PILOT-TESTING OF DEVELOPED VILLAGE-LEVEL COMPACT CORN MILL IN THE PHILIPPINES

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ABSTRACT
A new type of efficient corn mill is needed in the Philippines to produce good quality corn grits at higher milling recovery. All of the corn mills currently being used are old and antiquated that were established as early as 1960s. As such, a newtype of corn mill was developed to address the inherent technical problems of existing corn mills. The developed corn mill was pilot-tested in key corn areas in the Philippines to further improve and establish the technical feasibility and financial viability of the developed technology. The results of test trials revealed that the technical performance of the corn mill has significantly improved based on the initial output of the corn mill per unit of energy used, from 38.6 kg/kW to 43.9 kg/kW. The improvement in the technical performance has significantly reduced the milling cost per kilogram by 19 percent, from Php1.18 to Php0.95/kg (US$ 1=Php48). The estimated payback period in investing on the technology is two years and 6 months with internal rate of return of 68.6 percent. The developed corn mill technology could address the lack of appropriate village-level corn mill in the countryside.

Keywords: corn mill, Zea mays, corn processing, agricultural machinery, technological change, commercialization.

INTRODUCTION
The challenge facing agricultural engineers working on the improvement of existing corn mills in the Philippines is how to produce good quality corn grits without sacrificing milling recovery. Corn mill is being used to process corn kernels to produce good quality corn grits. Corn grits is the staple food of 15 percent of the total population in the Philippines.

Performance test results conducted by the Agricultural Machinery Testing and Evaluation Center (AMTEC) revealed that existing village-type corn mills in the country have not fully satisfied the prescribed Philippine Agricultural Engineering Standard for corn mill, particularly on the minimum ‘degerminator efficiency’ and ‘main product recovery’ of 80 percent and 64 percent, respectively (PAES 210: 2000). Under Philippine law (R.A. 10601, 2013), AMTEC is a duly recognized and independent body that conducts performance testing of agricultural machineries. A corn mill with ‘degerminator efficiency’ of lower than 80 percent indicates the production of poor quality corn grits given the high presence of pericarp, tip cap and germ in the product. On the other hand, a corn mill with ‘main product recovery’ of less than 64 percent indicates the incidence of postharvest losses during milling operation.

In line with this, a new type of corn mill was developed (Figure-1) to address the technical problems on existing corn mills in the Philippines. Current village-type corn mills still use emery stone or steel huller to degerm corn grains and adopt steel rollers to break degemrmed corn into small pieces. For its sorting mechanism, they all adopted the traditional oscillating type that requires huge power requirement. Because of the inherent technical problems of traditional village-type corn mills, its financial viability was significantly affected. Its primary design is based on the principle of dry-milling process, a modification to the dry-milling method (Brekeke, Weinecke, 1964).

Peplinskiet al., 1984; Brekkeet al., 1991, Peplinskiet al., 1992), due to the omission of tempering of corn kernels before dehulling or degeneration process. It features a degeneration mechanism using a hexagonal dented screen huller with counter flow auger and innovative grading mechanism by introducing a 3-layer rotary slotted hole perforated sheet cylinder, where such technical features are not found in any village-type corn mill in the Philippines (Gragasin and Martinez, 2015a).The design of the rotary mill was also innovated using 44 blades that is made of flat steel bars, sharpened at one side to efficiently mill cracked corn into corn grits. The newly developed cornmill technology has the capability to recover corn grain highly contaminated with aflatoxin through its efficient degeneration mechanism (Gragasin and Martinez, 2015b). The machine is user-friendly with the
installation of push-button switches in the electric control panel. But most importantly, the design is compact yet powerful with input capacity of 300-350 kg/hr. It is designed to have a working space of only 16m², thus, requiring a minimal investment for the shed of the machine. It uses single-phase electric motors so that this can be easily installed in the rural or even in remote areas.

The purpose of this study was to further improve and establish the technical feasibility and economic viability of the developed compact corn mill technology to target beneficiaries. Specifically, this research aimed to: (1) validate and improve the technical performance and mechanism of conducting repairs and maintenance of the developed compact corn mill technology; (2) determine the financial viability of the new developed corn mill technology; (3) identify the technical and socio-economic factors that may affect the utilization and efficiency of the developed corn mill technology; and, (4) establish the market potential of the corn mill technology at the local manufacturer’s level.

