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Development of Corn Mill for Village-Level of Operation

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ABSTRACT--- ***This research has successfully developed and field-tested an innovative corn mill with milling capacity of 260 kgh^{-1}. Majority of the available village-type corn mills in the Philippines have failed to meet the minimum 'product recovery' and 'degerminator efficiency' of 64% and 80%, respectively, as set by the Philippine Agricultural Engineering Standard (PAES). This resulted to the production of poor quality corn grits with high postharvest losses. The poor quality of corn grits discourages consumers who used to eat corn as their staple food. Facing these challenges, this research aimed to improve the design of village-type corn mill to satisfy the quality standard of PAES for corn mill. Performance tests results revealed that the developed technology is technically and financially viable. It has an output capacity of 240 kgh^{-1}, product recovery of 64.2-72.3% and degerminator efficiency of 81.2-91.5%. It is capable of producing good quality corn grits. Estimated operating cost per kg output of the developed corn mill technology is Php1.09 (US$1=Php48). The estimated financial internal rate of return of investing in the technology is 84.7%. Given its technical and financial viability, the newly-developed technology provides opportunities in ensuring the availability and accessibility of affordable good quality corn grits. This can lead to wider and sustainable consumption of corn grits as staple food in the country.***

Keywords: Corn mill, Zea mays, dry-milling, postharvest

1. INTRODUCTION

Corn is the second most important crop in the Philippines [1] and has been referred to as "the cereal of the future" because of its high nutritional value and wide utilization of its products and by-products [2]. White corn is the staple food of 15% of the total population in the country, while yellow corn is primarily used as feeds for livestock and poultry.

Village-type corn mills are widely used in the production of corn grits. Corn grits are milled corn kernels where the tip cap, outer covering, and germs have been removed and with particle size of not less than 0.86 [3]. A kernel of corn is comprised of four main parts, namely: pericarp (also referred to as hull), germ, tip cap, and the endosperm [4]. Corn grits product is achieved after the corn kernels have passed through the degermination, milling, and sorting processes.

The Philippine Agricultural Engineering Standard for corn mill requires that the performance of the machine should provide a minimum 'degerminator efficiency' of 80% and minimum 'main product recovery' of 64% [3]. Corn mill with 'degerminator efficiency' of lower than 80% indicates the production of poor quality corn grits given the high presence of pericarp, tip cap, and germ in the product. Likewise, corn mill with 'main product recovery' of less than 64% indicate the incidence of postharvest losses during milling operation.

Performance test results conducted by the Agricultural Machinery Testing and Evaluation Center (AMTEC) reveals that existing village-type corn mills in the country have not fully satisfied the prescribed Philippine Agricultural Engineering Standard (PAES) for corn mill, particularly on the minimum 'degerminator efficiency' and 'main product recovery' of 80% and 64%, respectively [3]. Under Philippine Law, AMTEC is a duly recognized and independent body that conducts testing of agricultural machineries.

Results of ex-ante evaluation reveals that in addition to the major problems concerning low product recovery and poor quality of corn grits, other major problems concerning the design of existing corn mills were the following: (i) difficulty of starting the engine especially if it is already engaged to the major components of the corn mill; (ii) a mismatch of its high input capacity with respect to its very low output capacity indicating inefficiency in its milling mechanism; and, (iii) high power requirement of the corn mill machine that resulted to high operating cost per kilogram output.

Majority of these village-type corn mills have milling capacity of 120-200 kgh^{-1} and uses different methods of milling corn grits. Its primary design is based on the principle of dry-milling process which is a modification to the dry-milling method [5,6,7,8] due to the omission of tempering of corn kernels before dehulling or degermination process. These village-type corn mills use emery stone or steel huller to degerminate corn kernels and adopt steel rollers to grind degerminated corn into small pieces. For its sorting mechanism, they all adopted the traditional oscillating type that requires huge power requirement.

Facing the many challenges that impinge the performance of existing village-type corn mills, it is imperative to develop a new design of village-type corn mill to improve the quality and recovery of corn grits. As such, the purpose of this research was to develop a village-type corn mill that conforms to the technical specifications of PAES and ensures the economic viability of the technology. It is expected that the widespread utilization of technically and economically viable corn mill in the countryside will contribute in providing good quality corn grits in the market.

