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INTEGRATING CABBAGE WASTE INTO PELLETIZED RABBIT FEED TO OPTIMIZE CALCIUM AND PHOSPHORUS CONTENT

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ABSTRACT

The utilization of agricultural waste as livestock feed ingredients is an important strategy to enhance sustainability in integrated farming systems. This study evaluated the effect of cabbage waste inclusion in pelletized rabbit feed on calcium and phosphorus content. A completely randomized design was applied using four dietary treatments containing 0%, 5%, 10%, and 15% cabbage waste. Mineral concentrations were analyzed to assess nutritional responses. The results demonstrated that cabbage waste significantly affected mineral composition of the pellets. Calcium content increased at inclusion levels of 5–15%, with the highest value observed at 15%, while phosphorus content showed a balanced but significant response across treatments. These findings indicate that moderate inclusion levels optimize mineral availability without compromising nutrient balance. This study demonstrates that cabbage waste can be effectively valorized as a functional feed ingredient, contributing to circular resource use. Overall, the integration of cabbage waste into pelletized rabbit feed supports nutritionally adequate, resource-efficient, and sustainable livestock production systems.

Keywords:
kalsium dan fosfo, limbah kubis, pakan pelet kelinci, pemanfaatan limbah pertanian, pertanian terpadu, sistem pakan berkelanjutan.

ABSTRACT

Pemanfaatan limbah pertanian sebagai bahan pakan ternak merupakan strategi penting untuk meningkatkan keberlanjutan dalam sistem pertanian terpadu. Penelitian ini bertujuan untuk mengevaluasi pengaruh penambahan limbah kubis dalam pakan pelet kelinci terhadap kandungan kalsium dan fosfor. Rancangan acak lengkap digunakan dengan empat perlakuan pakan yang mengandung limbah kubis sebesar 0%, 5%, 10%, dan 15%. Analisis mineral dilakukan untuk menilai respons nutrisi pakan. Hasil penelitian menunjukkan bahwa penambahan limbah kubis berpengaruh nyata terhadap komposisi mineral pelet. Kandungan kalsium meningkat pada tingkat penambahan 5–15%, dengan nilai tertinggi pada perlakuan 15%, sedangkan kandungan fosfor menunjukkan respons yang seimbang namun signifikan antar perlakuan. Temuan ini mengindikasikan bahwa tingkat penambahan yang moderat mampu mengoptimalkan ketersediaan mineral tanpa mengganggu keseimbangan nutrien. Penelitian ini menunjukkan bahwa limbah kubis dapat dimanfaatkan secara efektif sebagai bahan pakan fungsional yang mendukung pemanfaatan sumber daya secara sirkular. Secara keseluruhan, integrasi limbah kubis dalam pakan pelet kelinci mendukung sistem produksi ternak yang bernilai gizi, efisien sumber daya, dan berkelanjutan.

INTRODUCTION

The transition toward more sustainable agricultural systems requires innovation in the utilization of locally available resources while reducing reliance on conventional inputs (Pretty, 2018). One increasingly adopted strategy is the integration of agricultural subsectors, in which residues or by-products from one commodity are repurposed as inputs for another (Oyedeji et al.,

2024). Such integration enhances overall production efficiency and supports the principles of circular economy within agricultural systems (Duncan et al., 2023).

Within this framework, horticultural vegetable residues represent a valuable resource that remains underutilized, particularly as animal feed ingredients (Nurhamidin et al., 2019). Cabbage waste (*Brassica oleracea*), generated in substantial quantities during cultivation and postharvest handling, contains relatively high levels of macrominerals, especially calcium and phosphorus (Daniel et al., 2023; Pongrac et al., 2019; Shinali et al., 2024). These minerals play essential roles in animal physiology, including bone formation and maintenance, dental health, and metabolic regulation (John et al., 2023; Lall & Kaushik, 2021; Okoruwa et al., 2021). In rabbit production systems, maintaining an appropriate balance of calcium and phosphorus in the diet is critical for ensuring animal health and optimal performance (Gidenne, 2015; Gidenne et al., 2017; Mateos et al., 2010).

Although numerous studies have explored the use of agricultural by-products as alternative feed resources, most have focused primarily on general production performance or feed digestibility. Investigations that specifically assess the contribution of cabbage waste to the optimization of essential mineral content in rabbit diets remain limited (Rudra et al., 2015). Moreover, pelletized feeds are widely recognized for their advantages in improving nutrient uniformity, physical stability, and feeding efficiency (Hancock & Behnke, 2000; Muramatsu et al., 2015; Stark, 2012). However, the interaction between horticultural waste-based ingredients and the pelleting process—particularly with respect to calcium and phosphorus content—has not been sufficiently examined.

