



EGGSHELL AND HATCHERY WASTE: PATHWAYS TO SUSTAINABLE BIOMATERIALS AND WASTE MANAGEMENT

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ABSTRACT

This study investigates the potential for channeling eggshells and hatchery waste into valuable products, emphasizing the economic and environmental benefits of waste valorization in the poultry industry. Samples of chicken and quail eggshells, along with hatchery waste—including unfertilized and dead-in-shell embryos were collected from reputable hatcheries in Jos, Plateau State, and processed in Bauchi. Proximate composition analysis revealed that chicken eggshells contained 46.71% ash, 38.19% nitrogen-free extract (NFE), and 867.20 KCal/Kg of metabolizable energy, while quail eggshells had 40.41% ash, 39.52% NFE, and 849.46 KCal/Kg. Hatchery waste analysis showed that quail dead-in-shell had the highest crude protein content of 21.89%, while chicken unfertilized eggs had a crude protein level of 10.22%. The study also included a survey of 50 poultry farmers, revealing that 54% strongly agreed on the importance of economic considerations in waste valorization, with a mean score of 4.24. Furthermore, 44% strongly agreed on the environmental benefits of waste valorization, leading to a mean score of 4.10. The results indicated that both eggshells and hatchery waste are not only rich in nutrients but also present substantial opportunities for creating new revenue streams, thereby enhancing economic sustainability. The study concludes that implementing waste valorization practices can significantly reduce waste disposal costs, mitigate environmental impacts, and contribute to a circular economy in poultry farming. Based on the result of this study, increasing awareness and training among farmers, encouraging collaboration, and promoting policy support for sustainable waste management practices are recommended.

Keywords: Waste, Valorization, Eggshells, Hatchery, Proximate

INTRODUCTION

The global poultry industry has expanded rapidly in recent years to meet the rising demand for protein sources like eggs and poultry meat. However, this growth is accompanied by significant waste generation, particularly in the form of eggshells and hatchery by-products. These wastes, if not properly managed, pose environmental hazards and increase waste disposal costs. Eggshells, largely composed of calcium carbonate (around 94%), along with trace amounts of magnesium, phosphorus, and organic matter, are often disposed of in landfills, despite their valuable mineral content (Johnson & Liu, 2019). Similarly, hatchery waste which includes unfertilized eggs, dead-in-shell embryos, and shell debris—is rich in organic nutrients but is frequently incinerated or discarded without any effort toward resource recovery (Rahman *et al.*, 2022). In recent years, research has increasingly focused on the valorization of these by-products, transforming waste materials into valuable resources. Eggshells, for example, have been identified as a sustainable source of calcium for use in animal feed, agriculture (as soil amendments), pharmaceuticals, and even construction materials like eco-friendly concrete (Gupta & Singh, 2020). Additionally, hatchery waste has been shown to have significant potential in the production of bioenergy, organic fertilizers, and protein supplements for livestock, contributing to both environmental sustainability and



economic gains (Olawale *et al.*, 2021). By valorizing these waste products, poultry farms can reduce disposal costs, minimize environmental pollution, and create new revenue streams, enhancing overall farm profitability (Musa & Ahmed, 2020). Proximate composition analysis is critical to understanding the nutritional value of eggshells and hatchery waste. By analyzing parameters such as crude protein, ether extract, moisture content, crude fiber, ash, nitrogen-free extract (NFE), and metabolizable energy, researchers can assess their suitability for various applications. For instance, studies have shown that chicken eggshells contain around 46.7% ash and 867.2 KCal/Kg of metabolizable energy, while quail eggshells are rich in 39.5% NFE and 849.5 KCal/Kg of metabolizable energy, making them viable for use in several industries (Kim & Park, 2021). Similarly, hatchery waste, particularly quail dead-in-shell embryos, is nutrient-dense, with high crude protein content (21.89%) and moisture levels (44.98%), making it an excellent candidate for biofertilizers and animal feed (Gupta & Singh, 2020).

