AMERICAN JOURNAL OF ANIMAL AND VETERINARY SCIENCES

RESEARCH ARTICLE

# Mitigation of Quality Deterioration and Insect Infestation in Rice Bran During Storage Through Heat Treatment and Vacuum Sealing

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**Abstract:** Rice bran is a valuable feed ingredient due to its high energy and lipid content; however, its utilization is limited by quality deterioration during storage, including physicochemical changes and insect infestation. This study evaluated the effects of vacuum sealing and heat treatment on the physical properties, chemical composition, fatty acid profile, and insect infestation of rice bran stored under ambient conditions. Fresh rice bran was assigned to three treatments: Non-Vacuum-sealed (NV, control), vacuum-Sealed (VS), and heat-treated followed by vacuum sealing (HVS), and stored for 0, 30, 60, and 90 days. Storage duration significantly affected ($p<0.05$) physical properties in NV samples, which showed reduced bulk, tapped, and true densities and increased angle of repose at 90 days, indicating decreased flowability. In contrast, VS and HVS treatments maintained stable physical characteristics. Proximate composition remained largely unchanged ($p>0.05$), although moisture content increased in NV samples (13.08%) compared to VS and HVS (≈11.5-12.0%) at 90 days. Fatty acid composition, including oleic, palmitic, and linoleic acids, was not significantly affected by storage or treatment. Insect infestation was observed only in NV samples at 90 days (≤ 4 dead insects/kg), whereas no infestation occurred in VS and HVS treatments. In conclusion, vacuum sealing effectively preserves the physical and chemical stability of rice bran and prevents insect infestation, while heat treatment provides additional protection, enhancing storage stability under ambient conditions.

**Keywords:** Rice Bran, Vacuum Sealing, Heat Treatment, Storage Stability, Fatty Acid Composition

**Received:** 30-01-2026 | **Revised:** 19-03-2026 | **Accepted:** 15-04-2026 | **DOI:** 10.3844/ajavsp.2026.21.01.009

## Introduction

Rice bran is a promising alternative feed ingredient widely utilized in the livestock industry, particularly in rice-producing countries such as Indonesia [1] (Sari et al., 2024). Nutritionally, rice bran is rich in metabolizable energy and crude fat, and contains moderate levels of crude protein, B-complex vitamins, and essential minerals, making it a valuable component in poultry and ruminant diets [2]. Its incorporation into livestock rations has been shown to support animal performance while reducing feed costs, thereby improving production efficiency [3].

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As a byproduct of rice milling, rice bran is readily available during harvest at relatively low cost. However, its availability is limited during the off-season, leading to price fluctuations and supply instability [4]. Effective storage strategies are therefore essential to ensure year-round availability while maintaining their nutritional quality and economic value [6].

Despite its advantages, rice bran utilization is constrained by poor storage stability. Rapid quality deterioration occurs primarily due to lipase activity and subsequent lipid oxidation, leading to the formation of free fatty acids and rancidity under high-temperature, high-humidity conditions [1,3]. This deterioration reduces palatability, nutrient quality, and feed acceptability. In addition, rice bran is highly susceptible to insect infestation by storage pests such as beetles, weevils, and mites, which further contribute to nutrient loss, contamination, and potential toxin production [6]. These factors ultimately compromise animal health and productivity.

From a broader sustainability perspective, improving the storage stability of agro-industrial by-products such as rice bran contributes to climate action and net-zero emission goals [7]. Reducing post-production losses minimizes resource inefficiency, lowers waste generation, and decreases the environmental footprint associated with feed production systems [8]. Efficient utilization of locally available by-products can also reduce reliance on imported feed ingredients, thereby lowering transportation-related greenhouse gas emissions. As highlighted by Rosen et al. [9] in their work on climate action and net-zero emissions, optimizing resource efficiency and reducing losses across supply chains are critical strategies in achieving sustainable development targets. In this context, enhancing the storage stability of rice bran represents a practical contribution to more sustainable and climate-resilient livestock production systems.

