Journal of Mechanical, Electrical & Industrial Technology **Vol. 3, No. 1**
ISSN 3047-7778 **March 2026**

Performance evaluation of a locally-developed mini-corn (*Zea Mays L.*) milling machine

J.M. Limocon*, J. Salo, G. Salo
Bohol Island State University-Bilar Campus, College of Agricultural Sciences, Department of Agricultural and Biosystems Engineering, Zamora, Bilar, Bohol, Philippines
*6315, jessamae.limocon@gmail.com
** 6319, jamel.salo@bisu.edu.ph
** 6319, grace.salo@bisu.edu.ph

Abstract

Backyard farmers struggle with rising feed costs, limiting local feed production. As a result, they rely more on imported feeds, as commercial corn milling machines are expensive and suited for large-scale operations. The main objective of this study was to evaluate the performance of a locally developed mini corn milling machine for backyard livestock and poultry farmers. Specifically, it determines its capacity, recovery, particle size, noise level, and economic performance. The technical performance was laid out using Completely Randomized Design using two corn varieties: yellow and white. Statistical analysis using independent sample T-test showed that corn variety does not significantly affect the input capacity, output capacity, and recovery. However, it affects the performance in terms of milled corn particle size. The corn mill has an input capacity of 27.55 kg/hr and an output capacity of 27.03 kg/hr. The product recovery was 98.85%, and the noise emitted during the operation was 91.06 dB. The particle size of the milled corn constitutes 78.2% of $\geq$ 2mm, 10.9% of 2mm $< P \geq$ 1mm, 9% of 1mm $< P \geq$ 0.45mm, and 9% of $<$0.45mm. The machine had an operating unit cost of \$2.96 per hour or a total annual cost of \$46.02. The machine must mill at least 223.23 kg per year to break even all costs with a payback period of 3.7 years. Benefit-cost analysis showed that for every dollar spent on the machine, there is a \$1.5 return. The results indicate that the developed mini corn mill is suitable for small-scale corn milling operations.

Keywords: Mini-corn mill; Milled corn; Particle size, economic analysis

1. Introduction

Nutrients in feeds are necessary for high-quality production in livestock and poultry. Corn is the main feed ingredient in poultry animal feed production, accounting for 50-60% of the total mixed feed ration [1]. Corn has high nutritional quality not only for animal but for human consumption as well, which is the primary source of energy supplement, and can contribute up to 30% protein, 60% energy, and 90% starch, also with limited amino acids: lysine content of 30% and tryptophan content of 55% for poultry diets. White and yellow corn are two common varieties planted in the Philippines. Yellow corn contains carotenoids, which contribute to the yellowness of the egg yolk, a property that white corn does not have [2].

In the Philippine corn situation report (2022-2023), approximately 4,971.18 hectares of land were recorded for corn production, with an average landholding of 1.3 hectares [3]. Corn can account for up to 80% of the total feed costs in poultry production [4]. As of September 2022, the Philippine Statistics Authority (PSA) reported a total bird inventory of 200.21 million birds in the Philippines, including 19.99 million in Central Visayas, of which 8.91 million were native chickens [5]. However, the poultry producers are facing significant pressure from rising feed costs and escalating demand for poultry products, a pressure point that may be aggravated by limited local production and heavy reliance on imported feed products [6]

Most backyard farmers manage 10-50 heads and commonly produce poultry products primarily for household consumption and supplemental livelihood [7]. Postharvest operations for converting corn kernels into livestock and poultry feed include size reduction processes. A smaller particle size enhances nutrient digestibility, thereby improving feed energy conversion efficiency. Milling machines are available in the Philippine market; however, most are designed for village- and industrial-level operations, characterized by high capacity and high cost, making them unsuitable for individual ownership [8]. Therefore, a corn milling machine was designed and evaluated to match the farming scale of local farmers, aiming to reduce feed costs and create better livelihood opportunities.

The general objective of this study was to evaluate the performance of a mini-corn mill. Specifically, it aimed to assess capacity, product recovery, noise level, particle size distribution, and the cost of using the machine.

