Asian Journal of Agriculture and Rural Development
Volume 15, Issue 1 (2025): 94-101

Development of chicken manure pelleting machine for organic fertilizer production

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Article History

Received: 30 January 2025
Revised: 3 March 2025
Accepted: 28 March 2025
Published: 3 April 2025

Keywords

Flat die mill
Individual pellet density
Molasses-chicken manure ratio
Pellet durability index
Pelleting capacity
Pelleting efficiency
Pelleting recovery.

ABSTRACT

This research aimed to solve the chicken manure disposal problem in the Philippines' poultry industry by developing and evaluating a pelleting machine made from local materials. The machine utilized a flat die and roller system to pelletize dried chicken manure with molasses. Following PAES guidelines and PNS-BAFPS specifications, the study assessed pellet physical properties and processing costs, considering belt speeds (650, 950, 1250 rpm) and molasses-to-chicken ratios (2:100, 3:100, 4:100) in a completely randomized two-factorial experiment. Results showed that higher belt speeds (950 and 1250 rpm) significantly increased pelleting capacity, reaching a maximum capacity of 160.09 kg/hr and 165.12 kg/hr, respectively. An optimal 3:100 molasses ratio yielded 98.02% pelleting efficiency and 98.29% recovery, exceeding PAES minimum standards. Additionally, the produced pellets met PNS-BAFPS physical characteristics, and the pellet durability is comparable to that of the highest pellet durability index of 80%. However, moisture content exceeded recommended levels (47.07-48.63%), indicating the need for drying. At a processing cost of ₱4.26/kg, the machine provides an economical solution, with future development focused on incorporating drying technologies and conducting nutrient analyses.

Contribution/Originality: The main finding reveals that the machine has a maximum pelleting capacity of 165.12 kg/hr, an efficiency of 98.02%, and a recovery rate of 98.29%. The pelleted chicken manure meets the physical properties of pellets based on PNS BAFPS for organic fertilizer and provides an economical solution for the daily waste disposal of chicken manure in a typical poultry farm in the Philippines, with a processing cost per unit of ₱4.26/kg.

DOI: 10.55493/5005.v15i1.5324
ISSN(P): 2304-1455/ ISSN(E): 2224-4433

How to cite: Dichoso, J. G., Villota, E. M., Fabulac, J. V., & Malamug, V. U. (2025). Development of chicken manure pelleting machine for organic fertilizer production. *Asian Journal of Agriculture and Rural Development, 15*(1), 94–101.

1. INTRODUCTION

In the Philippines, the poultry industry is growing rapidly, with chicken production reaching 470.21 thousand metric tons in early 2023—a 3.3% increase from 2022 (Philippine Statistics Authority, 2023). Central Luzon led production during this period, contributing 34.5% of the total output. This growth has led to a substantial increase in chicken manure production, with the industry generating around 2.46 million metric tons of manure annually (Torres et al., 2023). Chickens produce manure equivalent to 3-4% of their body weight, which translates to about 80-100 grams per day (Manogaran, Shamsuddin, Yusoff, Lay, & Siyal, 2022). Adult chickens excrete 150-160 g of droppings daily (Tańczuk, Junga, Kolasa-Więcek, & Niemiec, 2019). Manure contains a large amount of ammoniacal nitrogen, and due to nitrification and denitrification processes, land spreading of poultry manure causes larger emissions of NH_3, N_2O, and NO_x than combustion (Billen, Costa, Van der Aa, Van Caneghem, & Vandecasteele, 2015). Unprocessed manure emits ammonia (NH_3), leading to skin, eye, and respiratory irritation, reduced feed consumption, weight gain, and egg production, and increased susceptibility to infections (Mohammad Al-Kerwi, Mardenli, Mahdi Jasim, & Al-Majeed, 2022). Additionally, spreading fresh manure on the land can result in emissions of greenhouse gases (GHGs), such as N_2O (Stiles, 2017).

