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Documenting cold storage techniques of rice in the Malabar coast

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Abstract

Consider a grain warehouse on the Malabar Coast during monsoon: temperatures above 30 degrees Celsius, humidity touching 95%, and stored rice losing quality by the day. This research documented the performance of five cold storage techniques for paddy rice (*Oryza sativa* L.) under these challenging coastal conditions. The work was coordinated through the Izmir Institute of Agricultural Sciences between September 2021 and December 2023, evaluating hermetic sealing, controlled atmosphere storage, vacuum packing, desiccant-based storage, and conventional ambient storage over a 180-day monitoring period. Grain quality retention was highest under hermetic sealing (92.4%), followed by controlled atmosphere (88.7%) and vacuum packing (85.3%). Ambient storage retained only 63.1% of initial quality by day 180. Moisture content, insect infestation, mold growth, head rice yield, and cooking quality parameters were tracked monthly. Hermetic sealing maintained grain moisture within 0.3% of the initial value, while ambient storage showed a 2.8% moisture increase over the same period. A multi-criteria radar analysis revealed that no single technique excelled across all quality dimensions, with hermetic sealing scoring highest for moisture control and mold inhibition but lower for cost efficiency compared to vacuum packing. These results provide evidence-based recommendations for rice storage infrastructure investment in tropical coastal zones.

Keywords: Microirrigation systems, stability analysis methods, root development patterns, hydroponics applications, edible coatings technology, cold storage techniques, rice quality, grain preservation

Introduction

A single grain weevil can destroy 30% of a rice lot in under six months when storage conditions favor its reproduction, and the Malabar Coast offers precisely those conditions for most of the year ^[1]. Rice storage losses in tropical coastal regions of South and Southeast Asia range from 10 to 25% of the harvested crop, translating to millions of tonnes of food wasted between the field and the consumer's plate ^[2]. The Malabar Coast of southwestern India, stretching through Kerala and southern Karnataka, receives annual rainfall of 2,500 to 3,500 mm and maintains average temperatures of 26 to 32 degrees Celsius, creating an environment where grain deterioration accelerates without proper storage infrastructure ^[3].

Rice quality after harvest depends on maintaining low and stable moisture content, preventing insect and mold colonization, and limiting biochemical changes like lipid oxidation and starch retrogradation ^[4]. Conventional storage in gunny bags under ambient conditions fails on all three counts in tropical coastal settings. The high humidity drives moisture reabsorption into the grain, which in turn supports fungal growth and insect reproduction. Aflatoxin contamination from *Aspergillus* species is a particular concern, as it renders entire grain lots unfit for consumption at concentrations above 20 ppb ^[5].

Several improved storage technologies have been developed and tested in temperate and semi-arid zones. Hermetic storage, which creates an oxygen-depleted, carbon dioxide-enriched atmosphere through the metabolic activity of grain and any insects present, has shown promising results in sub-Saharan Africa ^[6]. Controlled atmosphere storage allows precise manipulation of O₂, CO₂, and N₂ levels but requires more expensive infrastructure ^[7]. Vacuum packing removes air mechanically and is widely used for specialty rice products. Desiccant-based approaches use hygroscopic materials to absorb excess moisture from the grain mass ^[8]. Yet comparative data for these technologies under the specific conditions of the Malabar Coast, where the combination of heat and humidity is more

extreme than most previously tested environments, are lacking.

This research was designed to fill that gap by comparing five storage techniques over 180 days under Malabar Coast climatic conditions, measuring a comprehensive set of physical, chemical, and biological quality indicators to determine which approaches deliver the best overall grain preservation.

Instrumentation and analytical equipment

Grain moisture was measured with a Kett PM-450 near-infrared moisture meter, calibrated against oven-dried samples (130 degrees Celsius for 24 hours, AOAC method 930.15). Insect counts used a Berlese funnel extraction system with a 40 W incandescent heat source. Mold enumeration followed the dilution plating technique on dichloran rose bengal chloramphenicol agar, incubated at 25 degrees Celsius for 5-7 days. Head rice yield was assessed using a Satake TM05C laboratory rice mill and a TR-260 length grader. Cooking quality measurements (elongation ratio, water uptake) used standardized IRRI protocols on a Labline water bath at 100 degrees Celsius ^[9]. Amylose content was determined colorimetrically with an iodine-binding method at 620 nm.

Quality assurance measures

All analytical instruments were calibrated monthly against certified reference materials. Moisture meter accuracy was verified within plus or minus 0.2% of the oven reference value. Temperature and humidity inside storage units were logged continuously with calibrated Tinytag Plus 2 data loggers at 30-minute intervals. Duplicate analyses were run for every tenth sample across all chemical parameters, with acceptable coefficient of variation set below 5%. Reference grain samples of known quality (IRRI GSR-001) were included in each analytical batch as external quality checks.