DOI 10.35991/mein.v3i1.71

2. Materials and methods

2.1. Machine major parts and principle of operation

The machine, shown in Figure 1, comprised five (5) major components: the hopper, milling assembly, discharge chute, frame, and transmission assembly. It has an overall dimension of 400 x 200 x 720 mm (L x W x H). The machine was designed to be operated by one (1) person, whose primary tasks are loading the kernels and sacking the milled corn. The operator would first turn on the machine by plugging it into an electric power source. Corn kernels are loaded into the hopper at the upper part of the milling assembly. It had a regulator to control the flow of kernels into the milling chamber. The cross-sectional shape of the hopper was a truncated pyramid (top section) and semi-cylindrical (bottom section). It was made from a 1.3 mm-thick galvanized iron sheet. It was fastened to the milling assembly using heavy-duty hinges.

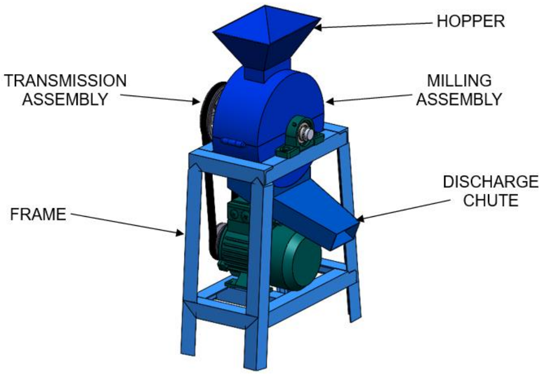

Figure 1. Design of the machine

The milling assembly, shown in Figure 2, consisted of a steel hammer mill mounted inside the cylindrical drum made from 3 mm-thick black iron (BI) sheets. Inside the drum, 12 steel hammers operate at 1,160 rpm. These hammers are attached to a 25mm shaft, which is connected to a revolving disc and a 150mm diameter pulley. Both components are secured to the main frame using pillow block bearings. Below the hammers, a 3 mm-thick retention screen with 6 mm holes allows the milled corn to pass through to the discharge chute. A belt-and-pulley system was used to transmit power to the milling assembly, with a center-to-center distance of 133 mm. The corn kernels were milled by the constant beating of the hammer mills, and the milled corn with a particle size below 6 mm exits through the discharge chute. The frame supports the entire structure of the machine, including the milling assembly and transmission assembly. It was constructed using angle bars and flat bars. It was designed to withstand the stresses and working loads during the operation.

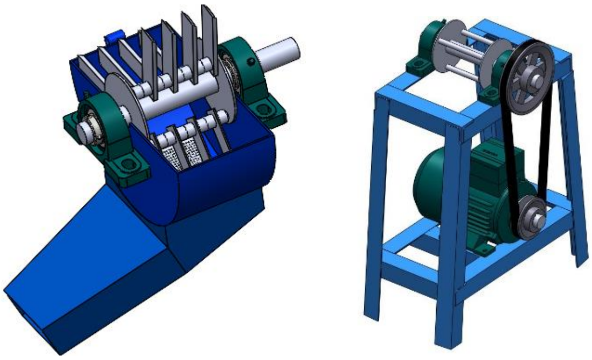

Figure 2. Milling assembly (left) and transmission assembly (right) of the mini-corn mill

2.2. Performance evaluation

The machine's performance parameters, in accordance with PAES 252:2021, were determined during the tests, including input capacity, output capacity, product recovery, and noise level [9]. Machine performance was evaluated using Completely Randomized Design across two corn varieties, white and yellow corn, with 5 replicates. The machine was operated at 1,160 rpm. The samples used were locally grown varieties of both white and yellow corn. The sample for each replication comprised five kilograms (5kg) and was randomly assigned among treatments, considering that good-quality corn kernels were included. It was randomly loaded into the hopper throughout the test. After the evaluation, three (3) 100-gram samples were collected per replication for particle size analysis. Sieving was done for one (1) minute using mesh sizes of 2 mm, 1 mm, and 0.45 mm. The particles retained on each sieve were weighed using a weighing scale. Raw data were collected during each trial, such as initial weight, final weight, machine loss, total final weight, operating time, noise level with and without load, and particle sizes ≥2mm, <2mm and ≥ 1mm, <1mm and ≥ 0.45mm, and < 0.45mm. The collected data were analyzed using an independent-samples t-test to determine the suitability of use of the two varieties for the mini-milling machine.