Effective management of chicken manure remains a challenge, especially for small-scale poultry farmers. In response, the Philippine government has enacted policies such as the Clean Water Act of 2004 and the Ecological Solid Waste Management Act of 2000, which emphasize the proper handling and disposal of animal waste, including chicken manure (Borines, Dadios, Salac, & Monares, 2018). The disposal of manure is the main concern of producers, as foul odors coming from the poultry farms continuously cause disturbances to their neighbors, health risks from disease-carrying flies, and conflicts within the community (Jose, Medina, De Torres, Kristel, & Dela Peña, 2019). The discharge of untreated effluent into the waterways, open dumping, and hazardous open-air burning of waste were among the unacceptable practices gathered in the survey (Grace, Victoria, Alaira, Sobremisana, & Macan8, 2010). Policy responses to waste management must be improved, and therefore, farm monitoring and socioeconomic and socio-ecological initiatives must be implemented (Dili, Kalaw, Miguel, & Ting, 2022), as well as regulation of the transport, handling, and disposal of chicken dung and animal manure to prevent the spread of diseases (Department of Agriculture Administrative Order No. 02, 2008).

Pelleting involves extruding bulk material through a die and transforming it into compact pellets. Compost pellets offer several advantages, including space conservation, suitability for mechanization, compatibility with farming equipment for spreading, reduced dust pollution, enhanced precision, and suitability for long-distance transport (Mavaddati, Kianmehr, Allahdadi, & Chegini, 2010). Pelleting technology that transforms raw materials like animal manure into uniform pellets also offers benefits in handling, storage, and transportation (Sharara, 2018). Beyond improving bulk density, pelletization simplifies the handling and storage of biofuel, making it comparable in efficiency to working with granular commodities such as corn, soybeans, and wheat (Mani, Sokhansanj, Bi, & Turhollow, 2006). Pelletized manures can be utilized for heating and power generation in addition to being a fertilizer (Wzorek, Junga, Yilmaz, & Niemiec, 2021). A gap remains in understanding the interaction between some of the pelleting parameters and their effect on the process outcomes (Nielsen, Mandø, & Rosenørn, 2020). Additionally, a comparison between the operating cost for dairy manure granulation and extrusion showed granulation to be at least 3.5 times greater than pelleting due to the cost of binder and energy required for granulation (Runge, Mahmoud, & John, 2018).

Thus, developing an economical pelleting machine specifically for chicken manure is crucial. The machine will convert the dried daily manure output from poultry farms into pellets and utilize the belt speeds and molasses (as binding agents) as factors. This will help reduce environmental pollution, support sustainable agricultural practices, and ensure compliance with laws governing chicken manure management in the Philippines.

2. MATERIALS AND METHODS

2.1. Design and Development

The machine was built with a strong main frame made of an angle bar with an appropriate thickness for stability, an electric motor of 5 hp to drive the machine, a hopper for receiving dried manure, a shaft, and a belt pulley to control speed, a pelleting chamber comprising a flat die and roller for the compaction and forming of the pellets, a pellet cutter for uniformity of pellet size, and a discharge chute for broken and good pellets, as shown in Figure 1.

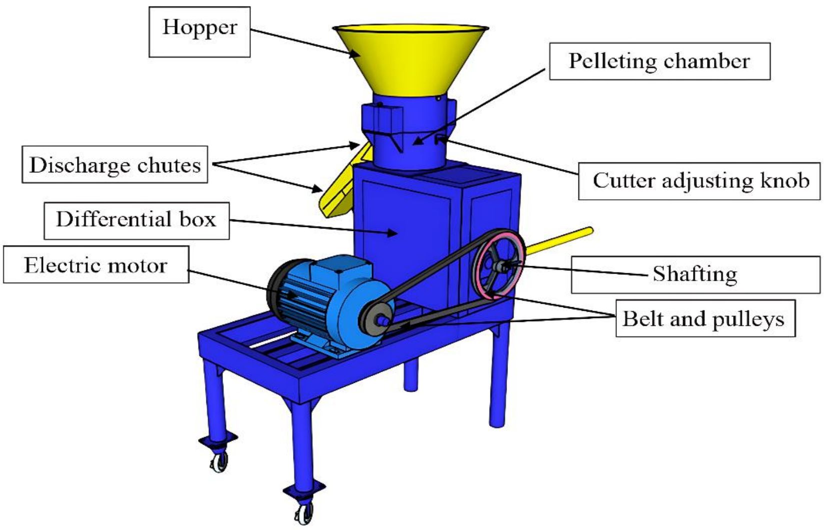

Figure 1. Isometric view of the developed chicken manure pelleting machine.

