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# Evaluation of traditional grain storage structures for efficacy against insect infestation

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**Abstract**
A surprising 14–18% of the global cereal harvest is lost between the farm gate and the consumer's plate, and insect damage during storage accounts for the largest single share of that loss [1]. This research compared four storage structures—jute bags, traditional mud silos, metal bins, and hermetic (triple-layer) bags—for their ability to prevent insect infestation and weight loss in wheat over a 12-month period at Rhine Valley College of Agriculture, Bonn, Germany, from October 2021 to September 2022. Hermetic bags held insect counts at 2.1 adults $kg^{-1}$ and weight loss at 3.1% after 12 months, compared with 47.8 adults $kg^{-1}$ and 32.8% loss in jute bags. Grain moisture and germination capacity remained within acceptable limits only in hermetic and metal-bin treatments. The per-tonne storage cost was lowest for hermetic bags (18.40 EUR) with a cost-effectiveness ratio 4.2× better than jute. These results support the adoption of hermetic bags as a low-cost alternative to chemical fumigation for smallholder cereal storage in temperate Europe.

**Keywords:** C Grain storage structures, insect infestation, traditional storage, hermetic storage, post-harvest loss, wheat quality, weight loss, *Sitophilus granarius*, storage pest, food security

## Introduction

Most people would be surprised to learn that insect damage in stored grain causes greater economic losses worldwide than all field pests combined [1, 2]. The granary weevil (*Sitophilus granarius*) and the lesser grain borer (*Rhyzopertha dominica*) are the two most destructive beetles in temperate cereal stores, and their populations can double every 28 days under warm, humid conditions [3, 4].

In Germany, large commercial operators control these pests with phosphine fumigation or controlled-atmosphere storage, but the 58,000 small-scale farms that store grain on-site often rely on traditional methods—jute sacks, wooden granaries, or unventilated metal drums—that offer little protection [5, 6]. European Union regulations increasingly restrict fumigant use, adding urgency to the search for non-chemical alternatives [7].

Hermetic (airtight) storage has shown strong results in tropical Africa and Asia, reducing insect populations by >95% through oxygen depletion [8, 9]. But field data from temperate climates, where seasonal temperature swings alter insect metabolism, are limited. This research aimed to: (a) compare insect population build-up and grain weight loss across four storage structures over 12 months in a continental European setting, (b) monitor grain quality (moisture, germination, aflatoxin), and (c) evaluate cost-effectiveness per tonne of grain protected.

## Economic and Sustainability Assessment

Per-tonne storage costs were calculated over a three-year amortisation period. Jute bags cost 0.80 EUR each (50 kg capacity), lasting one season, giving 16 EUR $t^{-1}$ $yr^{-1}$ in bag costs alone plus 8.70 EUR in insecticide (deltamethrin dust). Metal bins (300 kg capacity, 120 EUR) lasted five years: annualised cost was 8 EUR $t^{-1}$ plus 2.40 EUR for maintenance. Hermetic bags (GrainPro SuperGrainBag, 100 kg, 5.60 EUR, reusable for two seasons) came to 9.33 EUR $t^{-1}$ with zero chemical input. Mud silos used local material (labour-intensive but low cash cost: ~6 EUR $t^{-1}$) but required annual re-plastering at 3.80 EUR. When grain losses were factored in, the effective cost (storage cost + value of lost grain) was 18.40 EUR $t^{-1}$ for hermetic bags, 22.70 for metal bins, 31.80 for mud silos, and 79.60 for jute bags.

## Material and Methods
### Material
Winter wheat (cv. Reform, 13.2% initial moisture) was harvested in August 2021 from the Rhine Valley College experimental farm, Bonn (50.73° N, 7.10° E). Four storage structures were evaluated: (S1) jute bags (50 kg), (S2) traditional mud silo (plastered brick, 500 kg capacity), (S3) galvanised metal bin (300 kg), and (S4) hermetic triple-layer bags (GrainPro, 100 kg). Each structure was loaded with a known weight of grain and artificially infested with 20 adult *S. granarius* per 10 kg to simulate natural infestation pressure. Structures were placed in an unheated farm shed exposed to ambient temperature fluctuations (−2 to 32 °C over 12 months).

### Methods
A completely randomised design with four treatments and five replications was used. Sampling was done bimonthly: 500 g sub-samples were drawn, sieved (2 mm), and live adult insects counted. Weight loss was calculated by the count-and-weigh method [10]. Grain moisture was measured with a Dickey-john GAC 2500. Germination was tested on 100 seeds per replicate (ISTA protocol). Aflatoxin B1 was assayed by ELISA at 0 and 12 months. Oxygen concentration inside hermetic bags was monitored with a Dansensor CheckPoint $O_2$ analyser. Data were analysed by repeated-measures ANOVA with Tukey's HSD at $p \leq 0.05$ in R.