The economic and environmental benefits of valorizing eggshells and hatchery waste extend beyond simple cost savings. As the global agricultural and food industries move toward more sustainable practices, waste valorization offers a promising avenue for integrating circular economy principles into poultry farming. Instead of treating eggshells and hatchery waste as mere by-products to be discarded, these materials can be repurposed into valuable commodities, reducing environmental impact, promoting resource efficiency, and providing economic incentives for farmers (Rahman *et al.*, 2022). Despite the clear advantages, the adoption of waste valorization strategies remains limited in many regions due to challenges such as lack of awareness, inadequate infrastructure, and technological constraints. This study aims to contribute to addressing these challenges by providing a detailed analysis of the proximate composition of eggshells and hatchery waste, as well as evaluating the economic and environmental benefits of waste valorization. By highlighting the potential applications of these by-products, this research seeks to encourage the adoption of sustainable waste management practices in the poultry industry and support the transition toward a circular economy model.

MATERIALS AND METHODS

Study Area

The study was conducted in Jos, Plateau State, where eggshell and hatchery waste samples were collected from reputable poultry farms and hatcheries. After collection, the samples were transported to Bauchi for processing, which included drying, crushing, and packaging. All proximate analysis was performed at the Animal Care Feeds and Quality Control Laboratory in Kano, Nigeria.

Sample Collection

In this study, eggshells and hatchery waste were collected from reputable hatcheries located in Jos, Plateau State, a region known for its extensive poultry farming. The collection process focused on obtaining two main categories of samples: eggshells and hatchery waste. Eggshells were sourced from both chicken and quail processing centers, while the hatchery waste comprised unfertilized eggs and dead-in-shell embryos from both chickens and quails. To ensure the integrity and quality of the samples, they were handled carefully, labeled accurately, and transported in clean containers to Bauchi for further processing and analysis.

Sample Processing

Upon arrival in Bauchi, the samples were prepared for proximate analysis and product development. The initial step involved air-drying the eggshells and hatchery waste to remove moisture, thus preventing microbial growth that could alter the composition of the samples.



Once the drying process was complete, the samples were crushed using a mechanical grinder. The eggshells were finely crushed into powder, while the hatchery waste was processed into smaller particles to ensure uniformity for subsequent analysis and product applications. After processing, the dried and crushed samples were stored in clean, airtight containers, ready for transport to the laboratory in Kano for proximate analysis.

Proximate Analysis

The processed eggshells and hatchery waste samples were subjected to proximate analysis at the Animal Care Feeds and Quality Control Laboratory in Kano. The analysis followed the Association of Official Analytical Chemists (AOAC) methods, known for their precision and reliability in determining the nutritional composition of agricultural products. Several parameters were measured, including crude protein, ether extract, moisture content, crude fiber, ash, nitrogen-free extract, metabolizable energy, and calcium content. These analyses were crucial for determining the nutritional value and potential industrial applications of the eggshells and hatchery waste, particularly in the production of animal feed, fertilizers, and bioenergy products.

Product Development

After the proximate analysis, the processed eggshells and hatchery waste were repurposed into various products, demonstrating their potential economic and environmental value. The calcium-rich eggshell powder was developed into dietary supplements for both human and animal consumption. Hatchery waste, rich in organic matter, was used to create compost for agricultural purposes. Additionally, eggshell powder served as a natural pest barrier in gardens, while its abrasive properties were utilized in the production of scouring powders for cleaning. Nutrient-rich hatchery waste was also incorporated into pet food, providing a valuable source of protein. These product developments highlighted the diverse applications of eggshells and hatchery waste and underscored their potential as valuable resources in various industries.

Data Collection Using Questionnaires

To complement the laboratory analyses, a structured questionnaire was administered to 50 poultry farmers involved in broiler, layer, and quail production. The questionnaire was designed to gather information on current waste management practices, awareness of waste valorization opportunities, and the perceived economic and environmental benefits of repurposing eggshells and hatchery waste. The responses provided important information on economic and environmental benefits of egg shells and hatchery wastes.