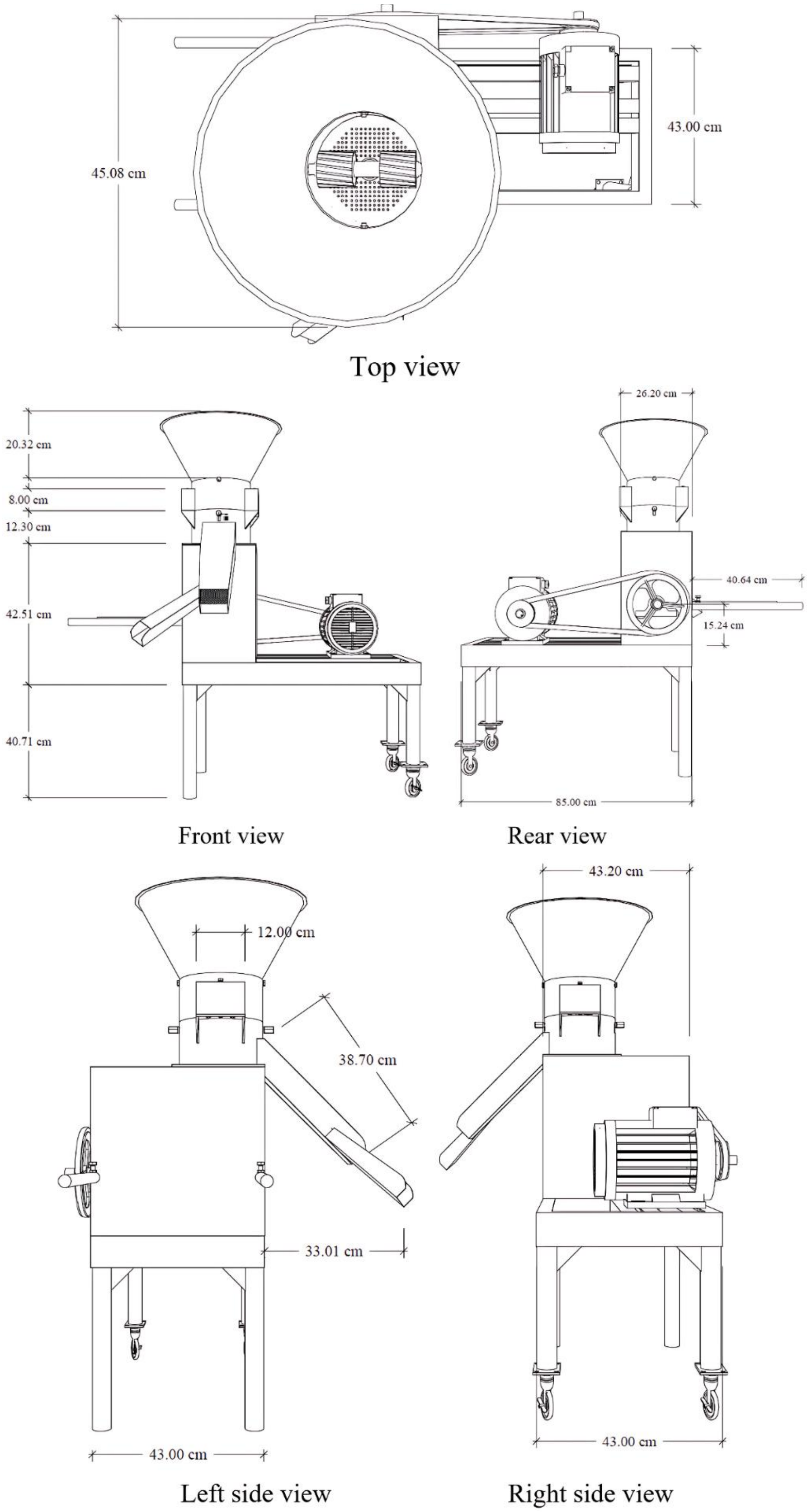

Figure 2. Orthographic design of the chicken manure pelleting machine.