2. METHODOLOGY

2.1 Evaluation of Existing Village-type Corn Mill

Existing corn mills specifically designed in the production of food were identified for characterization and evaluation. During the conduct of evaluation, the strength, weaknesses, and functionality of the current designs were fully observed. The results of the performance testing individually conducted by AMTEC on these corn mills have also served as reference during the evaluation. Corn samples used during the testing of these existing corn mills were limited to 5 kg and for one trial only due to the limitation of available samples that were brought in the different test areas in Luzon, Visayas, and Mindanao where these corn mills were located. For all the test trials conducted, the same variety was used and originated from the same lot.

2.2 Design and fabrication

The concept of the new design of corn mill was drawn through AutoCAD, detailing its major parts and components. A laboratory small-scale model was fabricated and tested to determine the performance of such new design under laboratory condition. Debugging and modifications were conducted on the different components of the proto-type laboratory unit until the desired performance of the corn mill was achieved in terms of the quality and quantity of corn grits produced.

The upscale model of the final design of the corn mill including its different parts and components were again drawn through AutoCAD. The AutoCAD drawings have served as reference in the fabrication of the final prototype unit and to clearly visualize the initial design of the corn mill in three dimensional perspectives. The fabrication of the different parts and components of the corn mill were all undertaken at the fabrication shop of PHilMech.

2.3 Performance testing

The technical performance of the corn mill was evaluated following the laboratory method of test for corn mill [9]. The parameters used in establishing the performance of the corn mill are as follows:

$$\text{Input Capacity } (kgh^{-1}) = \frac{Weight\ of\ corn\ kernel\ input\ (kg)}{Total\ loading\ time\ (h)} \quad (1)$$

$$\text{Output Capacity } (kgh^{-1}) = \frac{Weight\ of\ main\ product\ (kg)}{Output\ time\ (h)} \quad (2)$$

$$\text{Milling Capacity } (kgh^{-1}) = \frac{Weight\ of\ corn\ kernel\ input\ (kg)}{Total\ operating\ time\ (h)} \quad (3)$$

$$\text{Main Product Recovery } (\%) = \frac{Weight\ of\ main\ product\ (kg)}{Weight\ of\ input\ (kg)} \text{x}100 \quad (4)$$

$$\text{Main By-product Recovery } (\%) = \frac{Weight\ of\ by-product\ (kg)}{Weight\ of\ input\ (kg)} x\ 100 \quad (5)$$

$$Electric\ Energy\ Consumption\ (kWh) = Power\ consumed\ (kW) x\ Time\ operation\ (h) \quad (6)$$

The duration of each trial started with feeding of corn kernels in the intake hopper and ends after the last discharge from the output chute. The speeds of the rotating shafts were monitored using a tachometer. A digital clamp meter was used in monitoring and measuring the voltage and electric current during operation, while an electric meter was used in measuring the amount of electric energy consumed.

2.4 Laboratory Analysis

The main product and the by-products of the corn mill were analyzed in the laboratory following the laboratory method of test for corn mill [3]. As set by PAES, three samples weighing 100 grams each were collected from the degerminator outlet, rotary mill outlet, and the outlet chutes of the rotary sifter for physical laboratory analysis. Laboratory analysis were undertaken to determine the 'degerminator efficiency', losses, and percentage of corn grits of other sizes from each outlet. 'Degerminator efficiency' is defined as the ratio of the weight of degerminated corn kernel sample, to the initial weight of the sample, expressed in percentage [3].

2.5 Experimental Design and Statistical Analysis

The performance of the developed machine, i.e., input capacity (kgh^{-1}), output capacity (kgh^{-1}), main product recovery (%), power consumption, 'main product recovery' (%), and 'degerminator efficiency' (%) were compared according to the different design parameters of each component of the developed corn mill technology. Likewise, the performance of the developed corn mill technology in terms of its 'degerminator efficiency' and 'main product recovery' was compared to the set minimum quality standard for corn mill.

The data gathered were consolidated and analyzed using Analysis of Variance (ANOVA). Statistical analysis was performed using Statgraphics Plus, a statistic package software that performs and explains basic and advanced statistical functions.

