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Chapter

Improving Maize Shelling Operation Using Motorized Mobile Shellers: *A Step towards Reducing Postharvest Losses in Low Developing Countries*

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Abstract

Maize shelling is still a challenge in low developing countries with more efforts required to advance this operation. In Uganda, motorized immobile maize shellers have been fabricated locally to enhance the shelling operation. However, their performance has not elated the farmers. The unsatisfactory performance is a result of these shellers being fabricated by local artisan with finite understanding of the maize grain characteristics and operation factors to optimize maize shelling. In addition, farmers in these countries have a deficiency of power to operate the motorized maize shellers available. Transportation of these motorized maize shellers is also still a challenge and it imposes an extra cost to the farmers hence reducing their profits from maize growing. In this chapter, we reviewed maize shelling process in low developing countries particularly the categories of maize shelling, maize sheller design requirements, use of equations to design sheller parts, modification of the motorized maize shellers and case studies on the mobile maize shellers, comparing them with immobile maize shellers. The study concluded that on addition to other sheller performance attributes, motorized mobile maize shellers can solve transportation challenges associated with motorized immobile maize shellers.

Keywords: maize, shelling, mobile motorized shellers, post-harvest operations

1. Introduction

Maize is among the three critical cereal grains in the world, others being wheat and rice [1]. Maize was first identified in central Mexico 7000 years ago from a wild grass and Indigenous Americans converted it into food [2]. This cereal grain contains starch (60–80%), protein (8–12%), fat (3–5%), and minerals (1–2%) [3, 4]. It is grown worldwide, with Unites States, China, and Brazil as the top three maize-producing countries with a combined production of approximately 563 of the 717 million tons/year [2]. Maize contains nutrients for both humans and animals but it

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is also used for production of starch, oil and protein, alcoholic beverages, food sweeteners, and biofuels [5]. The significance of maize as a staple food in low developing countries can be compared to that of wheat in Asia. It is mostly consumed in Eastern, Western and Southern Africa in different forms such as *kenkey* in Ghana, *Ogi* in Nigeria, stiff porridge (*nsima*) in Malawi, maize meal (*ugali*) in Kenya [6], and posho and porridge in Uganda. In Sub Saharan Africa (SSA), over 208 million people bank on maize as a food source and being economically empowered [7]. Out of the 22 countries in the world where maize is mostly consumed, 16 of them are found in Africa [7]. This makes maize a very important cereal in Africa. Despite its importance, the losses of maize after harvest have decreased its availability among the poor people in Africa. In Uganda, for example, maize postharvest losses are about 30% [1] which has escalated hunger especially among the poor in the villages.

Maize processing include harvesting, dehusking, drying, shelling, storing, and milling. Compared to other operations, shelling still stand out as the most challenging operation that requires more work to improve it [8]. For the maize farmers to fully enjoy the financial benefits from their maize, appropriate technology that suits their needs is a requirement. In this regard, motorized immobile maize shellers have been fabricated locally to enhance the shelling operation. However, their performance has not elated the farmers. The unsatisfactory performance is a result of these shellers being fabricated by local artisans with finite understanding of the maize grain characteristics and operation factors to optimize maize shelling [1]. In addition, farmers in low developing countries have a deficiency of power to operate the motorized maize shellers available. It has been reported that transportation of these immobile maize shellers with the engines to run them from place to place is a big problem to sheller service providers; often requiring an additional carrier to move shellers to the farmers' field. The shelling service providers hence ask for an extra cost, which is usually passed on to farmers. These shellers also require extra time and energy to arrange the maize shelling environment at the farm level [9].

To consider the shelling power and sheller transportation problems, low cost motorized mobile maize shelling technologies have been developed as a result of modifying the available motorized immobile maize shellers. Some motorized mobile maize shellers were fabricated in 2012 by industrious fabricator Munyegera Agro-Machinery in Eastern part of Uganda [10]. Later, the multipurpose vehicle mobile maize shelling technology was introduced [1]. In Bangladesh, a two-wheel tractor mounted mobile sheller for small scale farmers was also introduced [9]. In this book chapter, maize shelling operation in low developing countries has been described with focus on encouraging a paradigm shift from the motorized immobile maize shellers to mobile maize shellers as a solution to the maize shelling constraints in these countries.

2. Maize shelling as a postharvest operation

Maize shelling as a postharvest operation is the removal of maize seeds from the cob [11]. This operation can be carried out either in the field or at the storage facility. Maize shelling is therefore an important step towards the processing of maize to various finished products like flour and maize bran.