2.2. Principles of Operation in the Testing

The machine aims to pelletize chicken manure. Three kilograms of chicken manure with a moisture content of 38% will be fed into the machine hopper and then transported into the pelleting chamber. It will be compacted to form pellets by the rotating movement of the flat die against the roller, cut by the pellet cutter, and then passed through a sieve, which separates the formed pellets from the unformed pellets. The formed pellets will be discharged through the chutes, while the unformed pellets will be mixed into the next batch for pelleting.

2.3. Design Considerations

The chicken manure pelleting machine is specifically designed to pelletize chicken manure entirely in line with the unit's established operational capabilities. This fabrication process prioritizes the use of locally available resources, with an electric motor serving as the power source for efficiency, capacity, and recovery. Its design prioritizes ease of operation and mobility, as well as simple repairs and component replacements. Furthermore, the machine aims to surpass traditional pelleting methods in terms of efficiency, with a target capacity of 2000 kg to 2500 kg of manure processed in an eight- to ten-hour daily operation. Lastly, it is based on Philippine Agricultural Engineering standards.

2.4. Performance Evaluation of the Machine

2.4.1. Pelleting Capacity

Pelleting capacity refers to the maximum output or production rate of a pelleting process or machine within a specified timeframe. It represents the amount of material that can be processed, shaped, and extruded into pellets per unit of time, typically measured in terms of volume or weight. This capacity is determined by various factors, including the size and efficiency of the pelleting equipment, the properties of the raw materials being processed, and the operational parameters of the pelleting process. Pelleting capacity is the ratio of the total weight of the pelleted chicken manure collected at the discharge to the total operating time the machine was able to pelletize the chicken manure-molasses mixture (1).

$$C_p = (W_o/T_o)\ x\ 100 \qquad [kg/hr] \qquad (1)$$

Where: C_p - Pelleting capacity, kg/hr.

W_o - Total weight of the pelleted chicken manure collected at the discharge, kg.

T_o - Total operating time, hr.

2.4.2. Pelleting Efficiency

Pelleting efficiency refers to the effectiveness and productivity of a pelleting process or machine in converting raw materials into pellets. It assesses how well the pelleting equipment utilizes input materials, energy, and resources to produce high-quality pellets with minimal waste or loss. Pelleting efficiency is the ratio of the weight of whole pellets to the weight of dried chicken manure pellet samples from the chicken manure pelleting machine output (2).

$$Pe = (W_{fp}/W_{fo})\ x\ 100 \quad [\%] \qquad (2)$$

Where: P_e - Pelleting efficiency, %

W_{fp} - Weight of whole pellets, kg.

W_{fo} - Weight of dried sample from the feed pellet mill output, kg.

2.4.3. Pelleting Recovery

Pelleting recovery is the ratio of the total weight of the collected pelleted chicken manure at the discharge chute to the total weight of the chicken manure-molasses mixture input (3).

$$Pr = (W_o/W_{in})\ x\ 100 \quad [\%] \qquad (3)$$

Where: P_r - Pelleting recovery, %

W_o - Total weight of the collected pelleted chicken manure at the discharge chute, kg.

W_{in} - Total weight of chicken manure-molasses mixture input, kg.

2.5. Assessment of the Physical Properties of the Pelleted Chicken Manure

The assessment of the physical properties of the pelleted chicken manure was subjected to the Philippine National Standard for the Organic Fertilizer/Organic Compost minimum requirements and the American Society of Agricultural and Biosystems Engineering (ASABE) standards.

2.5.1. Individual Pellet Density

The individual density of the pellets was calculated by measuring the length and diameter of the pellet using an electronic caliper and by measuring the mass of the pellet using an electronic balance with a precision of 0.01 grams. To achieve precise volume, the edges of the pellets were smoothed. Pellet density was calculated using Equation 4. Ten randomly selected samples were measured, and their properties were recorded.

$$IPD = (IP_w/\ IP_v)\ [g/mm^3] \qquad (4)$$

Where: IPD – Individual pellet density, g/mm³

IP_w – Individual pellet weight, g.

IP_v – Individual pellet volume, mm^3.