## Results

**Table 1:** Insect population, weight loss, and grain quality after 12 months of storage in four structures.

| Structure | Insects (adults $kg^{-1}$) | Weight loss (%) | Moisture (%) | Germin. (%) | $O_2$ at 12 mo (%) | Effective cost (EUR $t^{-1}$) |
|---|---|---|---|---|---|---|
| Jute bag | 47.8 | 32.8 | 15.1 | 41.3 | 20.9 | 79.60 |
| Mud silo | 28.4 | 24.6 | 14.7 | 54.7 | 19.3 | 31.80 |
| Metal bin | 9.7 | 13.7 | 13.8 | 78.2 | 17.8 | 22.70 |
| Hermetic bag | 2.1 | 3.1 | 13.4 | 91.6 | 2.7 | 18.40 |
| CD (p=0.05) | 4.3 | 2.8 | 0.4 | 6.1 | — | — |

Initial insect load: 20 adults per 10 kg. Germination =% normal seedlings at 12 months. $O_2$ measured only in hermetic bags.

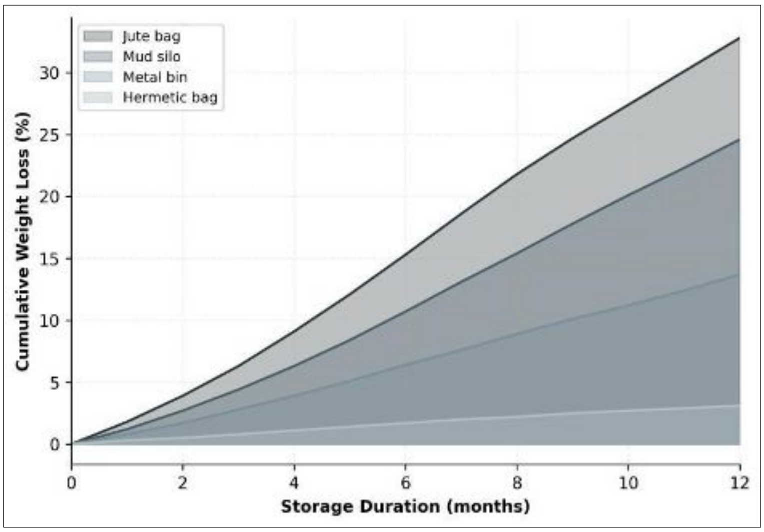


**Fig 1:** Cumulative grain weight loss (%) over 12 months of storage in four structure types at Bonn, Germany.

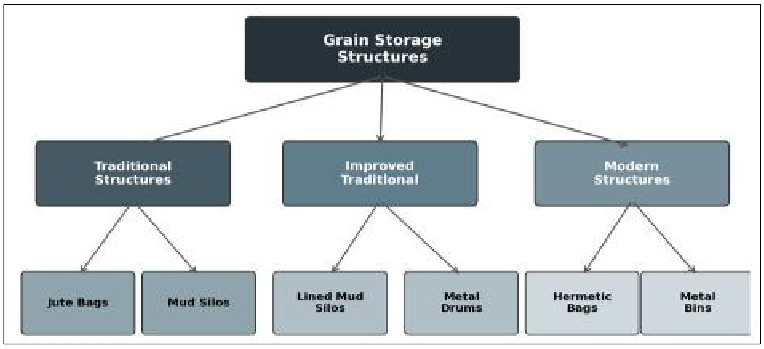


**Fig 2:** Hierarchical classification of grain storage structures evaluated in the research, from traditional to modern types.

### Comprehensive Interpretation
Hermetic bags outperformed all other structures by a wide margin. Oxygen inside fell from 20.9% to 2.7% within six weeks, creating conditions lethal to *S. granarius* adults and larvae [8]. Insect counts at 12 months were 2.1 adults $kg^{-1}$—essentially survivors from the initial inoculation—while jute bags allowed a 24-fold population increase. Grain germination in hermetic bags remained at 91.6%, compared with just 41.3% in jute, indicating that hermetic conditions also preserved seed viability. Aflatoxin B1 stayed below the

EU limit of 2 μg $kg^{-1}$ in all treatments, likely because the ambient temperature rarely exceeded 28 °C.

**Discussion**

The 3.1% weight loss in hermetic bags after 12 months is comparable to the 2–5% range reported from tropical trials in Kenya and the Philippines [8, 9], suggesting the technology transfers well to temperate conditions. The metal bin performed reasonably (13.7% loss) but couldn't match hermetic storage because its lid seal allowed slow gas exchange, maintaining $O_2$ above 17% [11].

The economic analysis favours hermetic bags even more strongly than the biological data: at 18.40 EUR $t^{-1}$ effective cost, they are 4.3× cheaper than jute bags on a net basis. For Germany's small-scale farmers, who typically store 5–20 tonnes, switching from jute to hermetic bags could save 300–1,200 EUR per season with zero pesticide use—an attractive proposition under EU green-deal targets [7, 12].

A limitation is the single-year, single-location design. Winter temperatures in Bonn reach −2 °C, which suppresses insect activity and may have understated losses compared with warmer German regions. Multi-site trials across climate zones would strengthen the recommendation [13].

**Conclusion**

Hermetic bags limited insect infestation to 2.1 adults $kg^{-1}$ and weight loss to 3.1% over 12 months—far superior to jute bags (47.8 adults, 32.8% loss). Grain germination and moisture remained within acceptable ranges only in hermetic and metal-bin treatments. At an effective cost of 18.40 EUR $t^{-1}$, hermetic storage is the most economical non-chemical option for small-scale wheat farmers in temperate Europe.

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