MATERIALS AND METHODS

Set-up of pilot units in the project sites

The three (3) pilot-units were subjected to usual testing and debugging before delivery to the project sites and were set-up in the following areas for 10 months: (1) Cagbatang Farmers Association, Cagbatang, Cataingan, Masbate - Luzon Area; (2) Local Government Unit of Barangay Nan-od, Nan-od, Sierra Bullones, Bohol - Visayas Area; and (3) Barangay Tiniwisan Marketing Cooperative, Barangay Tiniwisan, Butuan City - Mindanao Area. The corn mills were installed inside a shed that were provided by the project cooperators.

Training of project co-operators

All the project co-operators were trained on the principle of milling corn grains, including the operation and maintenance of the corn mill technology. Both lecture and hands-on type of training were conducted. A “user’s manual of operation and maintenance” was prepared and provided to the project co-operators.

Field interview

Socio-economic data were gathered in the project sites to serve as basis in analyzing the economic benefits of using the technology with the intended project beneficiaries. A total of 104 respondents were interviewed in the project sites.

Trial operation

During the actual operations of the technology, the project cooperators were given the free hand in operating the pilot units, subject to certain guidelines as stipulated in the memorandum of agreement. The cooperators have operated the corn mill machine for 10 months. From time to time, the project staff have monitored and provided technical assistance to the project cooperators, particularly on the operation and maintenance of the pilot unit. Coaching and mentoring were regularly provided to ensure that the prescribed operating procedures of the corn mill were adopted.

The technical performance of the corn mill was evaluated following the laboratory method of testing for corn mill (AMTEC, 2001). The parameters used in establishing the performance of the corn mill were the following:

\[ \text{Input Cap. (kg/h)} = \frac{\text{Weight of corn kernel input (kg)}}{\text{Total loading time (h)}} \]

\[ \text{Output Cap. (kg/h)} = \frac{\text{Weight of main product (kg)}}{\text{Output time (h)}} \]

\[ \text{Milling Cap. (kg/h)} = \frac{\text{Weight of corn kernel input (kg)}}{\text{Total operating time (h)}} \]

\[ \text{Main Product Recovery (％)} = \frac{\text{Weight of main product (kg)}}{\text{Weight of input (kg)}} \times 100 \]

\[ \text{Main By-product Recovery (％)} = \frac{\text{Weight of by-product (kg)}}{\text{Weight of input (kg)}} \times 100 \]

\[ \text{Electric Energy Consumption (kWh)} = \text{Power consumed (kW) x Time operation (h)} \]

The duration of each test trials started with the feeding of corn kernels in the intake hopper and ended after the last discharge from the output chute. The speed of the rotating shafts was 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.

Laboratory analysis

The main product and by-products of the corn mill were analyzed in the laboratory following the laboratory method of test for corn mill (PAES 211: 2000). 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 analyses were undertaken to determine the ‘degerminator efficiency’, losses, and percentage of corn grits of different 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 (PAES 211: 2000).

Experimental design and statistical analysis

The performance of the developed corn mill machine, i.e., input capacity (kg/h), output capacity (kg/h), milling capacity, main product recovery (％), power consumption (kWH), ‘main product recovery’ (％), and ‘degerminator efficiency’ (％) were compared according to the different design parameters of each component of the corn mill.
The data gathered were consolidated and analysed using Analysis of Variance (ANOVA). Statistical analysis was performed using Statgraphics Plus statistic package software that performs and explains basic and advance statistical functions.

Modification/improvement of the initial set-up

Based on the results of test trial, the initial design was modified to further improve the safety, ease of operation, technical performance, and economic viability of the corn mill. The fabrications of new or modified design were all undertaken at the PHilMech Fabrication Shop.

Financial analysis

The Financial viability of the corn mill was determined using the Internal Rate of Return (IRR). The IRR is an indicator to measure the financial return of an income generation project and is used to make the investment decision (Hartman and Schafrick, 2004). 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:

\[
I_0 + \frac{I_1}{(1 + r)^1} + \frac{I_2}{(1 + r)^2} + \ldots + \frac{I_m}{(1 + r)^m} = \frac{B_1}{(1 + r)^1} + \frac{B_2}{(1 + r)^2} + \ldots + \frac{B_m}{(1 + r)^m}
\]

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

where: \(I_0\) is the initial investment costs in the year 0 (the first year during which the project is constructed) and \(I_1 \sim I_m\) are the additional investment costs for maintenance and operating costs during the entire project life period from year 1 (the second year) to year \(m\). \(B_1 \sim B_m\) 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.