2.5.2. Pellet Durability Index

Pellet durability was measured according to the ASABE S269.4 standard (ASABE Standard S269.4 1991, 2007) by placing 500-gram pellet sample in a rotating chamber (tumbling box) for 10 minutes at a speed of 50 rpm (5).

$$PDI = (m_A - m_E)\ x\ 100 \qquad [\%] \qquad (5)$$

Where: PDI – pellet durability index, %

m_A – Mass of intact pellets (retained on a sieve for pellet size) after the test, g.

m_E – Mass of intact pellets (retained on a sieve for pellet size) before the test, g.

2.5.3. Pellet Moisture Content

The moisture content of pelletized chicken manure was obtained by placing the pelleted chicken manure samples in the oven at (105±3) °C for 48 h. Moisture content wet weight basis was used for moisture content determination (6).

$$MC = (W_i - W_f)/(W_i) \times 100 \quad [\%] \qquad (6)$$

Where: MC – moisture content, %

W_i – initial weight of chicken manure, g.

W_f – final weight of chicken, g.

2.6. Statistical Analysis

The data were analyzed using the Statistical Tool for Agricultural Research (STAR) 2.0.1, developed by the International Rice Research Institute (IRRI). The three (3) varying belt speeds (650, 950, 1250 rpm) and three varying molasses-chicken manure ratios (2:100, 3:100, 4:100) were used and assessed using ANOVA two-factorial Complete Randomized Design (CRD), followed by pairwise mean comparisons employing Least Significant Difference (LSD) at a 5% level of significance.

3. RESULTS

3.1. Design and Fabrication

The study successfully designed and fabricated a chicken manure pelleting machine. The machine was made from locally available materials for ease of replacement in case of wear and tear of parts. The fabrication took place at local fabrication shops in Nueva Ecija, Philippines.

3.2. Performance Evaluation of the Chicken Manure Pelleting Machine

3.2.1. Pelleting Capacity

Based on Table 1, the speed of the belt has a significant impact on pelleting capacity. The optimal pelleting capacity is reached at belt speeds of 950 rpm and 1250 rpm, resulting in capacities of 160.09 kg/hr and 165.12 kg/hr, respectively. In contrast, at a speed of 650 rpm, the capacity drops to 83.63 kg/hr. Various ratios of molasses to chicken manure did not notably affect pelleting capacity. With a peak capacity of 168.87 kg/hr, the machine can process 2,000 kg of chicken manure (with 38% moisture content) from around 40,000 adult chickens typical in small-scale poultry operations in the Philippines within approximately 11.84 hours. However, it falls short of the target processing time of 8-10 hours per day for typical poultry farm manure output, exceeding the maximum operation time by 1.84 hours. This study presents findings that differ from the conclusions of Lunguleasa, Spirchez, and Radulescu (2020), which suggested that increased pelletizing capacity leads to higher pellet density. While Lunguleasa et al. emphasized the positive influence of press capacity on pellet density, the current research highlights alternative factors influencing pellet quality, offering a broader perspective on the pelletizing process.

3.2.2. Pelleting Efficiency

The average pelleting efficiency at different chicken manure-to-molasses ratios significantly affects pelleting efficiency, with the highest efficiencies recorded at 3:100 and 4:100, achieving 97.95% and 98.02%, respectively. This is notably higher than the 96.51% efficiency observed at a 2:100 ratio. Additionally, varying belt speeds did not significantly affect pelleting efficiency (Table 1). According to Production Machinery -Feed Pellet Mill - Methods of Test (2019), the minimum acceptable pelleting efficiency is set at 92%. The measured efficiencies exceed this standard, ranging from 5.95% to 6.02% above the minimum, thus passing the Production Machinery -Feed Pellet Mill - Methods of Test (2019) criteria.

3.2.3. Pelleting Recovery

The average pelleting recovery in different chicken manure to molasses ratios significantly influences pelleting recovery, with the highest efficiencies achieved at 3:100 and 4:100, yielding 98.29% and 98.23%, respectively. This is considerably better than the 96.78% efficiency noted at the 2:100 ratio. Variations in belt speed did not have a significant impact on pelleting recovery (Table 1). According to Production Machinery -Feed Pellet Mill - Methods of Test (2019), the minimum acceptable pelleting recovery is set at 95%. The computed efficiencies surpass this threshold, ranging from 1.78% to 3.29% above the minimum, thus meeting the Production Machinery -Feed Pellet Mill - Methods of Test (2019) standards.