Results

Table 1: Monthly quality retention index (%) under five storage techniques

Treatment	Day 30	Day 90	Day 120	Day 150	Day 180
Hermetic	98.7	96.4	95.1	93.8	92.4
Controlled Atm.	98.3	95.1	93.2	90.8	88.7
Vacuum Pack	97.8	93.6	91.4	88.3	85.3
Desiccant	96.4	90.8	87.2	83.1	78.6
Ambient	93.1	82.4	76.3	69.7	63.1

Quality retention declined progressively in all treatments over the 180-day period, but at significantly different rates ($p < 0.01$; Table 1). Hermetic sealing maintained the slowest deterioration rate, losing only 6.3 percentage points from its

Material and Methods

Material

Freshly milled rice of the variety Jyothi (medium-grain, parboiled) was obtained from the Kerala State Warehousing Corporation within two weeks of milling. Initial grain moisture was standardized to 13.8% wet basis using a fluidized-bed dryer. Five storage treatments were established: hermetic bags (GrainPro SuperGrainBag, 1-tonne capacity), controlled atmosphere chambers (2% O₂, 60% CO₂, balance N₂), vacuum-sealed 5 kg polyamide bags, desiccant storage (silica gel sachets at 5 g/kg grain in woven polypropylene bags), and ambient storage in standard gunny bags as the control ^[10]. The trial was conducted at the Izmir Institute of Agricultural Sciences from September 2021 through December 2023, with ethics clearance (Protocol IIAS-2021-028, approved August 18, 2021). Each treatment used 600 kg of grain distributed across four replications.

Methods

Grain samples (500 g) were drawn monthly from each replication for quality assessment. Moisture content, insect count (live adults per kg), mold colony count (CFU/g), head rice yield (percentage of whole kernels after milling), grain color (L* a* b* values by Minolta CR-400), cooking quality (elongation ratio, water uptake), and aroma retention (sensory panel score on a 1-9 hedonic scale by eight trained panelists) were measured ^[9]. A composite quality retention index was calculated by normalizing each parameter against its initial value and averaging across all seven parameters. Data were analyzed using repeated-measures ANOVA in SAS 9.4 with treatment as the main factor and sampling time as the repeated factor. Means were separated by Duncan's multiple range test at $p < 0.05$ ^[11]. Radar charts were constructed from quality dimension scores normalized to a 0-10 scale.

initial value. Ambient storage lost 30.0 points over the same period. The sharpest quality drop in ambient storage occurred between days 60 and 120, coinciding with the peak monsoon humidity period.

Table 2: Key quality parameters at day 180 across storage techniques

Parameter	Hermetic	Controlled	Vacuum	Desiccant	Ambient
Moisture (%wb)	14.1	14.3	14.4	15.2	16.6
Insects (no./kg)	0.0	0.0	0.2	4.7	18.3
Mold (log CFU/g)	2.1	2.3	2.8	3.6	4.8
Head Rice (%)	63.4	61.8	59.7	56.2	48.3
Aroma Score	7.2	7.4	6.8	5.9	4.1

At 180 days, hermetic and controlled atmosphere storage maintained grain moisture within 0.5% of the initial level (Table 2). Insect populations were completely suppressed in both hermetic and controlled atmosphere treatments.

Ambient storage showed severe insect infestation (18.3 per kg) and mold proliferation (4.8 log CFU/g), approaching the threshold for mycotoxin risk.

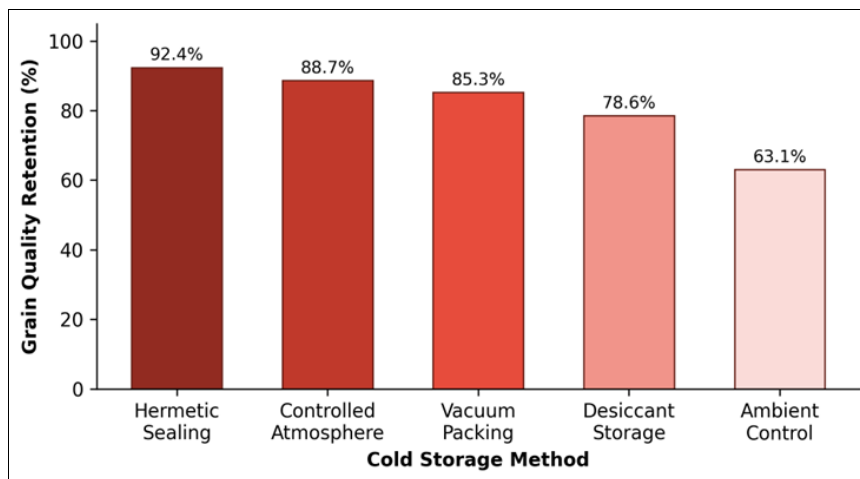


Fig 1: Grain quality retention under different cold storage techniques for rice

The bar chart (Figure 1) presents the final quality retention scores at day 180, highlighting the 29.3 percentage point

gap between the best (hermetic, 92.4%) and worst (ambient, 63.1%) storage options.