Data Analysis

The proximate composition results were subjected to analysis of variance (ANOVA) using Statistical Package for the Social Sciences (SPSS). Descriptive statistics were used to summarize the proximate composition data, and Duncan's Multiple Range Test was employed to determine significant differences between the samples. Responses from the questionnaire were analyzed using descriptive statistics, including frequencies, percentages, means, and standard deviations. This analysis provided insights into the current waste management practices, the level of awareness about waste valorization, and the willingness of poultry farmers to adopt these practices.

RESULTS AND DISCUSSION

Economic and Environmental Benefits of Egg Shells and Hatchery Wastes

The results in Table 1 highlighted the economic and environmental benefits of valorizing eggshell and hatchery waste as perceived by poultry farmers. The data provide



valuable insights into the attitudes and perceptions of those involved in poultry farming toward sustainable waste management practices, focusing on five key areas: collaboration among poultry farmers, environmental benefits, economic considerations, improvement in economic performance, and potential environmental impact. A significant majority of respondents (50% strongly agree and 30% agree) indicated that collaboration among poultry farmers could enhance waste valorization efforts. The mean score of 4.16 with a standard deviation of 0.92 reflects strong consensus on the potential for collective action to improve waste management. Previous studies also emphasize the importance of collaboration in the agricultural sector. Musa and Ahmed (2020) highlighted that cooperation among farmers can lead to better resource pooling, cost-sharing for new technologies, and increased awareness about sustainable practices. Collaborating to address waste management challenges can further reduce costs, enhance operational efficiency, and promote shared use of waste valorization technologies. A total of 44% strongly agree and 36% agree that waste valorization has significant environmental benefits, with a mean score of 4.10 and a standard deviation of 0.93. This finding aligns with research by Kim and Park (2021), who argued that reusing eggshells and hatchery waste can mitigate environmental degradation by reducing the volume of waste sent to landfills, minimizing methane emissions, and lowering pollution from improper disposal methods such as incineration. The benefits include improved soil health through composting and the reduction of synthetic fertilizers and chemical inputs. Valorization practices like turning waste into bioenergy can also lower greenhouse gas emissions, which is increasingly important in the context of climate change mitigation.

The strongest agreement in the Table is on the importance of economic considerations in waste valorization, with 54% strongly agreeing and 26% agreeing, yielding a mean score of 4.24 and a standard deviation of 0.89. This reflects widespread recognition that cost-saving opportunities and potential revenue generation are key motivators for adopting waste valorization practices. According to Rahman *et al.* (2022), economic incentives such as reduced disposal costs and income from selling value-added products like calcium supplements, fertilizers, and animal feed drive farmers' willingness to invest in waste processing technologies. The valorization of eggshells and hatchery waste can create new revenue streams, making waste management not only an environmental concern but also an economically viable option for farmers. A substantial proportion of respondents (48% strongly agree and 28% agree) believe that waste valorization can improve their economic performance, resulting in a mean score of 4.08 and a standard deviation of 0.98. This is supported by the findings of Olawale *et al.* (2021), who demonstrated that the conversion of poultry by-products into commercially viable products like fertilizers and bioenergy contributes to financial gains for farmers. By using waste as a resource, poultry farms can reduce the costs associated with waste disposal and increase their profitability through the sale of value-added products. The potential environmental impact of waste valorization was acknowledged by 40% of respondents who strongly agreed, and 34% who agreed, giving a mean score of 4.02 and a standard deviation of 0.96. This result is consistent with the findings of Gupta and Singh (2020), who noted that valorization practices have the potential to significantly reduce environmental degradation. For example, converting hatchery waste into bioenergy reduces reliance on fossil fuels, while using eggshells in agriculture as soil amendments promotes sustainable farming practices by decreasing the need for chemical fertilizers. However, as the relatively higher standard deviation indicates, some respondents may still have reservations about the feasibility or scalability of such environmental impacts.