Against this background, the present study introduces a novel approach by incorporating cabbage waste into pelletized rabbit feed formulations with an emphasis on optimizing calcium and phosphorus levels. This approach integrates waste valorization, feed processing technology, and rabbit nutrition within a unified framework of sustainable and integrated agriculture.

Therefore, the objective of this study was to evaluate the effect of cabbage waste inclusion in pelletized rabbit feed on calcium and phosphorus content. The findings are expected to contribute to the scientific basis for developing alternative feeds derived from horticultural residues and to support the implementation of efficient, sustainable, and value-added integrated agricultural systems.

RESEARCH METHODS

Experimental Site and Materials

The experiment was conducted under controlled conditions to evaluate the incorporation of cabbage waste into pelletized rabbit feed. Fresh cabbage waste (*Brassica oleracea*) was collected from local vegetable markets and sorted to remove non-edible and contaminated materials. The cabbage waste was then washed, chopped into small pieces, and oven-dried at a controlled temperature until a constant weight was achieved. The dried material was subsequently ground to produce cabbage waste flour, which was used as a feed ingredient.

Other feed ingredients used in the formulation followed standard rabbit nutrition practices and were selected to ensure that the diets met the general nutritional requirements of rabbits, except for the intentional variation in cabbage waste inclusion levels.

Experimental Design and Feed Formulation

The experiment was arranged using a completely randomized design (CRD) consisting of four dietary treatments representing different inclusion levels of cabbage waste flour in pelletized rabbit feed. The treatments were defined as follows: Pelletized feed without cabbage waste flour (T0 or Control); Pelletized feed containing 5% cabbage waste flour (T1); Pelletized feed containing 10% cabbage waste flour (T2); Pelletized feed containing 15% cabbage waste flour (T3).

Cabbage waste flour was incorporated into the diets by partially substituting conventional feed ingredients according to the treatment levels. The inclusion rates were selected based on preliminary considerations and the compositional characteristics of cabbage waste as reported in the manuscript.

All experimental diets were formulated to be as similar as possible in terms of crude protein and metabolizable energy, allowing the specific effects of cabbage waste inclusion on calcium and phosphorus content to be evaluated without confounding nutritional factors. Feed ingredients were thoroughly mixed prior to pelleting to ensure homogeneity of nutrient distribution across treatments. Each dietary treatment was prepared using identical processing conditions and subjected to the same pelleting procedure to minimize variation arising from feed manufacturing processes.

Pellet Production Process

Pellet production was carried out using a standard pelleting procedure. The mixed feed ingredients were conditioned with an appropriate amount of water to achieve suitable moisture content prior to pelleting. Pellets were produced using a pellet mill equipped with a uniform die size to ensure consistent pellet dimensions. The pellets were then air-dried and stored in airtight containers to prevent moisture absorption before further analysis. The pelleting process was conducted under consistent operating conditions for all treatments to minimize variation arising from processing factors.

Chemical Analysis of Feed

Samples of pelletized feed from each treatment were collected for laboratory analysis. Calcium and phosphorus contents were determined using standard analytical procedures commonly applied in feed analysis. Calcium concentration was measured using atomic absorption spectrophotometry, while phosphorus content was analyzed using a spectrophotometric method following acid digestion. All analyses were conducted in triplicate to ensure analytical accuracy and repeatability. The results were expressed on a dry matter basis.

Data Analysis

Data obtained from calcium and phosphorus analyses were subjected to analysis of variance (ANOVA) appropriate for a completely randomized design. When significant differences among treatments were detected, mean comparisons were performed using a post hoc test at a predefined

significance level. Statistical analyses were conducted using standard statistical software to ensure transparency and reproducibility.

Methodological Rigor and Reproducibility

To ensure reproducibility and methodological robustness, all experimental procedures—including raw material preparation, feed formulation, pelleting conditions, and laboratory analyses—were standardized across treatments. The experimental design and analytical methods were selected to allow clear attribution of observed differences in calcium and phosphorus content to the inclusion of cabbage waste in pelletized rabbit feed.

RESULTS AND DISCUSSION

Calcium Content of Pelletized Rabbit Feed

The inclusion of cabbage waste in pelletized rabbit feed significantly affected calcium content, as illustrated in Figure 1. The control treatment (0%) exhibited the highest calcium content (4.12%), which was statistically different ($p < 0.05$) from the diets containing cabbage waste. The inclusion of 5% cabbage waste resulted in a marked reduction in calcium content (2.33%), classified in a lower statistical group, indicating a significant decline compared with the control. However, increasing the inclusion level to 10% and 15% led to a significant recovery of calcium content, reaching 3.29% and 3.46%, respectively, with both treatments belonging to the same statistical group.