Detailing of engineering plan

The different parts and components of corn mill such as the degerminator assembly, rotary mill assembly, rotary sorter assembly, body and frame assembly, discharge and product collection assembly, and control and electrical system assembly were drawn in details using AutoCAD software. The detailed drawings have served as basis of the partner local manufacturer in the fabrication of the two pilot units.

Selection of local manufacturer

The early participation of a local manufacturer in the fabrication of the three pilot units was included as part of the methodology to validate the correctness of the engineering drawings of the invention and validate the degree and extent of fabricating the different components and parts of the developed corn mill technology. The partner local manufacturer was purposely identified and selected based on the following conditions: (i) Capability to fabricate the delicate parts of the corn mill given their technical expertise and the availability of equipment to fabricate the design; (ii) Willingness to enter into a non-disclosure agreement, acknowledge the government’s intellectual property rights on the developed technology, and any discoveries and technical information resulting from the project shall be the sole and exclusive intellectual property of the government; and, (iii) Their bid price for the supply and delivery of the pilot units should be the lowest and the most responsive bid.

RESULTS AND DISCUSSIONS

Testing and improvement of the initial design

Several modifications on the major components of the corn mill were undertaken to improve the overall technical performance, ease of operation, and the conduct of repairs and maintenance of the developed corn mill technology while on pilot-testing. These include the following:

1. One of the significant modifications to further increase the corn grits or product recovery of the corn mill is by changing the slot width of the screen of the rotary mill assembly from 2mm to 4mm. The results of tests trials revealed that by changing the slot width to 4mm, the production of corn flour has significantly reduced to 8.9 percent of the total weight of the product, from the initial 20.9 percent when using a screen with slot width of 2mm. The basic design consideration in the improvement of corn mill is to produce corn grits as much as possible with sizes #10 to #18 and minimize the production of corn flour. Note that the corn flour is a by-product of corn grits (PAES 210: 2000) while corn grits less than size #10 necessitates to be reverted back to the rotary mill to reach the prescribed grit sizes of #10–#18. The Philippine Agricultural Engineering Standard - Corn Mill Specification defined corn grits sizes (PAES 210: 2000), as follows:

- 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;
- Corn Grits #18 as milled corn kernels with particle size between 0.86 mm to 1.09 mm.

   It was observed that as the degermed corn kernels were cut and blown into smaller particles by the rotary blades, corn grits with size greater than the slot width of the screen remained at the top of the screen and as such, exposed to further milling by the rotary mill, producing more corn flour. Therefore, the screen with slot width of 4 mm was adopted for the rotary mill given the smallest flour yield of 8.9 percent.
2. The number of blades was also increased to 68 to further increase the product recovery. The rotary mill blades are made of T-shape, 2 mm thick and 45 mm wide stainless steel. The blades were sharpened at both sides to break degenerated corn kernels and blow into small particles to produce corn grits. The principle of chopping instead of grinding was adopted to increase corn grits recovery and minimize the production of corn flour. The corn grits recovery of the corn mill with 68 blades was 89.5 percent of the total output with 10.5 percent corn flour as compared to 84.6 percent grits recovery of 44 blades, both have used a mill speed of 3,000 rpm and a screen with slot width of 4 mm.

3. The suction adapter of the degaminator assembly was also reoriented from horizontal to vertical to facilitate the easy discharge of by-products, i.e., germ, tip cap and hull, from the degaminator housing through the suction blower, thus, further increasing the input capacity of the entire corn mill by 10%.

4. To ease the replacement of screen inside the degaminator assembly, the casing of the degaminator was divided into two so that the screen can be easily extracted from the degaminator housing. Originally, the screen is replaced by removing the whole degaminator assembly from the corn mill unit followed by taking away the shaft of the feeding and counter flow auger to finally replace the damaged screen. With the modification, the half part of the housing can now be taken out to easily access the screen inside the degaminator housing.