Various preservation strategies have been explored to address rice bran instability, including heat treatment to inactivate lipase enzymes, the use of antioxidants, improved packaging technologies, and controlled storage conditions [1,6,10]. Among these, vacuum packaging offers a simple and cost-effective way to limit oxygen exposure and prevent insect infestations, while heat treatment can reduce enzymatic activity that causes lipid degradation. However, limited studies have evaluated the combined effects of these approaches on both the physical and chemical stability of rice bran during storage.

Therefore, this study aimed to evaluate the effects of vacuum sealing and controlled heat treatment, individually and in combination, on the storage stability of rice bran. The research specifically assessed changes in physical properties, proximate composition, fatty acid profiles, and insect infestation over time. This study contributes to the development of practical, low-cost preservation strategies that support feed security, reduce post-harvest losses, and promote more sustainable livestock production systems.

## Materials and Methods

A total of 144 kg of fresh rice bran was collected from a rice milling factory located in Kampung Kelapa Tujuh, Suka Sukawening Village, Dramaga Subdistrict, Bogor Regency, West Java, Indonesia. Before allocation, the rice bran was thoroughly mixed to ensure homogeneity. The homogenized rice bran was then divided into 72 experimental units following a 3 × 4 factorial arrangement, consisting of three heat/packaging treatments (non-vacuum-sealed as control, vacuum-sealed, and heat-treated followed by vacuum sealing) and four storage durations (0, 30, 60, and 90 days), with six replicates per treatment combination.

Each experimental unit consisted of 2 kg of rice bran, packed in polyethylene sacks (thickness 110 μm; volume 5 L). For the heat-treated groups, rice bran was subjected to controlled heating to inactivate lipase, cooled to ambient temperature, and subsequently vacuum-sealed. All samples were stored at room temperature under identical environmental conditions throughout the experimental period.

Daily ambient temperature and relative humidity were recorded throughout the storage period to monitor environmental conditions that could influence rice bran stability.

### Physical Property Determination

Physical property determination was conducted according to Ridla et al. [10], including measurements of bulk density, tapped density, true density, and angle of repose, as described below.

Bulk Density (BD) was calculated as:

$$\text{Bulk density (g L}^{-1}\text{)} = \frac{W}{V_t}$$

Where *W* is the mass of the sample (g), and $V_{(b)}$ is the bulk volume (L).

Tapped Density (TD) was determined after tapping the container until a constant volume was obtained:

$$\textit{Tapped density } (g\ L^{-1}) = \frac{W}{V_t}$$

Where *W* is the mass of the sample (g), and $V_{(t)}$ is the tapped volume (L).

True density ($\rho_t$) was determined using the liquid displacement method:

$$\textit{True density } (Kg\ L^{-1}) = \frac{W}{(V_t - V_l)}$$

Where *W* is the mass of the sample (Kg), $V_t$ is the total volume of liquid plus sample (L), and $V_l$ is the volume of liquid alone (L).

Angle of repose (θ) was calculated using the geometry of the conical pile:

$$\theta = tan^{-1}\left(\frac{h}{r}\right)$$

Where *h* is the height of the pile (cm), and *r* is the radius of the base (cm).

## Chemical Property Determination

Proximate analysis was conducted to determine moisture, ash, crude protein, crude fat, and crude fiber contents. Moisture Content (MC) was determined by oven drying at 105 °C to constant weight (method number 925.10) [12], crude ash (CA) content by incineration at 550 °C (method number 923.03) [12], Crude Protein (CP) by the Kjeldahl method using a nitrogen-to-protein conversion factor of 6.25 (method number 984.13) [12], Ether Extract (EE) by Soxhlet extraction with ether (method number 920.39) [12], and Crude Fiber (CF) by successive acid and alkaline hydrolysis (method number 978.10) [12]. Nitrogen-Free Extract (NFE) content was determined by difference.