3.3. Physical Properties of the Pelleted Chicken Manure

3.3.1. Individual Pellet Density

As shown in Table 1, the individual pellet density of pelletized chicken manure is affected by belt speed (650, 950, and 1250 rpm) and molasses-to-chicken-manure ratios (2:100, 3:100, and 4:100). The 3:100 ratio has the maximum density (0.0019 g/mm^3) at 650 rpm. However, the other ratios (2:100 and 4:100) provide lower values. All ratios exhibit a more uniform pellet density at 950 rpm, with the 3:100 ratio retaining a slightly greater density (0.0015 g/mm^3) than the others. Pellet densities for all ratios are practically the same at 1250 rpm and are lower than at 950 rpm. Higher speeds (1250 rpm) lessen the differences between the ratios, producing uniform but slightly lower pellet densities, whereas the 3:100 ratio generally tends to produce higher pellet densities at lower belt speeds. This study presents findings that differ from the conclusions of Lunguleasa et al. (2020), which suggested that increased pelletizing capacity leads to higher pellet density. While Lunguleasa et al. (2020) the positive influence of press capacity on pellet density, the current research highlights alternative factors influencing pellet quality, offering a broader perspective on the pelletizing process.

Table 1. Summary of results.

Belt speed, rpm	**Pelleting capacity, kg/hr**			**Pelleting efficiency, %**			**Pelleting recovery, %**			**Individual pellet density, g/mm³**			**Pellet durability index, %**			**Moisture content, %**		
	Molasses-chicken manure ratio (w/w)																	
	2:100	3:100	4:100	2:100	3:100	4:100	2:100	3:100	4:100	2:100	3:100	4:100	2:100	3:100	4:100	2:100	3:100	4:100
650	77.41	86.95	95.53	96.21	97.73	97.06	96.54	98.42	97.56	0.0013	0.0019	0.0012	93.06	93.80	95.40	47.06	48.23	47.60
950	155.77	157.27	167.23	97.66	97.59	98.63	97.96	97.70	98.76	0.0013	0.0014	0.0015	94.67	95.13	94.60	48.63	48.63	48.43
1250	161.61	168.87	168.87	95.64	98.53	98.34	95.85	98.75	98.35	0.0012	0.0013	0.0013	93.67	94.67	95.33	47.76	48.63	48.00

Belt speed, rpm	Color			Consistency			Odor		
	Molasses-chicken manure ratio (w/w)								
	2:100	3:100	4:100	2:100	3:100	4:100	2:100	3:100	4:100
650	Black	Black	Black	Friable	Friable	Friable	No foul odor	No foul odor	No foul odor
950	Black	Black	Black	Friable	Friable	Friable	No foul odor	No foul odor	No foul odor
1250	Black	Black	Black	Friable	Friable	Friable	No foul odor	No foul odor	No foul odor

3.3.2. Pellet Durability Index

Pellet quality is defined as the ability to resist fragmentation and abrasion during handling without breaking up to reach destinations without generating a high proportion of fines (Amerah, Ravindran, Lentle, & Thomas, 2007; Briggs, Maier, Watkins, & Behnke, 1999). Table 1 shows that different molasses-to-chicken-manure ratios (2:100, 3:100, and 4:100) and belt speeds (650 rpm, 950 rpm, and 1250 rpm) improved the Pellet Durability Index (PDI) at belt speeds when the molasses-to-manure ratio is higher from 2:100 to 4:100, indicating that a larger molasses concentration improves pellet durability. The highest PDI was consistently obtained at 950 rpm out of all the rotational speeds, suggesting that this would be the best speed to maximize pellet durability. Equitably, 1250 rpm demonstrated slightly less durability than 950 rpm, whereas 650 rpm typically produced the lowest PDI values. Additionally, the data is not significant, indicating consistent measurements. Notably, the best PDI (95.4%) was achieved at a molasses-to-chicken manure ratio of 4:100 and a rotational speed of 950 rpm. This combination appears to offer the most favorable conditions for producing durable chicken manure pellets. Concerning pelleted organic fertilizer, potential damage may occur during spreading using centrifugal fertilizer spreaders or during soil incorporation at sowing. Durability is high when PDI exceeds 80%, medium between 70% and 80%, and low below 70% (Amoah et al., 2024), and this is also comparable to the founding of pellet durability, which is > 80% (Pampuro et al., 2017). Therefore, with the highest recorded PDI of 95.40% and the lowest at 93.07%, both values surpass the 80% threshold considered high, indicating that the pellets can withstand repeated transfers in feed handling systems.