2.2.1. Input Capacity

It is the weight of corn kernels per unit loading time into the hopper/intake pit, expressed in kilograms per hour (kg/hr):

$$\text{Input Capacity} = \frac{\text{weight of clean corn kernel input (kg)}}{\text{Loading Time (hr)}}$$

2.2.2. Output Capacity

The weight of the milled products collected per unit of time, expressed in kilograms per hour (kg/hr):

$$\text{Output Capacity} = \frac{\text{weight of milled product (kg)}}{\text{output time (hr)}}$$

2.2.3. Main Product Recovery

The ratio of the total weight of the milled products to the total weight of the input corn kernel expressed in percentages (%), where k is the percentage of by-products present in the output from the main product outlets (in decimal form):

$$\text{Main Product Recovery} = \frac{\text{weight of main product (kg)x } (1 - \text{k})}{\text{weight of input corn kernels (kg)}} \text{x } 100$$

2.2.4. Noise Level

The sound emitted by the machine, with and without load, was measured using a sound level meter at the operator's location. The noise level, expressed in decibels (dB), was measured approximately 50 mm from the operator's ear level.

2.2.5. Particle Size

A 100-g sample of milled corn was collected for each replication to determine particle size distribution. The analysis was conducted in triplicate. Each sample was sieved for one (1) minute using a set of sieves with mesh openings of 2 mm, 1 mm, and 0.45 mm.

2.3. Cost Analysis

The economic performance of the machine was calculated based on unit cost of operation, annual cost, break-even cost, payback period, and benefit-cost ratio. The annual cost is the sum of the fixed and variable costs. Fixed costs include depreciation, interest on investment, property tax, insurance, and shelter/housing. Variable costs consist of labor, repair and maintenance, and power consumption. The break-even point, payback period, and benefit-cost ratio assess when total benefits offset total costs [10]. During the calculation of the cost of machine use, the following assumptions were considered:

1. the machine was used for six (6) hours per day, with annual use of 800 hours;
2. salvage value of ten percent (10%) of the materials and fabrication cost;
3. machine life of ten (10) years;
4. repair and maintenance of three percent (3%) of the materials and fabrication cost per hundred (100) hours of use;
5. interest rate in the investment of ten percent (10%) of the mean of the materials and fabrication cost and the salvage value of the machine; and,
6. labor costs of $7.30 per day.

2.3.1. Annual cost

It was computed using the equation:

$$\text{AC} = \text{AFC} + \left(\frac{\text{A}}{\text{C}} \times \text{VC}\right)$$

where: AC = annual cost of using the machine, $/yr
AFC = annual fixed cost of machine, $/yr
A = annual area where the machine was used, yr
C = annual field capacity, ha/hr

VC = variable cost, \$/hr

Annual fixed costs (AFC) are expenses incurred regardless of whether the machine is operated or not. These are interest on investment, property tax, depreciation, insurance, and shelter/housing. It was computed using the following formula:

$$\mathrm{AFC} = \mathrm{D} + \mathrm{I\ on\ I} + \mathrm{TIS}$$

where: D = depreciation, \$
I on I = interest on investment, \$
T.I.S. = taxes, insurance, and shelter, \$

Depreciation (D) refers to the reduction in the value of a machine over time, regardless of usage. Several methods for computing depreciation are outlined in Engineering Economy. The Internal Revenue Service (IRS) recommends the Straight-Line Method as the simplest and most straightforward. It allocates an equal depreciation amount each year and is calculated using:

$$\mathrm{D} = \frac{\mathrm{PP} - \mathrm{S}}{\mathrm{L}}$$

where: D = depreciation
PP = purchase price
S = salvage or selling price
L = time between buying and selling, yr