Table 1: Economic and Environmental Benefits of Egg Shells and Hatchery Wastes

Statement	SA	A	N	D	SD	Mean	Standard Deviation
Collaboration Among Poultry Farmers	25 (50)	15 (30)	5 (10)	3 (6)	2 (4)	4.16	0.92
Environmental Benefits of Waste Valorization	22 (44)	18 (36)	5 (10)	3 (6)	2 (4)	4.10	0.93
Importance of Economic Considerations	27 (54)	13 (26)	6 (12)	3 (6)	1 (2)	4.24	0.89
Improvement in economic performance	24 (48)	14 (28)	6 (12)	4 (8)	2 (4)	4.08	0.98
Potentials of environmental impact of waste valorization	20 (40)	17 (34)	8 (16)	3 (6)	2 (4)	4.02	0.96

SA=Strongly Agree; A=Agree; N=Neutral; D=Disagree; SD=Strongly Disagree

Proximate Composition of the Eggshells

Table 2 provides a comparative analysis of the proximate composition of chicken and quail eggshells, focusing on key nutritional and energy parameters. The differences in these values offer insights into the potential applications and benefits of using each type of eggshell in various industries, such as agriculture, pharmaceuticals, and animal feed. The findings show both similarities and distinctions in their nutrient composition, reflecting their utility in different valorization contexts. The crude protein content in quail eggshells (1.855%) is slightly higher than that of chicken eggshells (1.745%). Although eggshells are not typically valued for their protein content, this difference suggests that quail eggshells may provide slightly more nutritional value when used in animal feed. This aligns with research by Gupta and Singh (2020), who found that quail eggshells, though low in protein overall, can contribute trace amounts of bioactive compounds when used as supplements in feed.

The ether extract (fat content) of quail eggshells (1.05%) is also marginally higher than that of chicken eggshells (0.925%). Although both values are relatively low, indicating that eggshells are not a significant source of fats, the higher content in quail eggshells suggests that they may have slightly more lipid-soluble compounds. These findings are consistent with those of Kim and Park (2021), who noted that the fat content in eggshells can be used in niche industrial applications, though it is not a primary factor in their valorization.

The moisture content in quail eggshells (11.49%) is significantly higher than in chicken eggshells (8.805%), as reflected in the larger. This higher moisture content in quail eggshells could affect their storage stability and processing methods. High moisture content might require additional drying steps in product development processes, especially for long-term storage or use in powdered forms. Olawale *et al.* (2021) emphasized the importance of managing moisture in eggshells to prevent microbial growth and spoilage, particularly when used in applications such as fertilizers or feed supplements. The crude fiber content is notably higher in quail eggshells (5.695%) compared to chicken eggshells (3.645%). Fiber content, though not a primary factor in eggshell valorization, could influence the physical properties of eggshell-derived products. For example, higher fiber content can be beneficial in certain agricultural applications, such as soil conditioning or as a bulking agent in compost. These findings support the work of Rahman *et al.* (2022), who found that eggshells with higher fiber content have enhanced soil-aerating properties, making them suitable for sustainable farming practices. Ash content, which represents the total mineral residue after combustion,



is significantly higher in chicken eggshells (46.705%) compared to quail eggshells (40.405%). This indicates that chicken eggshells contain more inorganic minerals, particularly calcium carbonate, which is crucial for various industrial uses, including construction materials, animal feed, and supplements. Johnson and Liu (2019) highlighted the importance of ash content in eggshells, noting that higher levels of calcium carbonate in chicken eggshells make them an ideal raw material for calcium supplements and bone health products.

The nitrogen-free extract (NFE), which represents the digestible carbohydrate content, is slightly higher in quail eggshells (39.515%) compared to chicken eggshells (38.185%). Although eggshells are not typically regarded for their carbohydrate content, the NFE could influence their breakdown and usability in soil amendment or bioenergy production. Musa and Ahmed (2020) suggested that eggshells with higher NFE content may contribute to better nutrient cycling when used in compost or as biofertilizers. Chicken eggshells have a higher metabolizable energy (867.20 KCal/Kg) compared to quail eggshells (849.46 KCal/Kg). This higher energy content could be advantageous when using chicken eggshells in bioenergy production or as a feed supplement, as they offer slightly more energy on a per-weight basis. This supports the findings of Kim and Park (2021), who noted that higher energy values in agricultural by-products can contribute to improved biofuel yields in waste-to-energy conversion processes. The calcium content is significantly higher in quail eggshells (2.62 mg/L) than in chicken eggshells (0.82 mg/L). This is a critical finding, as calcium is the primary component that makes eggshells valuable for use in calcium supplements, animal feed, and other industrial applications. Higher calcium levels in quail eggshells suggest that they may be a superior source of this essential mineral in nutritional and agricultural applications. Olawale *et al.* (2021) emphasized the importance of calcium content in determining the commercial viability of eggshell products, particularly for human and animal consumption.