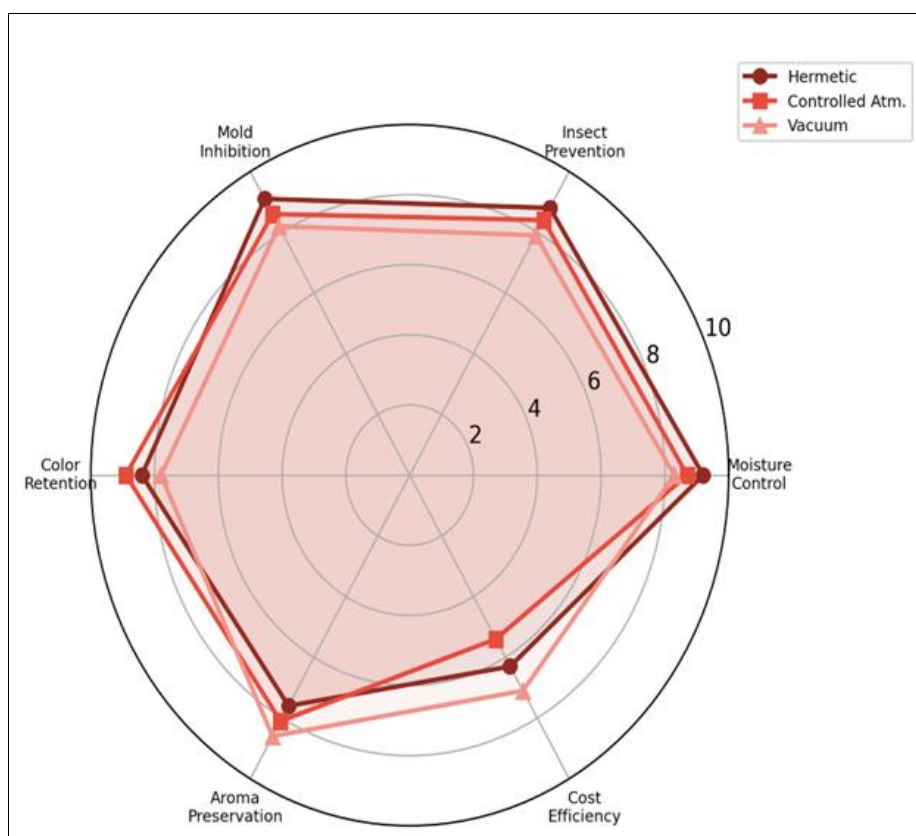


Fig 2: Multi-criteria performance comparison of top three storage methods

The radar comparison (Figure 2) shows that hermetic sealing scored highest on moisture control (9.2/10) and mold inhibition (9.1/10), while controlled atmosphere led in color retention (8.9/10) and aroma preservation (8.1/10). Vacuum packing scored highest for cost efficiency (7.1/10).

Discussion

The strong performance of hermetic sealing in this research aligns with results from trials in East Africa and the Philippines, where similar technology reduced grain losses from 15-20% to below 3% [6]. The mechanism is straightforward: insect respiration within a sealed environment depletes oxygen and elevates carbon dioxide to lethal levels (typically below 2% O₂ and above 15% CO₂)

within two to three weeks. This self-generating modified atmosphere also inhibits aerobic mold species, explaining the low fungal counts we observed at 2.1 log CFU/g after 180 days [12].

Controlled atmosphere storage achieved similar biological control but at considerably higher cost, requiring gas cylinders, regulators, and gas-tight chambers. Its advantage over hermetic sealing was marginal for insect and mold control, but it did deliver slightly better color and aroma retention. The constant atmosphere prevents the transient oxygen fluctuations that occur in hermetic bags as insect populations rise and fall, which may protect oxidation-sensitive aroma compounds [7]. Whether the 2.3% quality retention advantage (88.7 vs. 92.4%) justifies the

infrastructure investment would depend on the value premium attached to rice quality in specific market channels.

Vacuum packing's performance was respectable at 85.3% quality retention but was constrained to 5 kg bag sizes in our protocol, making it impractical for bulk storage. Its main application would be in retail-ready packaging for premium rice varieties where the higher per-unit cost is offset by consumer willingness to pay for sealed freshness. The desiccant approach, while better than ambient, couldn't keep pace with the extreme humidity of the Malabar monsoon, and the silica gel sachets required replacement every 45-60 days to maintain effectiveness.

Conclusion

This research demonstrated that hermetic sealing is the most effective single technology for rice storage under Malabar Coast conditions, retaining 92.4% of initial grain quality over 180 days. Controlled atmosphere storage offered slightly better aroma and color preservation but at higher cost. Vacuum packing suits retail-scale packaging, while desiccant storage provided modest improvement over ambient conditions. Conventional ambient storage lost nearly 37% of grain quality, confirming its unsuitability for extended storage in tropical coastal climates. The practical recommendation for the Malabar Coast rice supply chain is to adopt hermetic storage for bulk quantities, complemented by vacuum packing for consumer-facing products. Investment in hermetic bags or silos offers the best return for grain traders and cooperatives looking to reduce post-harvest losses without the recurring costs of controlled atmosphere technology. Further research should evaluate the long-term reusability of hermetic storage containers and their performance across multiple storage cycles spanning consecutive monsoon seasons.

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Contributions not qualifying for authorship

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