Fatty acid composition was determined as Fatty Acid Methyl Esters (FAME). Lipid samples were methylated and analyzed by Gas Chromatography with a Flame Ionization Detector (GC-FID). Identification and quantification of fatty acids were performed by comparison with FAME standards (method number 969.33) [12].

## Insect Infestation Assessment

Insect infestation was evaluated by quantifying beetle contamination during storage, following the method described by Ridla et al. [6]. At each storage interval (0, 30, 60, and 90 days), rice bran samples were homogenized, and a representative subsample (500 g) was collected from each treatment. Subsamples were evenly spread on a white tray and visually examined under adequate lighting. All live and dead insects were manually separated and counted. Infestation intensity was expressed as the number of beetles per kilogram of rice bran (individuals $kg^{-1}$). Insects were morphologically identified to the genus level, with a particular emphasis on common storage pests, such as *Tribolium* spp. and *Sitophilus* spp.

## Analytical Methods

Data on physical and chemical characteristics were analyzed using a two-way factorial analysis of variance (ANOVA) based on a completely randomized design. The model included the main effects of treatment (heat/packaging) and storage duration, as well as their interaction. When significant effects were observed ($p<0.05$), mean separation was performed using an appropriate post hoc multiple comparison test.

# Results and Discussion

## Storage Room Conditions

During the 90-day storage period, the storage room experienced persistently high relative humidity and warm temperatures. Maximum relative humidity commonly ranged from about 89 to 98%, while minimum values remained high, generally between 67 and 86%, indicating a consistently humid environment (Figure 1). Such conditions are unfavorable for storing rice bran, as high humidity promotes moisture absorption and accelerates lipid hydrolysis, oxidation, microbial growth, and insect infestation [13].

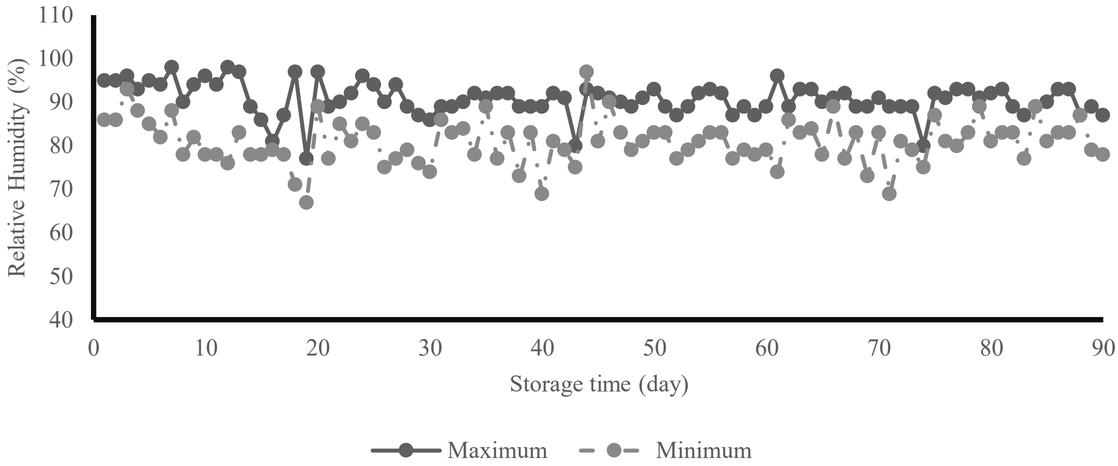


**Fig. 1: Storage room relative humidity from 30 August to 30 November 2025**

Ambient temperatures showed moderate fluctuations, with minimum values ranging from approximately 22.2 to 29.8 °C and maximum temperatures reaching 25.4 to 30.9 °C. Several days recorded temperatures above 30 °C, which are conducive to enzymatic activity and insect development (Figure 2). The combination of high humidity and warm temperatures created a challenging storage environment, underscoring the need for protective strategies, such as heat treatment and vacuum sealing, to maintain rice bran quality during prolonged storage under tropical conditions [14].