2.5 Economic analysis

The economic viability of the corn mill was determined using the Internal Rate of Return (IRR). The IRR is an indicator to measure the financial return on investment of an income generation project and is used to make the investment decision [10]. The IRR is obtained by equating the present value of investment costs (cash out-flows), and the present value of net incomes (cash in-flows). This can be shown by the following equality:

$$I_0 + \frac{I_1}{(1+r)^1} + \frac{I_2}{(1+r)^2} + \cdots . + \frac{I_m}{(1+r)^m} = \frac{B_1}{(1+r)^1} + \frac{B_2}{(1+r)^2} + \cdots . + \frac{B_m}{(1+r)^m}$$

$$\sum_{n=0}^{m} \frac{I_n}{(1+r)^n} = \sum_{n=1}^{m} \frac{B_n}{(1+r)^n}$$

where; I_0 is the initial investment costs in the year 0 (the first year duringwhich the project is constructed) and I_1 ~ I_m are the additionalinvestment costs for maintenance and operating costs during the entireproject life period from year 1 (the second year) to year m.B_1 ~ B_m are the annual net incomes for the entire operation period(the entire project life period) from year 1 (the second year) to year m.

By solving the above equality, the value of r or commonly known as the Internal Rate of Return(IRR) was obtained.

3. RESULTS AND DISCUSSION

3.1 Aspect of Design

To address the problems of existing village-type corn mills, the following were fully considered in coming up with a new design: (i) utilization of electric motor to resolve the difficulty of starting the engine of the corn mill; (ii) outright separation of germ, tip cap, and hull from the endosperm during the degermination process to improve the quality of corn grits and increase its capacity; (iii) adoption of hammer mill's basic design instead of using steel roller or steel huller to minimize the high production of corn flour during milling, thereby, achieving higher product recovery; (iv) development of new type of sorter instead of heavily relying on the design of traditional oscillating-type to reduce the power requirement of the corn mill machine; and, (v) the installation of a discharge outlet after the degermination process to easily check the condition of the degerminated kernels.

In line with this, the process flow of the corn mill design is shown in Figure1. The major components of the designed village-type corn mill are as follows (Figure2): (i) the degerminator assembly, (ii) the milling assembly, and (iii) the rotary sorter assembly. Likewise, the corn mill is also equipped with the following primary components, as follows: (i) blower for the suction of germ, hull, and tip cap from the degerminator chamber and directing these corn by-products to the cyclone; (ii) separate input hoppers that serve as storage bins for corn kernels and degerminated corn kernels before flowing directly to the degerminator assembly and milling assembly through gravitational force, respectively; (iii) the electric motors that serve as the prime-movers of the major components of the corn mill; (iv) control panel that contains the "on" and "off" push bottom switches of the degerminator assembly, milling assembly, rotary sorter assembly, and the blower including the emergency switch for ease of operation and to ensure the safety of the operator.

The major and primary components of the corn mill are lodged in a mainframe with a leveller installed at the bottom of the corn mill.

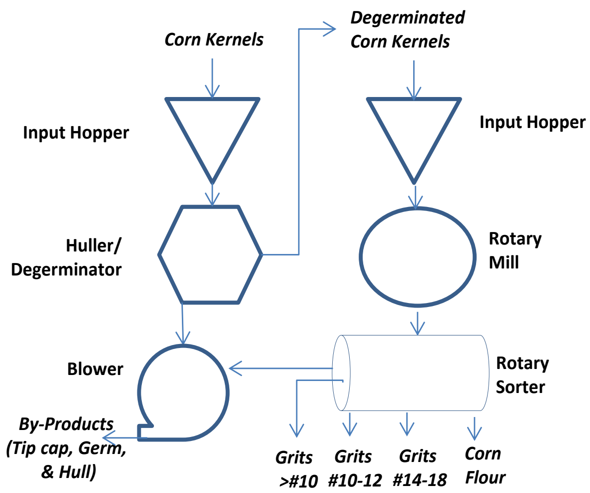

Figure 1: Design of the Village-Type Corn Mill

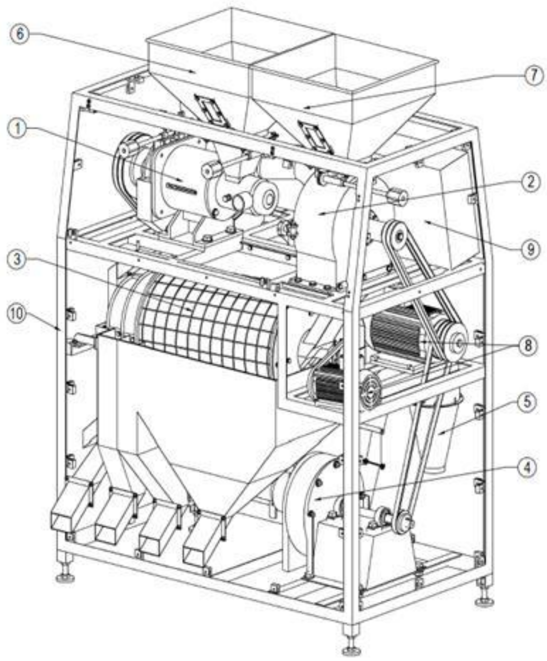

Figure 2. Design of the Village-Type Corn Mill

3.2 Performance Evaluation of the Developed Corn Mill

During the laboratory testing of the major components of the prototype unit of the corn mill, the performance of each component were fully observed and several modifications were undertaken until the desired output have been achieved, as follow:

3.2.1 Huller-Degerminator Mechanism

In the initial design, emery stone was used in the degerminator assembly. However, after the field testing in Cataingan, Masbate, Philippines wherein a total of 1,228 kg of corn grains were milled, the Emery Stones were partly torn. As such, the degerminator assembly was redesigned using a more durable material, a carbon steel hexagonal dented screen huller for its abrasive mechanism with counter flow steel auger.

The technical performance of the Dented Screen Huller was tested and compared with the Emery Stone during laboratory test trials. As shown in Table1, the performance of Dented Screen Huller was significantly more superior than the Emery Stone in terms of milling capacity and output capacity. While the Emery Stone could produce higher input capacity of 257.6 kgh^{-1} than that of Dented Screen Huller at 201.7 kgh^{-1}, the latter can provide higher output capacity of 149.2 kg/h than the former due to its higher milling recovery of 80%. The difference in milling recovery reveals the inefficiency of emery stone-type as dehuller/degerminator of a corn mill.

Table - 1. Performance of corn mill using different types of dehuller-degerminator mechanism

Performance Parameters	Emery Stone	Dented Screen Huller
Input Cap. (kgh^{-1})	257.6^{a}	201.7^{a}
Output Cap. (kgh^{-1})	85.5^{a}	149.2^{b}
Milling Rec. (%)	71.3^{a}	80.0^{a}
Milling Cap. (kgh^{-1})	119.9^{a}	181.7^{b}
Degerminator Eff. (%)	91.5^{a}	94.7^{a}

Note: Means across row having the same super script are not significantly different at 5% level.

It was observed during the series of test trials that the clearance between the rotating auger and the hexagonal dented screen huller of the degerminator is highly critical on the performance of the corn mill taking into full consideration the utilization of a 5-hp electric motor, single-phase for its prime mover. Table2 shows the result of the laboratory test trials on the performance of the corn mill with different clearances between the rotating auger and the hexagonal dented screen huller of the degerminator. The results revealed that by limiting the inflow of corn grain inside the degerminator from 444.6 kgh^{-1} to only 324.9 $kgh^{-1}$by adjusting the clearance between the auger and the dented screen huller from 13mm to 9mm, the product recovery and degerminator efficiency of the corn mill have significantly improved to 79.3% and 82.8%, respectively.

Table - 2. Performance of corn mill usingdifferent clearance between the augerand the dented screen huller

Milling Performance Parameters	Clearance	
	9 MM	13 MM
Milling Recovery (%)	79.3^{a}	76.9^{a}
Degerminator Efficiency (%)	82.8^{a}	74.7^{a}
Input Capacity (kgh^{-1})	324.9^{a}	444.6^{b}
Output Capacity (kgh^{-1})	216.2^{a}	237.5^{a}
Milling Capacity (kgh^{-1})	261.0^{a}	290.2^{a}
Current Reading (dominant)	11.2^{a}	32.1^{b}

Note: Means across row having the same super script are not significantly different at 5% level.

On the other hand, the results indicated that having a clearance of 13 mm between the rotating auger and the hexagonal screen huller would yield a sub-standard corn grits output of the corn mill with degerminator efficiency of 74.7% only. Likewise, it was observed that having a clearance of 13 mm between the auger and the hexagonal screen huller would result to the over loading of the capacity of the electric motor. The dominant electric reading of the 5-hp electric motor was 32.1 amperes during the trial for 13 mm clearance which is far above the safe full electrical load of 20.6 amperes for a 5-hp electric motor, single-phase.

Based on the results of performance tests, therefore, the setting of 9 mm clearance between the rotating auger and the hexagonal dented screen huller was adopted as part of the design of the degerminator component of the corn mill given the utilization of a 5-hp electric motor as prime mover of the degerminator assembly.