This trend suggests that low inclusion levels of cabbage waste may dilute calcium concentration due to partial substitution of conventional mineral-rich ingredients. Conversely, higher inclusion levels appear to compensate for this effect, likely due to the relatively high calcium content inherent in cabbage waste. From a nutritional perspective, the calcium values observed at 10% and 15% inclusion levels fall within an acceptable range for rabbit diets, supporting bone development and dental health.

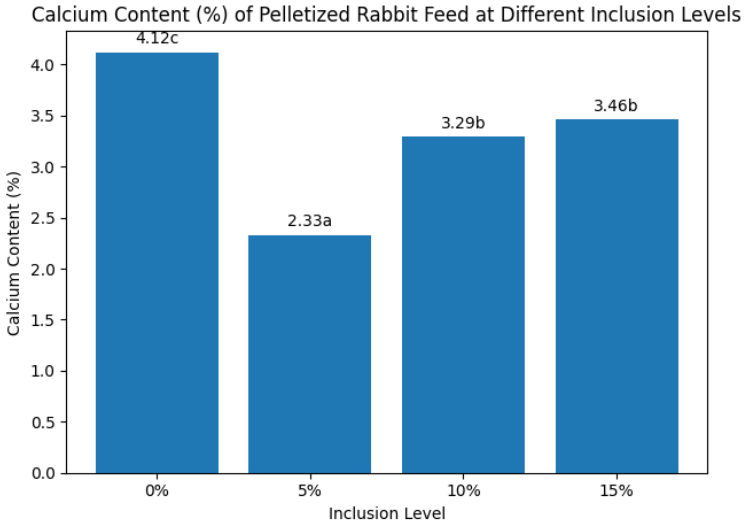

Figure 1. Phosphorus content (%) of pelletized rabbit feed at different inclusion levels.

These findings are consistent with previous studies reporting that vegetable-based by-products can serve as effective calcium sources when included at appropriate levels in animal feeds

(Shinali et al., 2024; Teshome et al., 2024; Yohannes et al., 2024). Earlier research has demonstrated that leafy vegetable residues contribute substantial calcium content (Caunii et al., 2010; Natesh et al., 2017), provided that inclusion rates are optimized to avoid nutrient imbalance (Haque et al., 2023; Natesh et al., 2017). The present results extend these findings by showing that pelletization does not diminish the calcium contribution of cabbage waste and may even enhance nutrient uniformity in the final feed product.

Phosphorus Content of Pelletized Rabbit Feed

Phosphorus content was also significantly influenced by cabbage waste inclusion, as shown in Figure 2. The highest phosphorus concentration was observed at the 15% inclusion level (0.57%), which differed significantly ($p < 0.05$) from the 10% treatment that recorded the lowest value (0.52%). The control (0%) and 5% inclusion treatments showed intermediate phosphorus contents (0.53% and 0.56%, respectively), indicating a non-linear response to increasing cabbage waste levels.

The observed pattern suggests that phosphorus availability in the pelletized feed is influenced not only by the inclusion level of cabbage waste but also by interactions among feed ingredients during formulation and pelleting. The increase in phosphorus content at higher inclusion levels may reflect the cumulative contribution of cabbage waste phosphorus, as well as improved mineral retention during feed processing.

From a nutritional standpoint, the phosphorus levels across all treatments remained within ranges considered adequate for rabbit growth and metabolic functions. This is particularly important given the close physiological relationship between calcium and phosphorus metabolism. The relatively balanced Ca:P ratio observed at higher inclusion levels indicates that cabbage waste can be incorporated into pelletized rabbit feed without compromising mineral equilibrium (Adegbeye et al., 2020; Bakshi et al., 2016).

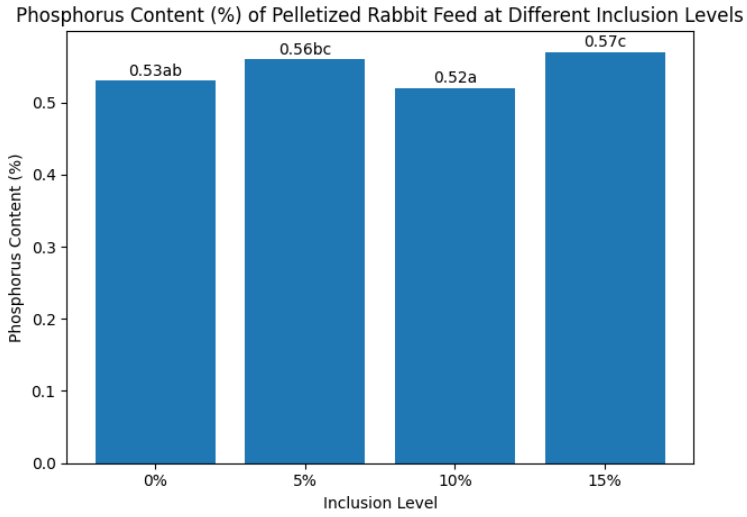

Figure 2. Phosphorus content (%) of pelletized rabbit feed at different inclusion levels.