Interest on investment (I on I) is the amount of interest paid on loan proceeds used to purchase investments; even if money is not borrowed, it is included in operational cost estimates, since the money used to buy a machine cannot be used for other productive enterprises. It was computed using the following formula:

$$\mathrm{I\ on\ I} = \left(\frac{\mathrm{PP} + \mathrm{S}}{2}\right)\mathrm{i}$$

where: i = 10-20%
PP = purchase price
S = salvage or selling price

Farm machinery may be taxed at the same rate as other farm property. Wide variations exist from state to state in both sales tax amounts and assessed valuations. Property and sales tax would be about 1.5-2% of the purchase price. One who does not insure carries the risk alone, so farmers who invest in machinery must insure against losses due to injury, fire, theft, and other risks. Insurance is about 0.25% of the machine purchase price.

Farmers typically provide storage for their machinery to protect it from theft and harsh weather, which helps preserve functionality and extend the machine's lifespan. Proper housing also helps maintain the machine’s resale value. The cost of housing or shelter for farm machinery generally ranges from 1% to 2% of the machine's purchase price.

Variable cost is the cost that varies with use. Operator labor would be paid at a skilled labor rate. Actual operating costs include electricity consumption and repair and maintenance, estimated at 5% of the material and fabrication cost per 100 hours of use.

$$\mathrm{VC} = \mathrm{L} + \mathrm{O} + \mathrm{F} + \mathrm{R\&M}$$

where: VC = variable cost, \$/hr
L = labor cost, \$/hr
E = Electric consumption cost, \$/hr
R&M = repair and maintenance, \$/hr

2.3.2. Cost of Operation

Cost of Operation. The cost of operating the machine (Cu), expressed in \$/unit, can be calculated by dividing the annual cost equation (AC) by the annual weight where the machine was used.

$$\mathrm{Cu} = \frac{\mathrm{AFC}}{\mathrm{A}} + \frac{\mathrm{VC}}{\mathrm{C}}$$

where: Cu = cost of operation per unit, \$/unit
AFC = annual fixed cost, \$/yr
A = annual weight where the machine was used, yr
C = actual machine capacity, kg/hr

VC = variable costs, \$/hr

2.3.3. Break-even point

Break-even Point. A break-even point occurs when the profit covers the expenses, meaning no profit or loss. It is important to determine whether the machine is feasible to market to assess whether it generates enough income to cover its expenses. In the cost curve, we can plot the breakeven point. It was computed using:

$$\mathrm{A} = \frac{\mathrm{AFC}}{\mathrm{CR} - \frac{\mathrm{VC}}{\mathrm{C}}}$$

where: A = break-even point, kg/yr
AFC = Annual Fixed Cost, \$/yr
CR = Custom rate, \$/kg
VC = Variable cost, \$/hr
C = Capacity, kg/hr

2.3. Payback Period

Payback Period. This is the required time to recover the cost of investing, such as the cost of the machine. It was calculated using the following equation:

$$\mathrm{PP} = \frac{\mathrm{IC}}{\mathrm{NI}}$$

where: PP = Payback period, yr
IC = Investment cost, \$
NI = Net income, \$/yr

2.3. Benefit-cost ratio

Benefit-Cost Ratio. The benefit-cost ratio (BCR) of the machine is the discounted value of the machine's annual benefits divided by the discounted value of the machine's annual costs. It is an accepted procedure for making go/ no-go decisions compared to alternatives. If the value of BCR is greater than 1, it is feasible.

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

where: B_t = total benefit at any time t, \$
C_t = total cost at any time t, \$
i = is the discount rate, in decimal form
n = lifespan of the machine, year(s)

3. Results and discussion

3.1. Machine Description

The fabricated mini-corn milling machine is presented in Figure 3. The machine comprised of a hopper, a milling assembly, a discharge chute, a frame, and a transmission assembly powered by a 1.5 hp electric motor. Loading of corn kernels takes place in the hopper. The milling assembly, composed of twelve hammers, milled the corn kernels with constant beating, and the milled corn with a particle size below 6 mm exits through the retention screen and the discharge chute.