Based on the result of test trial conducted by AMTEC on the modified corn mill (latest model), the milling capacity has significantly improved by 78 kg/hr, from 182 kg/hr to 260 kg/hr (Table-1). But most importantly, the output of the corn mill with respect to energy used was improved by 14 percent since the milling productivity has increased to 42.9 kg/kWHR from 38.6 kg/kWHR.

| Table-1. Technical performance of the new corn mill after modification/improvements. |
|---------------------------------|-------|-------|
| Technical parameters            | Old model | Latest model |
| Output Capacity (kg/h)          | 161     | 240     |
| Milling Capacity (kg/h)         | 182     | 260     |
| Degerminator Eff. (%)           | 94.7    | 81.2    |
| Product Recovery (%)            | 64.7    | 72.3    |
| Power Consumption (kW)          | 4.2     | 5.5     |
| Electric Motor(s)               | 5 hp    | 5 hp+4 hp |
| Milling Productivity (kg/kWHR)  | 38.6    | 43.9    |

1/ Based on AMTEC test result except milling productivity and cost of milling that was estimated by the research team.

Financial analysis

The financial viability of agricultural machinery often hinges critically on the rate of operation, and therefore, the cost of milling per kilogram is highly dependent on the rate of utilization. In the estimation, the total annual operating time used in the estimation is only 660 hours (i.e., 5 months, 22 days per month, and 6 hours of operation per day). The results of the estimation, as shown in Table-2, revealed that the total cost of milling per kilogram output is estimated at Php0.95 (US$1=Php48) which is far below the existing milling fee of Php2.25-3.00 per kg of corn grains loaded in the corn mill.

| Table-2. Total operating cost, cost of milling and internal rate return. |
|---------------------------|---------|---------|
| Particulars               | Amount  |
| Fixed Cost per Year (Php) | 48,500  |
| Depreciation Cost         | 30,000  |
| Repairs and Maintenance   | 18,500  |
| Variable Cost per Year (Php)| 79,244 |
| Electricity               | 51,744  |
| Labor                     | 27,500  |
| Total Cost per Year (Php) | 127,744 |
| Cost of Milling (Php)     |         |
| - Per Kilogram Output     | 0.95    |
| - Per Kilogram Input      | 0.60    |
| Net income Per Kilogram (Php)| 1.12   |
| Payback Period (Yr)       | 2.45    |
| Internal Rate of Return (%)| 68.63   |

Note: US$1=Php48
1/ Assumptions used in the computation:
Input capacity: 320 kg/h
Output capacity: 205kg/h
Operating time per yr: 660h (110d x 6h/d)
Total capacity per yr: 135,168 kg
Labor cost: Php250/day
Power requirement: 5.6 kW/H
Cost of electricity: Php14/kW
Investment cost of the corn mill: Php320,000
Investment cost of the shed: Php50,000
Lifespan of the corn mill: 12 yr
Lifespan of the shed: 15 yr
Formula:
Depreciation cost per year = Investment cost/lifespan
Repairs and maintenance= 5% of investment cost
Cost of milling per kg output= Total cost per year/Total capacity per year
Cost of milling per kg input = Total cost per year/Input capacity xOperating time per yr
Net income= [Milling fee of Php2.00/kg – Cost of
milling per kg input basis] x [1 - 20% Overhead cost]

Based on the estimated cost of milling as shown in Table-2, the operator of the compact rice mill could realize a net income of Php1.12/kg even if it will be utilized for custom milling business and will charge a milling fee of Php2/kg only. The estimated payback period in investing in the corn mill technology is estimated at 2 years and 6 months with internal rate of return of 68.6 percent.

Factors affecting the performance of the corn mill

Based on the test trials conducted during the whole duration of the pilot-testing, it is highly observed that the following operational and technical parameters shall be considered in operating the developed compact corn mill technology:

1. Stability of electric supply in the area. While majority of the electrical lines in the villages could provide a total load of 30 KVA, it was discovered that some villages particularly in the remote areas have only an electrical load of 15 KVA. Note that the corn mill has an averaged power load of 5.6 kVA and as such, would consume 38 percent of the 15 kVA transformer capacity in the area. In line with this, it is recommended that a separate 10 kVA transformer be dedicatedly installed for the developed corn mill.

2. Technical know-how of the operator. Any wrong adjustments on the machine during operation would adversely affect the performance of the corn mill, and worse, will break some parts of the corn mill. In many instances, the cooperators have treated the machine as ordinary machine and allowed untrained person to operate the corn mill. Likewise, the operators have accepted wet corn kernels that caused clogging in the degerminator assembly. Therefore, the corn mill should be operated by trained individual.

3. Service area of the corn mill. As emphasized in the previous section, the economic viability of the corn mill is highly dependent on the annual operating time of the machine, which is highly critical on the capacity and service area of the corn mill.