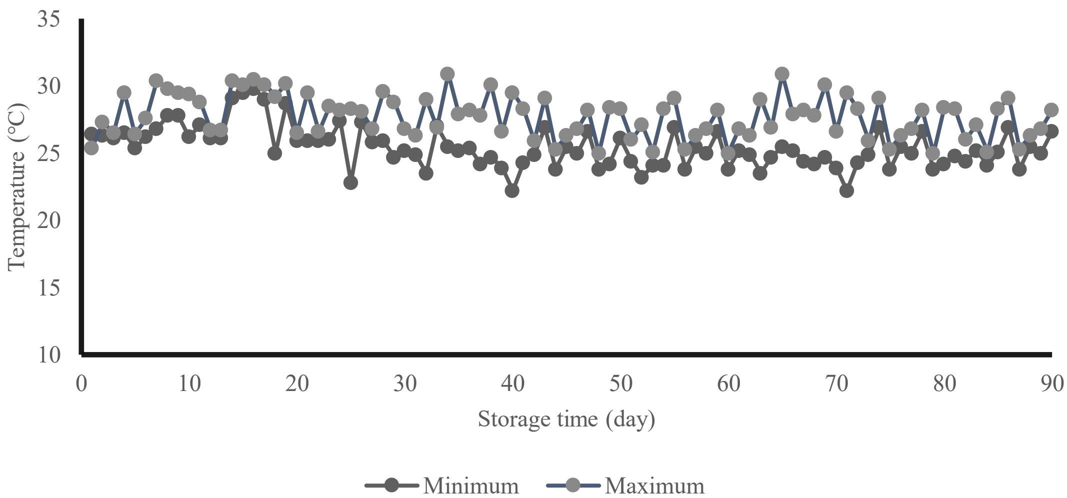


**Fig. 2: Storage room temperature from 30 August to 30 November 2025**

## Physical Property

Based on the results presented in Table 1, the physical properties of rice bran were significantly affected by storage time and the combination of the applied treatments ($p \leq 0.05$). Bulk density, tapped density, and true density remained stable across treatments up to 60 days. At 90 days, the nonvacuum-sealed (NV) treatment showed a marked reduction in bulk density (284.72 g $L^{-1}$), tapped density (488.42 g $L^{-1}$), and true density (1.28 g $L^{-1}$) compared with VS and HVS. Angle of repose increased in NV at 90 days (19.64°), indicating poorer flowability. Vacuum-Sealed (VS) and heat-treated vacuum-sealed (HVS) treatments maintained consistent physical properties throughout storage.

**DOI: 10.3844/ajavsp.2026.21.01.009**

**Table 1: Physical properties of rice bran during storage under different packaging conditions**

| Storage Time | Treatments | Buck Density g/L | Tapped Density g/L | True Density Kg/L | Angle Repose ° |
|---|---|---|---|---|---|
| 0 day | NV | 299.43ᵃ | 498.41ᵃ | 1.35ᵃ | 17.17ᵃ |
| | VS | 301.52ᵃ | 499.83ᵃ | 1.35ᵃ | 17.45ᵃ |
| | HVS | 303.24ᵃ | 501.23ᵃ | 1.36ᵃ | 17.83ᵃ |
| 30 days | NV | 298.98ᵃ | 499.43ᵃ | 1.35ᵃ | 18.27ᵃ |
| | VS | 301.31ᵃ | 500.22ᵃ | 1.35ᵃ | 17.64ᵃ |
| | HVS | 303.53ᵃ | 501.29ᵃ | 1.36ᵃ | 17.67ᵃ |
| 60 days | NV | 299.62ᵃ | 498.82ᵃ | 1.35ᵃ | 18.47ᵃᵇ |
| | VS | 300.12ᵃ | 497.71ᵃ | 1.35ᵃ | 17.16ᵃ |
| | HVS | 302.21ᵃ | 500.21ᵃ | 1.35ᵃ | 17.68ᵃ |
| 90 days | NV | 284.72ᵇ | 488.42ᵇ | 1.28ᵇ | 19.64ᵇ |
| | VS | 300.54ᵃ | 498.82ᵃ | 1.35ᵃ | 17.75ᵃ |
| | HVS | 300.65ᵃ | 500.52ᵃ | 1.35ᵃ | 18.06ᵃᵇ |
| SEM | | 0,670 | 0.992 | 0.009 | 0,136 |
| p-value | | 0.047 | 0.039 | 0.048 | 0.050 |