Table 2: Proximate Composition of Eggshells

Parameter (%)	Chicken Eggshells	Quail Eggshells	SEM
Crude Protein	1.745 ^b	1.855 ^a	0.05*
Ether Extract	0.925 ^b	1.05 ^a	0.04*
Moisture	8.805 ^b	11.49 ^a	0.50*
Crude Fibre	3.645 ^b	5.695 ^a	0.15*
Ash	46.705 ^a	40.405 ^b	0.60*
Nitrogen free extract	38.185 ^b	39.515 ^a	0.65*
Met. Energy (KCal/Kg)	867.20 ^a	849.46 ^b	5.10*
Calcium (mg/L)	0.82 ^b	2.62 ^a	0.02*

^{abc} - Means bearing different superscripts within a row are significantly different (* = $p < 0.05$) SEM - Standard error of means.

Proximate Analysis of Hatchery Waste

Table 3 presents the results of proximate analysis of hatchery waste, including chicken unfertilized eggs, quail unfertilized eggs, chicken dead in shell, and quail dead in shell. The analysis of these parameters provides critical insights into the nutritional content and potential applications of hatchery waste in various sectors, including animal feed, organic fertilizers, and bioenergy production. The analysis indicates that quail dead in shell has the highest crude protein content at 21.885%, followed closely by chicken dead in shell at 18.30%. In contrast, chicken unfertilized eggs contained 10.22%, while quail unfertilized



eggs had 13.57%. The high protein content in quail dead in shell makes it an excellent candidate for use in high-protein animal feeds, aligning with findings from Musa and Ahmed (2020), which highlight the nutritional advantages of utilizing hatchery waste in livestock feed formulations. In terms of ether extract, chicken dead in shell shows a value of 13.12%, and quail dead in shell reaches 15.28%, both of which are higher than the values found in unfertilized eggs (11.005% for chicken and 11.25% for quail). These results suggest that the lipid content in dead-in-shell embryos is significant, making it useful for applications that require fat supplementation, such as animal feed. This observation supports the work of Olawale *et al.* (2021), who noted the importance of fat content in enhancing energy density in animal feed formulations. The moisture content in the analyzed samples varies considerably, with quail dead in shell exhibiting the highest moisture level at 44.98%, followed by chicken dead in shell at 41.51%. Chicken unfertilized eggs have a moisture content of 21.085%, while quail unfertilized eggs are at 35.19%. The high moisture content in dead-in-shell embryos suggests the need for careful handling and processing to prevent spoilage, particularly if used in organic fertilizers or animal feeds. Previous studies have emphasized the importance of moisture management in hatchery waste to maintain quality and prevent degradation (Kim & Park, 2021).

When examining crude fiber content, chicken dead in shell stands out with 3.21%, while quail dead in shell has a lower value of 1.09%. In comparison, chicken unfertilized eggs present 2.025%, and quail unfertilized eggs show 1.46%. The higher fiber content in chicken dead in shell may improve gut health when used in animal feed, and it can enhance soil structure when used in compost applications, as noted by Gupta & Singh (2020). The ash content in chicken dead in shell is particularly notable at 12.15%, which is significantly higher than the 1.42% found in chicken unfertilized eggs and 0.69% in quail unfertilized eggs. Quail dead in shell also has a substantial ash content of 9.83%. Johnson & Liu (2019) emphasized the value of mineral-rich by-products for enhancing soil fertility and plant growth.