3.3.3. Pellet Moisture Content

Increasing belt speed, the moisture content peaks at 950 rpm (48.63%) for all ratios and then gradually decreases at 1250 rpm. Although the variations are insignificant at higher speeds, a greater molasses-to-chicken manure ratio (3:100 and 4:100) often yields a slightly higher moisture content than the 2:100 ratio. For the 2:100 ratio, the lowest moisture level (47.06%) was recorded at 650 rpm. According to these findings, pelletized chicken manure retains moisture best at 950 rpm and higher molasses concentrations (Table 1).

3.4. Economic Analysis

The estimated processing cost of ₱4.26 per kilogram of chicken manure is based on an economic analysis that takes advantage of economies of scale and accounts for fixed costs, including a machine cost of ₱51,891.15. With a flock of 40,000 adult chickens, each producing an average of 4.3 kg of manure monthly, the farm generates approximately 17,200 kg of manure per month. Over eight annual cycles, this amounts to 137,000 kg of manure with 75% moisture content, or 80,092 kg at 38% moisture content. The processing cost per kilogram of pelleted manure is calculated by dividing the total fixed and variable costs by the annual manure production, resulting in a cost of ₱4.26 per kg.

4. CONCLUSION

The study successfully demonstrated the effectiveness of a chicken manure pelleting machine in processing chicken manure into pellets. A complete analysis of the machine's performance, focusing on pelleting capacity, efficiency, and recovery across varying belt speeds (650, 950, 1250 rpm) and molasses-chicken manure ratios (2:100, 3:100, 4:100), provided significant insights into improving the pelleting process for organic fertilizer production.

The highest pelleting capacities were achieved at belt speeds of 1250 rpm, with outputs of 165.12 kg/hr, respectively. The highest pelleting efficiency was obtained with molasses-chicken manure ratios of 4:100, achieving efficiencies of 98.02%. Similarly, the highest pelleting recovery rates were observed with ratios of 3:100 and 4:100, resulting in pelleting recoveries of 98.29% and 98.23%, respectively. Given the machine's efficiency and a processing cost of ₱4.26 per kilogram, it is recommended to operate the machine at 1250 rpm with a 3:100 molasses-chicken manure ratio for optimal pellet production.

Considering the physical properties of the pelleted chicken manure, the highest IPD of 0.0019 g/mm³ was achieved at 650 rpm with a 3:100 ratio, while the highest PDI of 95.40% was obtained at 650 rpm with a 4:100 ratio. The belt speed significantly influenced pellet moisture content, with the lowest moisture content of 47.63% observed at 650 rpm. The optimal combination for achieving the highest IPD, PDI, and lowest moisture content was a belt speed of 650 rpm with a 3:100 molasses-chicken manure ratio.

Economically, the machine presents a viable solution for chicken manure pellet production, especially in the context of sustainable agriculture, where there is a growing demand for cost-effective and environmentally friendly fertilization methods. The machine exceeds the Philippine National Standard (PNS) for pelleting efficiency and recovery, as outlined in the Feed Pellet Mill Method of Test. To process the manure from 40,000 chickens, the machine requires 12 hours of continuous operation. The produced pellets passed the selected minimum requirements for the specification for organic fertilizer and compost/soil conditioner, specifically in color, consistency, and odor. However, it does not pass the recommended moisture content; therefore, it is recommended to dry the pelleted chicken manure to attain this standard. It is also recommended that testing of the organic matter content, C:N content, and Total NPK of the pelleted chicken manure be conducted for further data on the product for possible utilization.

Funding: This research was supported by the Department of Agricultural and Biosystems Engineering of the College of Engineering, Central Luzon State University, under the scholarship grant of the Department of Science and Technology Engineering Research for Development and Technology (DOST-ERDT) of the Department of Science and Technology - Science Education Institute (DOST-SEI).
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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