2.1 Maize shelling in developed countries

In developed countries like Europe, North America, and China, maize shelling operation is done using combine harvesters [12]. Combine harvesters (**Figure 1**)

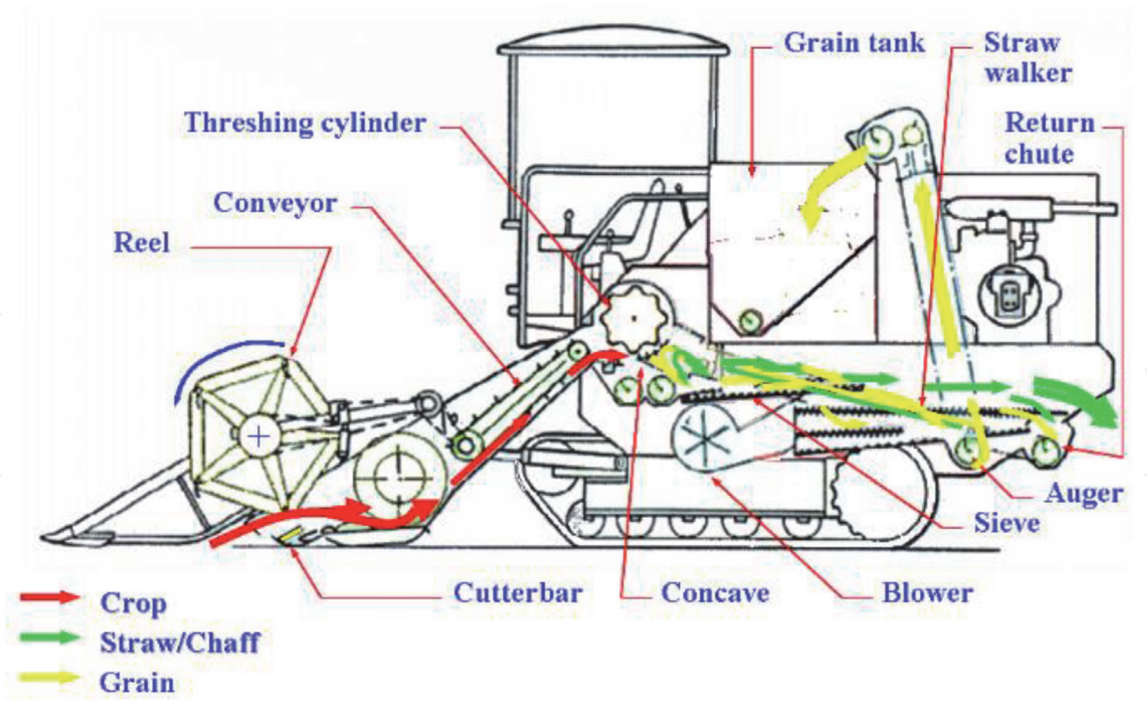

Figure 1.
Different components of a combine harvester [13].

simultaneously perform operations of ear picking, threshing, separation, and cleaning on the mature maize plants in the field. The purpose of this mechanized maize harvesting technology is to replace manual labor to harvest maize from fields in time with minimum loss while maintain high quality standards [14]. Some of the advantages of mechanized maize shelling include: reduced drudgery, enhanced productivity, time consciousness of agricultural operation, and availing labor for other agricultural operations. Combine harvester designers are working towards the quality of the process automatic controls and protecting the environment [15].

2.2 Maize shelling in low developing countries

Maize shelling in low developing countries is still a challenge to its value addition as it is tiresome and requires a number of labor hours [11]. A major issue for maize value chain is that good quality maize is difficult to find among farmers. Many times, buyers are ready to pay a high price for maize grains from farmers with good quality maize. However, good quality maize is often unavailable due to poor postharvest handling. The impacts of quality at postharvest level can be attributed to poor drying and storage methods among other factors. For example, maize drying on the bare ground, and storage in dump places and aflatoxin growth [10]. Beside drying and poor storage, maize post-harvest losses are also due to use of rudimentary tools like tapered cylindrical metallic shelling device [16].

Maize shelling methods can be categorized as traditional maize shilling, manual maize shelling, and motorized maize shelling based on the technology used.