NV = Non Vacuum-sealed as control, VS = Vacuum-Sealed, and HVS= heat-treated followed by vacuum sealing

SEM: Standard error of mean

The deterioration observed in the NV treatment after 90 days highlights the sensitivity of rice bran physical characteristics to oxygen exposure during storage. Reduced bulk, tapped, and true densities in NV indicate structural breakdown of particles, likely caused by lipid oxidation, enzymatic activity, and moisture redistribution [15]. These changes increase particle cohesion, as reflected by a higher angle of repose, and may negatively affect flowability, mixing uniformity, and feed-handling efficiency. Conversely, VS and HVS treatments maintained stable physical properties throughout storage, confirming the protective role of anaerobic-vacuum-sealed conditions in suppressing oxidative and enzymatic degradation [4]. The inclusion of a heat treatment before vacuum sealing further enhances stability by inactivating lipase enzymes, thereby preserving particle integrity and ensuring consistent handling quality during extended storage. In addition, Ridla et al. [10] and Ridla et al. [15] reported that rice bran quality, as assessed by physical properties, was strongly associated with chemical composition.

## Chemical Property

Table 2 presents the chemical properties of rice bran during storage under different packaging treatments. The moisture content of rice bran remained relatively stable across all treatments during the initial storage period (0-60 days), ranging from 11.57% to 12.03%. After 90 days of storage, a numerical increase in moisture content was observed in the nonvacuum-sealed (NV) treatment (13.08%), whereas moisture levels in vacuum-sealed (VS; 11.59%) and heat-treated, followed by vacuum-sealed (HVS; 11.98%) samples remained comparatively stable. Although neither treatment nor storage duration significantly affected moisture content ($p = 0.082$), the increase observed in NV samples with prolonged storage suggests a greater tendency to accumulate moisture under nonvacuum conditions.

This trend is likely associated with residual air trapped in the package headspace during sealing. Rice bran is hygroscopic, and in sealed but nonvacuum systems, entrapped humid air represents the primary internal source of moisture during storage [17]. Under conditions of elevated ambient relative humidity and temperature fluctuations, water vapor in the headspace may redistribute and be progressively adsorbed by the product. Because the packages were hermetically sealed, moisture uptake was not driven by diffusion from the external environment but rather originated from the internal atmosphere of the package [18-19]. In contrast, vacuum sealing reduced headspace humidity and water vapor pressure, thereby limiting the availability of moisture [6]. Heat treatment before vacuum sealing may have further contributed by lowering initial moisture content and partially inactivating hydrolytic enzymes [19].

In addition to moisture, other chemical composition parameters, including crude ash, crude protein, crude fat, crude fiber, and carbohydrate contents, were generally stable throughout the storage period, with no significant effects of treatment or storage time (p>0.05). The stability of ash content indicates minimal mineral loss or contamination during storage, suggesting that the packaging systems effectively preserved the inorganic fraction of rice bran [6] (Ridla et al., 2023a). Similarly, the relatively constant crude protein content across treatments implies limited protein degradation, which may be attributed to reduced moisture availability and restricted oxygen exposure, particularly in vacuum-sealed samples [20-21].