Figure 3. Photographic view of the mini-corn milling machine

3.2. Performance of the machine

The results of the technical test are presented in Table 1. The input capacity of the mini corn mill was 25.39 kg/hr using white corn and 27.55 kg/hr using yellow corn. The corresponding mean output capacities were 25.12 kg/hr and 27.03 kg/hr for white and yellow corn, respectively. The mean product recovery was 98.55% for white corn and 98.22% for yellow corn. The noise level emitted by the machine without a load was 81.2 dB. On the other hand, the noise level while milling yellow corn was recorded at 102.8 dB, while white corn produced a slightly lower level of 101.86 dB. Concerning particle size distribution, white corn has 76.8% for size greater than or equal to 2 mm, 10.6% between 2 mm and 1 mm, 6.3% between 1 mm and 0.45 mm, and 6.3% smaller than 0.45 mm. On the other hand, the particle size of milling yellow corn was 71.1%, 10.9%, 9%, and 9%, respectively.

Table 1. Machine performance using white and yellow corn varieties

Performance Parameter	White Corn	Yellow Corn	p-value
Input Capacity, kg/hr	25.39	27.55	0.554 ns
Output Capacity, kg/hr	25.12	27.03	0.594 ns
Product Recovery, %	98.85	98.22	0.493 ns
Noise Level without Load, dB	81.32	81.08	0.779 ns
Noise Level with Load, dB	101.86	102.80	0.427 ns
Particle Size, P			
$P \geq 2mm$	78.2	74.2	0.001**
$2mm < P \geq 1mm$	10.8	11.4	0.217 ns
$1mm < P \geq 0.45mm$	6.4	9.4	0.011*
$P < 0.45mm$	6.4	9.4	0.874 ns

* means are different at 5% level of significance.
** means are different at 1% level of significance
ns means are not significantly different

Statistically, the machine performance was significantly affected by particle size ($P \geq 2$ mm, p = 0.001 and $1mm < P \geq 0.45mm$, p-value = 0.011). This is likely due to differences in the mechanical properties of corn kernel varieties [11]. Furthermore, regarding input capacity, output capacity, main product recovery, and noise level, no significant differences were observed in the performance of the machine across corn varieties (both white and yellow). These results are similar to those of Gragasin et al., who found that corn varieties do not affect machine capacity or product recovery [12]. While the machine's noise level was slightly above the PAES 251:2021 threshold of 100 dB, the difference is minimal [13]. Hence, the machine can be operated for both white and yellow corn varieties with satisfactory results.

The total fabrication cost of the mini corn mill was $258.32. Based on the assumptions, the cost analysis results in an operating unit cost of $2.96 per hour or a total annual cost of $45.22. As shown in the cost curve shown in Figure 4, a minimum custom milling rate of $0.31 per kilogram will require the machine to mill at least 223.23 kg per year to break even all costs with a payback period of 3.7 years. The machine's benefit-cost ratio considering the custom rate of operation is 1.5.

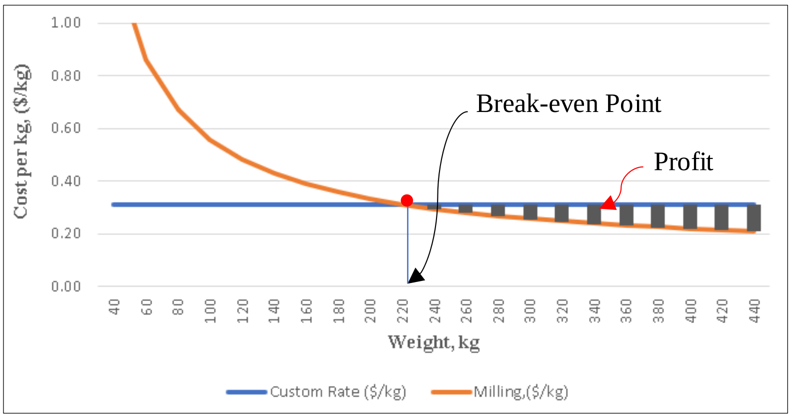

Figure 4. Cost curve of using the mini-corn mill

4. Conclusion

The results of the study, under controlled conditions, led to the following conclusions: performance was not affected by the variety used in terms of input capacity, output capacity, product recovery, and noise level; the particle sizes of the yellow and white corn varieties, however, were significantly affected; the machine can be operated for both white and yellow corn varieties; and based on the assumptions made, the machine is economically feasible for individual and group ownership, such as cooperative and farmers' associations.