2.2.1 Tradition maize shelling

Maize is shelled traditionally by hand (**Figure 2**). Here, the grains are detached from the cob by pressing them with the thumb [2]. The technique produces unbroken kernels but the process is tedious. A few kilograms can be shelled in an hour, with damages left on shellers' fingers. Another simple and common method of traditional maize shelling is to rub two maize cobs against each other in order to

Figure 2.
Maize shelling by hand [16].

detach the maize kernels [17]. However, these traditional methods of shelling are, not efficient, consume a lot of time, and require a lot of energy with very low productivity since farmers can shell only a few kilograms/hour.

2.2.2 Manual maize shelling

This method is almost similar to the traditional method of shelling except that it requires more energy compared to traditional methods to run manual maize sheller (**Figure 3**). For some manual shellers, two people are required during shelling, one person constantly feeds the maize cobs and the other operates the equipment by rotating the handle [8] while other manual shellers require one person [2]. Hand-operated shellers, requires less time to shell the maize compared to the traditional methods. These come in several models, and they are usually driven by rotating the handle or a pedal. With the output capacity of 14–100 kg/min, they are more suitable for small-scale maize production [2]. Hand-operated maize shellers are also suitable for shelling maize for seed purpose since damaged maize kernels are fewer compared to motorized maize shellers [18].

2.2.3 Motorized maize shellers

This method uses the same concept as hand-operated maize shellers except that the shellers are powered using a motor or an engine (**Figure 4**). The shellers under this method can be categorized into immobile and mobile maize shellers [10]. These shellers save time and they reduce on the drudgery during maize shelling. However, the challenges with some of these shellers is that they are heavy [8], do not clean the maize kernels and are characterized with a broken percentage of 8.4 [1] which is

Figure 3.
Manual maize sheller [18].

Figure 4.
Motorized maize shelling [19].

above the recommended 2% [20]. Motorized maize shellers use mechanically generated power to shell the maize. To facilitate speedy shelling of maize in large scale maize production, motorized maize shellers are recommended compared to hand-operated maize sheller [2]. The output of motorized maize shellers range between 500 and 2000 kg/hour and they can be operated by tractor power take off (PTO) or engines with power varying from 5 to 15 hp depending on the equipment used [2].

3. Maize sheller design considerations

The design objective is to obtain maximum shelling performance from the equipment. The performance of shellers in terms of shelling efficiency, grain damage percentage, output capacity, cleaning efficiency, and power requirement is a function of design parameters, operating factors, physical and engineering properties of maize [21].

3.1 Design parameters

Design parameters include: cylinder diameter, cylinder speed, shelling length, clearance between the spikes and the concave, diameter holes in the concave, spike shape, size, and arrangement on the shelling drum and the blower type. Uttam et al. [11] recommended 886 rpm and 12.05–13.64% for shelling speed and moisture content, respectively [1] for the best shelling results. At these conditions, the study concluded that the shelling efficiency, cleaning efficiency, grain recovery efficiency, total grain losses, and output capacity were 87.08, 95.89, 95.48, 2.96, and 623.99 kg/h respectively. Chilur and Kumar [22] developed and evaluated the performance of a modified dehusker cum sheller. In their study, they recommended a clearance of 25 mm between the spikes and the concave for good shelling results.

3.2 Operating factors

Operating factors include grain moisture content, shelling speed, and the feeding rate. An evaluation of these factors depends on the knowledge and understanding of the equipment's mode of operation.

Shelling efficiency is increased by reducing the moisture content [23]. This can be attributed to less resistance to the removal of maize grains from the cobs due to low moisture. The grain damage percentage increases with a reduction in moisture content [1]. This can be attributed to less deformability of the grains which reduces the breakage at low moisture content. The sheller output capacity also increases with a reduction in moisture [24]. This can be attributed to the reduced time needed to remove maize grains from maize cobs as moisture content lowers. Likewise cleaning efficiency increases with a decrease in moisture content [25]. This can be attributed to the negligible moisture content of the chaff as the grain moisture content reduces.

The shelling efficiency is increased by an increase in shelling speed [23]. This can be attributed to the increased ease in the removal of maize grains from the cobs as a result of increased impacts and resistance created between the shelling drum and the concave as the shelling speed increases. Increased shelling speed increases the grain damage percentage [1]. This can be attributed to the more force exerted to the maize grains on the cobs as a result of higher cylinder speed and frequency of impacts at higher shelling speed. Increased shelling speed causes an increase in the output capacity. The output capacity of the sheller also increases with an increase in shelling speed [24]. This can be attributed to more removal of maize grains from the maize cobs due to increased impacts and resistance created between shelling drum and the concave with the increased shelling speed. Likewise, the cleaning efficiency increases with an increase in the shelling speed [25]. This may be attributed to an increase in the air flow rate produced by the sheller blower as the shelling speed raises.