Ether extract content showed only minor numerical variations among treatments during storage, indicating that lipid loss through volatilization or degradation was limited. This observation is consistent with the moisture stability and supports the role of vacuum-based packaging in slowing lipid hydrolysis and oxidation. Likewise, crude fiber content remained largely unchanged, reflecting the structural stability of cell wall components under the applied storage conditions. Nitrogen-free extract content, calculated by difference, exhibited corresponding minor fluctuations that primarily reflected changes in other proximate components rather than true carbohydrate degradation [22].

Although most chemical composition parameters were not significantly affected, even small changes, particularly in moisture and lipid-related fractions, are biologically and technologically relevant. Increased moisture availability can accelerate lipid hydrolysis, oxidative deterioration, and susceptibility to microbial growth and insect infestation. Therefore, the overall stability of chemical composition observed in VS and HVS treatments highlights the effectiveness of vacuum-based packaging, especially when combined with heat treatment, in maintaining rice bran quality during extended storage under tropical conditions [23-25].

**Table 2: Chemical composition of rice bran during storage under different packaging conditions**

| Storage Time | Treatments | Moisture content | Crude protein | Crude fiber | Ether extract | Nitrogen free extract |
|---|---|---|---|---|---|---|
| | | --%-- | ------------------------- % DM --------------------------- | | | |
| 0 day | NV | 11.67 | 12.47 | 14.45 | 16.45 | 44.96 |
| | VS | 11.68 | 12.67 | 14.96 | 16.96 | 43.73 |
| | HVS | 11.79 | 12.31 | 14.39 | 16.39 | 45.12 |
| 30 days | NV | 12.03 | 12.31 | 15.08 | 16.08 | 44.50 |
| | VS | 11.65 | 12.61 | 14.25 | 16.25 | 45.24 |
| | HVS | 11.77 | 12.11 | 14.57 | 16.57 | 44.98 |
| 60 days | NV | 11.63 | 12.19 | 15.37 | 16.37 | 44.44 |
| | VS | 11.64 | 12.53 | 14.57 | 16.57 | 44.69 |
| | HVS | 11.57 | 12.63 | 14.86 | 16.86 | 44.08 |
| 90 days | NV | 13.08 | 11.16 | 15.97 | 15.47 | 44.42 |
| | VS | 11.59 | 12.47 | 14.92 | 16.92 | 44.10 |
| | HVS | 11.98 | 12.58 | 14.61 | 16.61 | 44.66 |
| SEM | | 0.114 | 0.119 | 0.139 | 0.119 | 0.132 |
| p-value | | 0.082 | 0.264 | 0.271 | 0.198 | 2.562 |

NV= Non Vacuum-sealed as control, VS = Vacuum-Sealed, and HVS = heat-treated followed by vacuum sealing

SEM: Standard error of mean

## Fatty Acid Composition

The fatty acid composition of rice bran remained relatively stable across treatments and storage periods (Table 3). Oleate was the predominant fatty acid, accounting for approximately 40.55-42.20% of total fatty acids, followed by palmitate (24.72-25.27%) and linoleate (19.63-20.11%). Minor fatty acids, including myristate, stearate, linolenate, and laurate, were present at low proportions throughout storage. Across 0-90 days, no consistent declining or increasing trends were observed for major unsaturated fatty acids. The V+P treatment tended to show numerically higher oleate, palmitate, and linoleate values compared with K and V treatments at most storage times, particularly at 60 and 90 days. However, statistical analysis indicated that neither storage duration nor treatment significantly affected any individual fatty acid fraction (p>0.05). The low SEM values further suggest limited variability among replicates.