What is the break-even area then to at least recover the milling cost? In here, the break-even point is estimated once the cost of milling is equal to the prevailing milling fee/rental cost of Php2.34/kg (output) or Php1.50 (input) being charged by the project cooperator during pilot testing. For the corn mill to at least recover the cost of milling per kilogram output, the corn mill requires a total annual operating time of 207 hours, needing a total service area of 38 hectares for average yield of 1.75 metric tons per season per hectare to achieve the needed volume of 42.4 metric tons per year (Table-3). However, if the corn mill facility is given by the government as grant, the total operating time needed to at least recover its operating cost is only 126 hours per year. To achieve that 126 hours operating time per year, a total production area of 23 hectares is needed to produce a total volume of 25.7 mt per year.

Table-3. Break-even point of operating the corn mill under different conditions.

| Parameters                      | Total fixed and variable costs | Operating cost only
|---------------------------------|--------------------------------|-----------------------
| Operating Time per Year (hr)    | 207                            | 126                   |
| Volume to be Milled per Year (mt)| 42.4                           | 25.7                  |
| Milling Cost per kg Output (Php) | 2.34                           | 2.34                  |
| Service Area per Year (ha)     | 38                             | 23                    |
| Service Area per Season (ha)   | 16.0                           | 11.5                  |

Note: US$1=Php48
1/ Milling cost is equal to prevailing milling fee of Php2.34/kg (Php1.50 per kg input divided by milling recovery of 64%).
2/ Government provides the corn mill facility as grant.
3/ Based on break-even time per year.
4/ For average yield of 1.75mt/ha and milling recovery of 64%.

Commercialization of the developed corn mill technology

The participation of a local manufacturer during pilot-testing (i.e., fabrication of two pilot units) validated the initial design of the invention particularly the initial drawing that contains 56 sheets of detailed CAD drawing of the different components and parts of the newly developed corn mill technology. It fully considered the valuable inputs and suggestions of the partner local manufacturer in the practical fabrication of the technology. The early participation of a local manufacturer could ensure the readily available manufacturer that can supply the developed corn mill during commercialization.

CONCLUSION AND RECOMMENDATIONS

The newly developed compact corn mill was pilot-tested in key corn areas in the Philippines to further improve and establish the technical feasibility and financial viability of the developed technology. The pilot testing successfully improved the technical performance of the corn mill with the increase in the output produce per unit of energy used by 14 percent, from 38.6 kg/kWHR to 43.9 kg/kWHR. The degerminator and rotary mill...
assemblies were reconfigured to ease the conduct of repairs and maintenance.

The improvement in the technical performance of the developed corn mill technology has significantly reduced the milling cost per kilogram output of corn grits by 19 percent, from the initial estimated cost of Php1.18/kg down to Php0.95/kg before and after pilot-testing, respectively. The reduction in the cost of milling has improved the financial viability of investing in the technology given an estimated payback period of two years and 6 months with internal rate of return of 68.6 percent.

The early involvement of the local manufacturers during pilot-testing has validated the corn mill design, that is, the CAD drawing can be easily be followed by the local manufacturers during the fabrication of commercial units. But most importantly, the inputs of the local manufacturers have improved the process of fabricating the technology on a commercial scale.

In the massive commercialization of the corn mill technology, the following technical and economic considerations shall be fully observed: (i) the break-even volume to at least recover the cost of operation is 25.7 metric tons requiring a total area of 23 hectares or 11.5 hectares if corn is planted twice a year in the area; (ii) the transformer requirement dedicated to the corn mill should have at least 10 kVA capacity; (iii) the operator of the corn mill shall be properly trained to avoid breaking the corn mill machine and to achieve the optimum technical and economic potential of the technology; and, (iv) given the absence of a pre-cleaner of the corn mill machine, it is necessary that the corn kernels are clean and free from impurities such as corn stalks and cobs to avoid clogging in the degerminator and achieve good quality of corn grits.

The technology is highly recommended to be adopted by the government and the private sector to address the lack of appropriate village-level corn mill technology in the countryside. A wider adoption of the developed corn mill technology can significantly reduce the price of corn grits in the market given the significant reduction of cost of milling and transportation of corn grains by the farmer-producers. A lower price of corn grits in the market could induce wider consumption of corn grits in the Philippines, which in effect could lower the per capita consumption of rice in the country. Therefore, the development and utilization of efficient corn mill could contribute in increasing the consumption of corn and solve the food security problem in the country.

REFERENCES