3.2.2 Milling Mechanism

The milling mechanism of the corn mill is basically a hammer mill type wherein the blades are made of T-shape, 2 mm thick and 45 mm wide stainless steel. The blades are sharpened at both sides to chop degerminated corn kernels and blown into small particles as it impact to the front wall casing of the rotary mill assembly. The principle of chopping instead of grinding is adopted to increase the corn grits recovery and minimize the production of corn flour. Note that the corn flour is a by-product of corn grits [3] while grits bigger than size #10 necessitates to be reverted back to the rotary mill to reach the prescribed grit size of #10-18. The Philippine Agricultural Engineering Standard - Corn Mill Specification defined Corn Grits #10 as milled corn kernels with particle size between 1.8 mm to 2.0 mm; Corn Grits #12 as milled corn kernels with particle size between 1.5 mm to 1.7 mm; Corn Grits #14 as milled corn kernels with particle size between 1.2 mm to 1.4 mm; Corn Grits #16 as milled corn kernels with particle size between 1.10 mm to 1.19 mm; and, Corn Grits #18 as milled corn kernels with particle size between 0.86 mm to 1.09 mm [3].

To test the performance of the rotary mill using different number of blades with 3-hp, single-phase as the prime mover for the blower and the rotary mill, laboratory trials were pursued. Using the same mill speed of 3,000 rpm and screen with slot width of 4mm to all test trials, the results reveal that the utilization of 68 blades can significantly improve the production of corn grits with less corn flour than by using 44 blades. Table3 shows that the corn grits recovery of the rotary mill with 68 blades is 89.5% of the total output with 10.5% corn flour.

Table3.Average grits recovery at various number of blades of the rotary mill

Number of Blades	Grits Recovery (%)	% Flour (%)
44	84.6[a]	15.6[a]
68	91.1[b]	8.87[b]

Note: Means across column having the same super script are not significantly different at 5% level.

In order to verify whether the size of the slot width of the screen can significantly affect the performance of the rotary mill, laboratory test trials were also conducted for this purpose. The results of performance tests (Table4) reveal that by using a screen with sloth width of 2 mm, 20.9% of the corn grits were converted into corn flour. It was observed that as the degerminated corn kernels were cut and blown into smaller particles by the rotary blades, corn grits with size greater than the slot with of the screen remain at the top of the screen and as such, expose to further milling by the rotary mill. Therefore, the screen with slotted width of 4mm is adopted for the rotary mill given the smallest flour yield of 8.9%.

Table 4. Average grits recovery at different type of screen used in the rotary mill

Type of Screen	Grits Recovery (%)		Flour (%)	Dominant Load Ampere (A)
	Grits greater than No. 10	Main Product Recovery		
2 mm	0.05 [a]	79.05 [a]	20.90 [a]	16.40 [a]
3 mm	35.38 [b]	53.07 [b]	11.55 [b]	14.43 [b]
4 mm	45.18 [c]	45.96 [c]	8.87 [b]	16.70 [a]

Note: Means across column having the same super script are not significantly different at 5% level.

3.2.3 Sorting Mechanism

The sorter of the developed corn mill has adopted the principle of the design of a grader for gravel and sand. In the design, three layers of rotating cylindrical screens were used to efficiently sort corn grits sizes of greater than #10, #10-12, #14-18, and the corn flour. The cylindrical screens were inclined by 3 degrees to allow the grits to freely flow downward during sorting.

As shown in Table5, the design of the corn mill could sort corn grits with size #6-8, #10-12, #14-18, and corn flour. Based on the results of test trials conducted, the dominant product of the developed corn mill is grits greater than #10 followed by grits #10-12. As shown in the table, only 10.5% of the total degerminated corn kernels are transformed into corn flour indicating that the design of the corn mill's milling mechanism is efficient in producing corn grits with little production of corn flour, thereby, generating higher corn grits recovery.

Table5.Percent composition of corn grits and flour produce by the developed corn mill

Corn Grits Sizes	Average (%)
Grits # 7, 8	33.0
Grits # 10, 12	41.8
Grits # 14, 16, 18	14.7
Corn Flour	10.5
Total	100

3.3 Technical Features of the Developed Corn mill

Overall, the improved corn mill has a milling capacity of 250-270 kgh^{-1}. Its 'degerminator efficiency' of 82.0- 94.7% and 'main output product recovery' of 64.7-71.0% have both fully satisfied the minimum technical specifications for corn mill as set by PAES [3].

The utilization of electric motors for its prime mover, instead of using gasoline or diesel engine that requires heavy force for manual start-up of the engine, was undertaken to pave the way for the installation of push-button switches to ease the operation of the corn mill. Majority of villages in the remote areas in the Philippines that traditionally consume white corn grits as their staple food have ready access to electricity.