**DOI: 10.3844/ajavsp.2026.21.01.009**

The stability of fatty acid profiles across treatments indicates that the lipid composition of rice bran was largely preserved during the 90-day storage period. Oleate and linoleate, which are most susceptible to oxidative degradation, did not show marked reductions, suggesting that oxidative processes were minimal under the conditions studied [5]. The slightly higher numerical proportions of unsaturated fatty acids observed in the vacuum plus heat (V+P) treatment may reflect partial inactivation of lipase activity combined with reduced oxygen availability, thereby limiting both hydrolytic and oxidative reactions. In support of these findings, Sari et al. [23] reported a comprehensive evaluation of optimal dry-heat stabilization conditions using an oven, demonstrating improved phenolic retention and enhanced antioxidant activity in rice bran.

In contrast, the control treatment showed small numerical fluctuations in minor fatty acids, such as laurate and linolenate, which may be associated with early-stage lipid degradation; however, these changes were not statistically meaningful. The absence of significant differences aligns with the relatively short storage period and moderate initial moisture levels. These findings indicate that vacuum sealing, particularly when combined with heat treatment, effectively maintains lipid quality, even though changes in individual fatty acids may be subtle and remain below statistical detection thresholds during short- to medium-term storage [4]. In addition, the use of antioxidants has been reported as an alternative strategy to enhance rice bran stability during extended storage periods [1].

**Table 3: Fatty acid composition of rice bran during storage under different packaging conditions (% of total fatty acids)**

| Storage Time | Treatments | Oleate | Palmitate | Linoleate | Myristate | Stearate | Linolenate | Laurate |
|---|---|---|---|---|---|---|---|---|
| 0 day | K | 41.25 | 24.91 | 20.09 | 3.15 | 1.46 | 1.44 | 0.18 |
| | V | 41.45 | 25.01 | 19.71 | 2.99 | 1.37 | 1.38 | 0.17 |
| | V+P | 41.57 | 24.87 | 19.88 | 2.97 | 1.39 | 1.40 | 0.19 |
| 30 days | K | 41.77 | 24.81 | 19.63 | 2.94 | 1.45 | 1.42 | 0.13 |
| | V | 40.83 | 24.91 | 19.92 | 3.05 | 1.27 | 1.35 | 0.17 |
| | V+P | 42.02 | 25.16 | 20.04 | 3.25 | 1.49 | 1.50 | 0.20 |
| 60 days | K | 41.55 | 24.88 | 19.67 | 2.89 | 1.37 | 1.28 | 0.15 |
| | V | 40.55 | 24.72 | 19.68 | 2.87 | 1.15 | 1.68 | 0.14 |
| | V+P | 42.17 | 25.27 | 20.11 | 3.19 | 1.52 | 1.47 | 0.21 |
| 90 days | K | 41.30 | 25.01 | 19.71 | 3.16 | 1.40 | 1.23 | 0.09 |
| | V | 40.65 | 24.82 | 19.73 | 3.10 | 1.30 | 1.32 | 0.11 |
| | V+P | 42.20 | 25.07 | 19.89 | 3.98 | 1.57 | 1.49 | 0.19 |
| SEM | | 0.228 | 0.064 | 0.071 | 0.121 | 0.048 | 0.048 | 0.015 |
| p-value | | 0.968 | 0.669 | 0.753 | 0.896 | 0.567 | 0.875 | 0.894 |

NV = Non Vacuum-sealed as control, VS = Vacuum-Sealed, and HVS = heat-treated followed by vacuum sealing

SEM: Standard error of mean

## Insect Infestation

The occurrence of insect infestation in rice bran under different storage treatments is summarized in Table 4. No insects were detected in any treatment during the initial storage periods (0, 30, and 60 days), indicating that early storage conditions were not conducive to insect development. After 90 days of storage, insect presence was observed only in the nonvacuum-sealed (NV) treatment, whereas rice bran stored under Vacuum-Sealed (VS) and Heat-treated Vacuum-Sealed (HVS) conditions remained free of infestation. Although the NV packages were designed to limit oxygen exposure, small amounts of air were likely trapped during packaging, allowing insect eggs to survive and partially develop. However, the reduced oxygen environment restricted insect viability, as indicated by the presence of fewer than four insects per kilogram, all of which were found dead [6, 26,27].