Moreover, to further enhance the machine's performance, an optimization study on operating speed should be conducted to address its low processing capacity. Future investigations may consider using a higher-power-rated electric motor to improve overall performance.

Credit authorship contribution statement

Jessa Mae Limocon: Conceptualized and conducted the study, analyzed and interpreted the data, and prepared the original manuscript. **Jamel Salo**: Supervision, Writing – review & editing. **Grace Salo**: Scholarly suggestion, review, and proofreading.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The researchers extend their sincere gratitude to the Bohol Island State University, Bilar Campus administration for their support, which greatly contributed to the completion of the study.

References

[1] M. Dayo, "Quality Protein Maize (QPM): A High Protein Corn for Swine and Poultry," *Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD)*, Philippines, Aug. 2015.

[2] A. Akinbobola, "Difference Between White and Yellow Corn / Maize," 2019. Accessed: Apr. 26, 2025. [Online]. Available: https://www.livestocking.net/nutritional-difference-white-maize-yellow-maize-effect-poultry-birds

[3] G. Calimuhayan, "Corn Situation Report, Annual (2022-2023)," *Philippine Statistics Authority-Cordillera Administrative Region*, Philippines, Apr. 30, 2024.

[4] M. Miraflor, "Rising prices of animal feed ingredients push meat prices higher," *Manila Bulletin*, Philippines, Feb. 22, 2021. Accessed: Apr. 26, 2025. [Online]. Available: https://mb.com.ph/2021/2/22/rising-prices-of-animal-feed-ingredients-to-push-meat-prices-higher

[5] PSA, "Chicken Situation Report July to September 2022," *Philippine Statistics Authority* , Philippines, Dec. 29, 2022.

[6] USDA, "Livestock and poultry: World Market and Trade," *United States Department of Agriculture, Foreign Agricultural Service*, United States, pp. 1–25, Apr. 10, 2025.

[7] G. Enario, "Assessing the Utilization of Indigenous Feed Alternatives by Backyard Poultry Farmers: A Survey in Zamboanga del Sur, Philippines," *International Journal of Scientific Research and Management (IJSRM)*, vol. 13, no. 06, pp. 04–16, Jun. 2025, doi: 10.18535/ijsrm/v13i06.p01.

[8] E. N. Dominguez, “Design, Fabrication, and Performance Evaluation of a Hammer Mill for Small-Scale Corn Milling Operation,” *International Research Journal of Innovations in Engineering and Technology*, vol. 05, no. 09, pp. 46–50, 2021, doi: 10.47001/irjiet/2021.509007.
[9] PAES 252, “Corn Mill - Methods of Test,” *Philippine Agricultural Engineering Standards (PAES)*, pp. 1–25, 2021.
[10] D. Hunt, *Farm Power and Machinery Management*, 10th ed. Edition Iowa State University Press, 2121 South State Avenue, Ames, IOWA 50014, 2001.
[11] M. A. F. AbdEl Maksoud, “MECHANICAL PROPERTIES OF CORN KERNELS,” *Misr Journal of Agricultural Engineering*, vol. 26, no. 4, pp. 1901–1922, Oct. 2009, doi: 10.21608/mjae.2009.107576.
[12] M. A. Gragasin, I. V. Salapare, J. P. Illustrisimo, and R. C. Martinez, “Design, Testing and Evaluation of Mobile Corn Mill for Village-Level Operation in the Philippines,” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 8, no. 2, p. 604, Apr. 2018, doi: 10.18517/ijaseit.8.2.3306.
[13] PAES 251, “Agricultural Machinery-Corn Mill-Specifications,” *Philippine Agricultural Engineering Standards (PAES)*, pp. 1–9, 2018.