The developed corn mill is capable of producing corn grits #6-8, #10-12, #14-18, corn flour, and degerminated corn. The compact corn mill requires only a small working space. The developed corn mill has a total length of 157 cm, width of 116 cm, height of 192 cm and with a total weight of around 530 kg. The corn mill can be operated by one person.

3.4 Economic Analysis

Based on the technical performance of the developed corn mill machine, the economic viability of the corn mill was analyzed. The results of the estimation, as shown in Table-6, reveal that the total cost of milling per kilogram output is estimated at Php1.09 (US$1=Php48) which is far below the existing milling fee of Php2.25-3.00 per kg of corn kernels loaded in the corn mill. It is noteworthy to mention that the current scheme used by corn millers in collecting milling fee is based on the total weight of corn grain loaded to the corn mill and not based on the corn grits milled. Therefore, the current milling fee of Php2.25-3.00 per kg (input basis) is actually equal to Php3.50-4.70 per kg based on product recovery of 64%. The milling fee currently being charged by the rice millers is only Php1.75-2.50 per kg (output basis).

Even using a milling fee of Php2.0 per kg (output basis), the estimated profit is about Php0.91 per kg, the difference between the estimated milling cost per kg output as shown in Table6 and the assumed milling fee of Php2.00 per kg. This is equivalent to total projected annual income of Php138,378 for a total annual capacity of the corn mill of 152,064 kg. From this, the estimated payback period is 2.54 years. The internal rate of return of investment is estimated at 84.70%.

Table6. Annual operating cost per kg output of the corn mill[1/], In peso per year (US$1=Php48)

Particulars	Amount
I. Fixed Cost	43,750
Depreciation Cost	26,250
Repairs and maintenance	17,500
II. Variable Cost per Year	122,681
Electricity	73,181
Labor	49,500
III. Total Cost per Year	166,431
IV. Total milling cost per kilogram output	1.09

1/Assumptions used in the computation:
Input Capacity: 300 kgh^{-1}Output Capacity: 192kgh^{-1}
Operating time per yr: 792h Total capacity per yr: 152,064 kg
Investment cost: Php350,000Power requirement: 6.6 kwh^{-1}
Lifespan of corn mill: 10 yrDepreciation cost: 10% of investment
Days of operation per yr: 198 d at $4hd^{-1}$
Repairs and maintenance: 5% of investment cost
Profit= milling fee of Php2.25/kg - Total operating cost

4.CONCLUSIONS AND RECOMMENDATION

Based on the laboratory and field trials, this research has successfully developed an innovative compact corn mill with milling capacity of 260 kgh^{-1}. The corn mill has an output capacity of 240 kgh^{-1} with 'main product recovery' of 64.7-72.3%. The 'degermination efficiency' of the corn mill is high at 81.2-94.7%. Test results revealed that the technical specifications of the corn mill have fully satisfied the Philippine Agricultural Engineering Standard (PAES) for corn mill in terms of minimum 'main product recovery' of 64% and 'degermination efficiency' of 80%.

The newly developed village-type corn mill technology features a degerminator mechanism using a hexagonal dented screen huller with counter flow auger and an innovative rotary sorter mechanism by introducing a three-layer rotary slotted hole perforated sheet cylinder. Both of these newly designs are not found in any village-type corn mill in the Philippines. This research has likewise improved the design of hammer mill using 68 blades that is made of flat steel bars, sharpened at both sides to efficiently mill degerminated corn kernels into corn grits. The developed corn mill machine is user-friendly with the installation of push-button switches in the control panel of the corn mill.

The efficiency of the developed technology can be easily detected to the cost of milling per kilogram output, which is estimated at Php1.09 per kg. Prevailing milling fee in the country ranges from Php3.50-4.70 per kg (output basis). The massive diffusion of the technology will hopefully reduce the prevailing milling fee in the countryside.

The result of economic analysis revealed that the technology is economically viable given an internal rate of return of investment of (IRR) of 84.7% and payback period of 2.5 years.

Given the technical and economic viability of the corn mill, the aggressive commercialization of the newly developed technology is imperative. This is to minimize postharvest losses incurred by inefficient available village-type corn mills that failed to pass the quality standard for corn mill.

Facing the many challenges in the country's agriculture, the newly-developed technology can provide solutions and opportunities in ensuring the availability and accessibility of affordable good quality corn grits. This can lead to the wider and sustainable consumption of corn grits as staple food in the country.

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