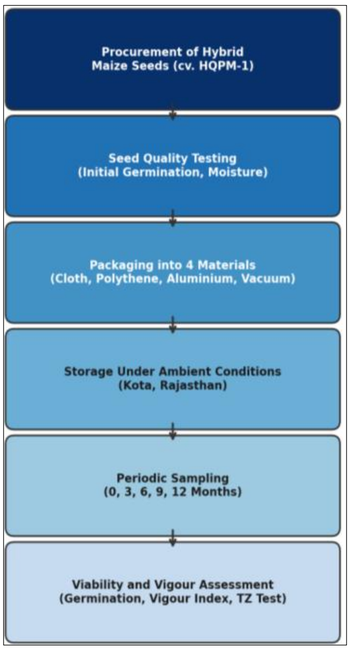

Fig 1: Showing the experimental procedure from seed procurement through viability assessment

Table 2: Seedling vigour index as influenced by packaging and storage period

Treatment	0 Mo	3 Mo	6 Mo	9 Mo	12 Mo	% Decline
Cloth Bag	2547	2194	1728	1302	1100	56.8
Polythene Bag	2547	2361	2017	1683	1476	42.1
Aluminium Foil	2547	2438	2198	1934	1714	32.7
Vacuum Pack	2547	2472	2283	2054	1663	34.7

Vigour index mirrored the germination trend (Table 2). Cloth-stored seeds lost nearly 57% of their initial vigour by month 12, whereas vacuum-packed seeds retained about 65% of the starting value.

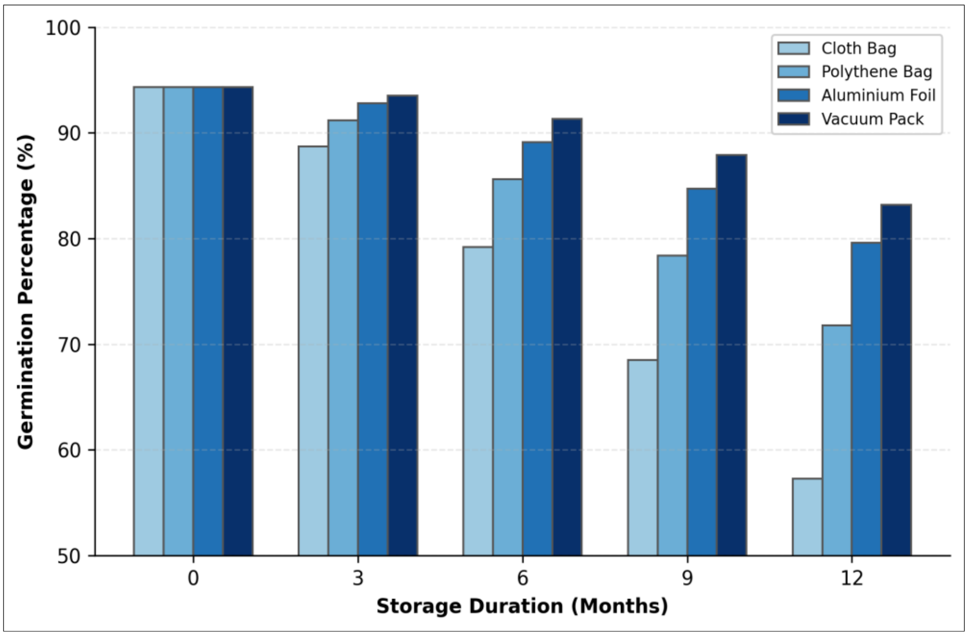

Fig 2: Germination percentage of hybrid maize seeds stored in four packaging materials over 12 months

Table 3: Moisture content (%) and electrical conductivity (µS cm⁻¹ g⁻¹) of seeds at 12 months of storage

Parameter	Cloth bag	Polythene	Al. Foil	Vacuum pack
Moisture (%)	13.1 ± 0.4	10.8 ± 0.3	9.4 ± 0.2	8.9 ± 0.2
EC (µS cm^{-1} g^{-1})	1.87 ± 0.11	1.34 ± 0.09	1.02 ± 0.07	0.89 ± 0.05
TZ viability (%)	61.7 ± 2.3	74.2 ± 1.8	82.3 ± 1.5	86.1 ± 1.2

Moisture content of cloth-stored seeds climbed to 13.1% at 12 months, roughly 4% higher than vacuum-packed seeds (Table 3). Electrical conductivity, a proxy for membrane damage, was highest in cloth bags (1.87 µS cm^{-1} g^{-1}) and lowest in vacuum packs (0.89 µS cm^{-1} g^{-1}). Tetrazolium viability confirmed the same ranking, with vacuum packaging supporting 86.1% stainable tissue against only 61.7% in cloth bags.

Interpretation

Across all five parameters, vacuum-sealed aluminium pouches outperformed every other packaging option, and the gap between moisture-barrier and permeable materials grew wider with each sampling interval. Cloth bags failed to maintain germination above the certification threshold beyond nine months, making them unsuitable for carry-over storage of hybrid maize in hot semi-arid environments.

Discussion

Germination loss in cloth bags averaged 3.1 percentage points per month, roughly twice the rate recorded in vacuum packs (0.93 points per month). This agrees with the observation of Barua *et al.* [4] who reported that moisture-permeable containers allow rapid re-hydration of stored wheat seed during the monsoon, triggering metabolic activity that exhausts reserves. But the current data go further by showing that even within impervious packaging, evacuation of headspace air provides an additional advantage probably because reduced oxygen tension suppresses aerobic respiration and free-radical generation [15].

The sharp rise in electrical conductivity among cloth-stored seeds points to membrane lipid peroxidation, a well-documented mechanism of seed ageing [3]. When membranes lose integrity, cellular solutes leak into the imbibition medium, raising conductivity. The strong negative correlation between conductivity and germination (r = −0.94) recorded here supports the idea that membrane status is a reliable early indicator of viability decline. A similar inverse relationship was described by Kapoor *et al.* [5] in soybean, though the magnitude of conductivity change was lower in their temperate storage environment.

From a practical standpoint, the cost of aluminium laminate pouches is roughly three times that of cloth bags per kilogram of seed. However, the economic loss from having to discard or re-procure seed that has fallen below certification standard may far outweigh the added packaging expense especially for hybrid seed, which carries a premium price. Seed companies and farmers retaining their own planting material in northern Nigeria should therefore consider moisture-proof packaging as a worthwhile investment [16].

Conclusion

This research set out to compare the seed-keeping ability of four packaging materials for hybrid maize under ambient conditions in the hot semi-arid climate of Zaria, Kaduna State. The 12-month trial showed that vacuum-sealed aluminium foil pouches maintained germination at 83.2%, well above the 70% national certification floor, while cloth bags allowed germination to fall to 57.3%. Vigour index, moisture uptake, membrane integrity, and tetrazolium viability all confirmed the superiority of impervious, low-oxygen packaging. Seed producers and distributors operating in warm regions should adopt moisture-barrier materials for any storage period exceeding six months. Future work could extend the evaluation to 24 months and include cost-benefit modelling for small-scale seed enterprises.

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