Comparable findings have been reported in previous studies using vegetable residues and leafy by-products in animal feeds, in which moderate to high inclusion levels improved phosphorus availability without adverse effects (Bakshi et al., 2016; Kasapidou et al., 2015; Yang et al., 2021). The

present study provides additional evidence that cabbage waste, when processed into pellets, can serve as a reliable phosphorus source within an integrated feeding system.

Implications for Integrated and Sustainable Feeding Systems

Overall, the results presented in Figures 1 and 2 highlight that cabbage waste inclusion at 10–15% represents an optimal range for maintaining adequate calcium and phosphorus levels in pelletized rabbit feed. The statistical differentiation among treatments underscores the importance of dosage optimization rather than mere substitution of conventional ingredients.

Figure 3 illustrates the broader implications of integrating cabbage waste into pelletized rabbit feed as part of a sustainable and integrated agricultural system. The utilization of cabbage waste as a feed ingredient contributes directly to the reduction of agricultural residues while simultaneously optimizing calcium and phosphorus content in rabbit diets, as evidenced by the experimental results. Through pelletization, nutrient uniformity and feed efficiency are improved, which supports more consistent mineral intake by animals (Leyva-Jimenez & Bailey, 2016; Tumuluru, 2019). Beyond nutritional benefits, this approach offers economic advantages by lowering feed formulation costs and reducing dependence on conventional feed resources. Collectively, these outcomes demonstrate how waste valorization can strengthen circular agricultural practices, enhance resource-use efficiency, and support environmentally sustainable livestock production systems.

From a systems perspective, these findings reinforce the potential of cabbage waste valorization as part of an integrated and sustainable agricultural framework. By transforming horticultural residues into nutritionally functional pelletized feed, this approach reduces waste, lowers feed costs, and supports circular resource use (Nath et al., 2023). The analytical evidence provided by calcium and phosphorus responses strengthens the argument that cabbage waste can be strategically integrated into rabbit feeding systems without compromising nutritional quality.

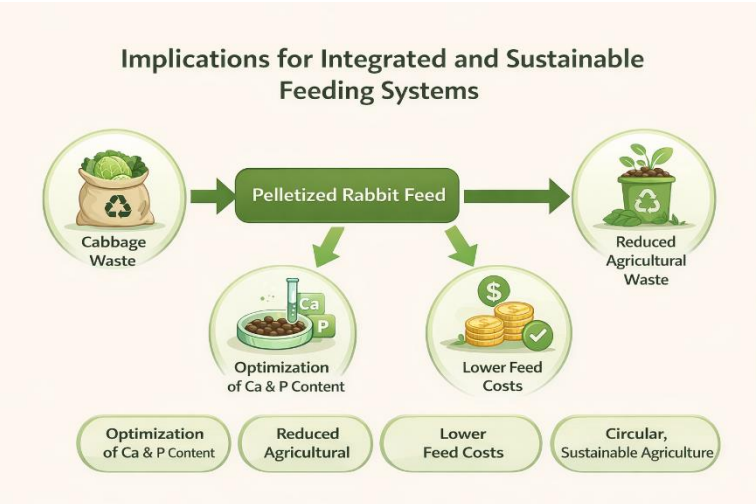

Figure 3. Implications of cabbage waste integration into pelletized rabbit feed within a sustainable agricultural system.

CONCLUSION

This study demonstrates that the strategic incorporation of cabbage waste into pelletized rabbit feed effectively enhances mineral composition, particularly calcium and phosphorus, with

inclusion levels of 5–15% showing the most nutritionally relevant outcomes. The observed increase in calcium content and the balanced response of phosphorus confirm that cabbage waste functions not merely as an alternative feed ingredient, but as a nutritionally active component when processed through pelletization. These findings highlight the importance of optimizing inclusion rates to achieve mineral adequacy while maintaining nutrient balance in rabbit diets.

Beyond nutritional outcomes, the principal novelty of this research lies in its systems-based approach, integrating vegetable waste valorization with livestock feed formulation within a sustainable agricultural framework. By linking crop residue management to feed quality improvement, this study provides empirical evidence that agricultural by-products can be efficiently reintegrated into productive cycles without compromising feed value. The results therefore support the development of circular, resource-efficient feeding strategies and offer a scalable model for sustainable rabbit production systems aligned with integrated agricultural practices.

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