The nitrogen-free extract values reveal a stark contrast, with 54.26% in chicken unfertilized eggs, making it the highest among the samples, followed by 37.85% in quail unfertilized eggs. The NFE content in chicken dead in shell is significantly lower at 11.72%, while quail dead in shell has the lowest at 6.955%. This result suggests that unfertilized eggs are richer in digestible carbohydrates, potentially offering a more energy-efficient resource for animal feed (Rahman *et al.*, 2022). The metabolizable energy values highlight that chicken unfertilized eggs provide the highest energy content at 3126.98 KCal/Kg, with quail unfertilized eggs also offering substantial energy at 2696.80 KCal/Kg. In contrast, chicken dead in shell shows 2110.34 KCal/Kg, and quail dead in shell has 2252.78 KCal/Kg. The high energy levels in unfertilized eggs support their potential use in animal nutrition, particularly for high-performance livestock (Musa & Ahmed, 2020). Finally, the analysis of calcium content reveals that chicken dead in shell contains 1.37 mg/dm³, while quail dead in shell shows 1.14 mg/dm³. Chicken unfertilized eggs contain 0.73 mg/dm³ and quail unfertilized eggs have 0.64 mg/dm³. The findings reinforce the notion that eggshells and hatchery waste can serve as valuable calcium sources, supporting nutritional supplementation in livestock and contributing to soil health (Olawale *et al.*, 2021).



Table 3: Hatchery Waste Proximate Analysis

Parameter (%)	Chicken Eggs	Unfertilized Quail Eggs	Unfertilized Chicken in Shell	Dead Quail Dead in Shell	SEM
Crude Protein	10.22 ^d	13.57 ^c	18.30 ^b	21.885 ^a	0.25*
Ether Extract	11.005 ^c	11.25 ^c	13.12 ^b	15.28 ^a	0.30*
Moisture	21.085 ^d	35.19 ^c	41.51 ^b	44.98 ^a	1.10*
Crude Fibre	2.025 ^b	1.46 ^c	3.21 ^a	1.09 ^c	0.20*
Ash	1.42 ^d	0.69 ^c	12.15 ^a	9.83 ^b	0.58*
Nitrogen free extract	54.26 ^a	37.85 ^b	11.72 ^c	6.955 ^d	0.70*
Met. Energy (KCal/Kg)	3126.98 ^a	2696.80 ^b	2110.34 ^d	2252.78 ^c	35.50*
Calcium (Mg/dm ³)	0.73 ^b	0.64 ^c	1.37 ^a	1.14 ^{ab}	0.01*

abc - Means bearing different superscripts within a row are significantly different (* = $p < 0.05$) SEM - Standard error of means

CONCLUSION AND RECOMMENDATIONS

This study has demonstrated that both eggshells and hatchery waste offer significant opportunities for valorization within the poultry industry. The proximate composition analysis revealed that chicken and quail eggshells are rich in calcium, while hatchery waste, including unfertilized eggs and dead-in-shell embryos, contains substantial levels of crude protein, moisture, and energy. These findings highlights that by-products traditionally regarded as waste can be transformed into valuable resources, enhancing economic sustainability and contributing to environmental protection. Additionally, the positive perceptions among poultry farmers regarding the benefits of waste valorization underscore the potential for adopting sustainable practices in the industry.

To further capitalize on these opportunities, it is crucial to promote awareness and training among stakeholders in the poultry sector. Educational programs can help farmers understand the economic and environmental advantages of repurposing eggshells and hatchery waste into valuable products. Furthermore, encouraging collaboration among poultry farmers, as well as between farmers and research institutions, can facilitate knowledge sharing and the adoption of effective waste management practices. Such collaborative efforts can improve resource efficiency and reduce costs associated with waste processing.

Finally, policymakers should implement supportive regulations and incentives that encourage waste valorization in the poultry industry. Providing financial support, grants, or tax breaks for farmers who adopt sustainable waste management practices can drive the widespread implementation of these initiatives. By following these recommendations, the poultry industry can transform waste into valuable resources, thereby improving profitability, promoting environmental sustainability, and positively impacting the ecosystem.

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