**Table 4: Insect infestation levels in rice bran during storage under different packaging conditions**

| | Storage Time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 day | | | 30 days | | | 60 days | | | 90 days | | |
| Treatments | NV | VS | HVS | NV | VS | HVS | NV | VS | HVS | NV | VS | HVS |
| Insect infestation | - | - | - | - | - | - | - | - | - | + | - | - |

NV = Non Vacuum-sealed as control, VS = vacuum-sealed, and HVS = heat-treated followed by vacuum sealing

(+) presence of insect infestation (≤4 dead insects/kg); (-) absence of insect infestation

The insects detected in the NV treatment were identified as *Tribolium castaneum*, a common pest of stored rice and rice bran products. This species is widely distributed in tropical and subtropical regions and is characterized by a reddish-brown, flattened body with a length of approximately 3-4 mm. *T. castaneum* is known for its high reproductive capacity under favorable storage conditions, which often leads to rapid population growth over time [6, 28]. The absence of insect infestation in the VS and HVS treatments indicates that anaerobic vacuum-sealed storage, particularly when combined with heat treatment, can effectively suppress insect development during extended storage [6, 29].

### Limitations and Recommendations

This study demonstrates the effectiveness of vacuum sealing and heat treatment in improving the storage stability of rice bran; however, several limitations should be noted. The experiment was conducted under ambient conditions without controlled temperature and humidity, which may influence lipid oxidation, moisture changes, and insect activity. In addition, the storage period was limited to 90 days and may not fully reflect long-term commercial storage conditions. The study also focused on physicochemical properties, fatty acid composition, and insect infestation, but did not evaluate other important indicators, such as free fatty acids, peroxide value, microbial load, or mycotoxin contamination. Furthermore, economic feasibility and scalability were not assessed.

Future research should include controlled-environment studies and extended storage durations to better simulate real conditions. A comprehensive quality evaluation should include lipid oxidation, microbial safety, and mycotoxin analysis. Economic assessments are also needed to determine practical applicability.

For implementation, vacuum sealing is recommended as an effective storage method, particularly in humid regions, with heat treatment added to enhance enzyme inactivation. Developing low-cost packaging systems and standardized heat treatment protocols will support wider adoption and improve feed sustainability.

## Conclusion

The results demonstrate that the storage stability of rice bran is strongly influenced by packaging and heat treatment. Vacuum sealing, particularly when combined with controlled heat treatment, effectively maintained physical characteristics, proximate composition, fatty acid profiles, and prevented insect infestation during storage up to 90 days. In contrast, nonvacuum storage showed increased moisture content, physical deterioration, and limited insect presence at prolonged storage. Heat-treated and vacuum-sealed rice bran provides superior protection against quality degradation, supporting its application as a practical strategy to extend shelf life and ensure feed safety under ambient storage conditions.

## Acknowledgment

The authors gratefully acknowledge Mr. Arim Suhaerim, of PD AA Berkah Jaya, for his cooperation and support as an industrial partner and end user of the heat-treated and vacuum-sealed premium rice bran technology.

## Funding Information

This research was funded by the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia under the Commercial Innovation Synergy Research Scheme, Fiscal Year 2025 (Grant No. 45673/IT3.D10/PT.01.03/P/B/2025).

## Author's Contributions

Muhammad Ridla: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing original draft.
Nahrowi: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing original draft.
Geetha Subramaniam: Conceptualization, Methodology, Investigation, Data curation, Formal analysis.

## Ethics

This study did not involve the use of live animals or animal-derived experimental procedures; therefore, ethical approval was not required.

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**DOI: 10.3844/ajavsp.2026.21.01.009**


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