Increasing the feeding rate decreases the shelling efficiency [26]. This can be attributed to the increase in unshelled grains that comes with the increase in the feeding weight as the feeding rate increases. The increased feeding weight causes an imperfect contact between concave and shelling drum. Also, increasing the feeding rate, decreases the broken grain percentage. This is due to increasing the weight entering the sheller through the hopper which acts as a cushion that reduces the effect of the grains with the shelling unit and this reduces the broken grain percentage.

To find out how different design and operating factors of maize shellers affect their performance, studies have been conducted. Aremu et al. [27] designed, constructed, and assessed the performance of the motorized maize shelling machine. The experiment used three pulleys to change the shelling speed between 623 and 886 rpm with moisture content at levels of 13, 15, and 17%. Their study noted that maize grains of lower moisture contents were easily removed from the maize cobs. This was in agreement with what [28] found out when they conducted a similar experiment under the same conditions. The study further noted that shelling speed is directly proportional to the shelling efficiency and output capacity.

In most of the earlier studies, one operation factor was studied at ago using different experiments. However, using factorial experiments, the researcher can compare all treatments that can be created by different factor levels [29]. Factorial experimentation is highly recommended because every observation gives information about all the factors in the experiment. Srison et al. [30] used a factorial experiment to study different factors affecting losses and power consumption of axial flow corn shelling unit at different levels of the main effects. The study results revealed that peg tooth clearance, concave rod clearance, and concave clearance had significant difference on the shelling losses and power consumption, but not on grain breakage. Ugwu and Omoruyi [31] conducted an experiment to find out the effect of moisture content and feeding rate on the shelling efficiency. A 2 hp electric motor was used to provide the drive through belt connections to drive the pulley on the shelling chamber. The factorial experiment was conducted using three different moisture contents and feeding rates. The feeding rates were 3.75, 4.75, and 5.75 kg/s. The moisture contents were 10, 15, and 20%. The study observed that the shelling efficiency of the maize sheller was significantly and negatively affected by moisture contents of more than 15%. The results obtained also showed that shelling efficiency of the equipment was 99.01% at a moisture content of 10%.

3.3 Physical factors

The important crop physical factors include the moisture content, the biometric properties such as length, width, arithmetic and mean diameter, shape, volume and surface area of the grains [32], grain cob ratio, grain bulky density, sphericity, angle of response, terminal velocity, one thousand grain mass, and porosity [2]. One thousand grain weight, density, sphericity, and surface area of different grains are required when designing different separating, handling, storing, and drying systems. Bulky density, true density, and porosity are needed when sizing grain hoppers and storage facilities [33]. They can also affect the rate of heat and mass transfer of moisture during aeration and drying processes. Density is used to separate materials with different densities or specific gravities.

The arithmetic mean diameter (D_a) in mm and geometric mean diameter (D_g) in mm of the grains can be calculated using Eqs. (1) and (2) according to [32].

$$D_a = \frac{(L + W + T)}{3} \tag{1}$$

$$D_g = (L \times W \times T)^{\frac{1}{3}} \tag{2}$$

where
L: length of the maize grain, mm
W: width of the maize grain, mm
T: thickness of the maize grain, mm

The sphericity (ϕ) is surface area of a sphere with the same volume of the maize grain can be determined using Eq. (3) according to [34].

$$\phi = \frac{(L \times W \times T)^{\frac{1}{3}}}{L} \tag{3}$$

The surface area, S in mm^2 of agricultural products generally indicates the patterns of behavior in a flowing fluid such as air, as well as the ease of separating additional materials from the product during cleaning by pneumatic means. The surface area of the grains can be calculated using Eq. (4) according to [33].

$$S = \pi \left(D_g\right)^2 \tag{4}$$

The bulk density of the main grains can be calculated using Eq. (5) according to [34].

$$\rho_b = \frac{4M}{\pi D^2 h} \tag{5}$$

where

ρ_b: bulky density, gcm^{-3}

M: mass of grains that fills the height of 150 cm measuring cylinder, g

D: internal diameter of glass sampler, cm

h: height of the maize in the glass jar sampler, cm

The angle of response can be calculated using Eq. (6) according to [35].

$$\theta = \tan^{-1}\left(\frac{h_0}{r}\right) \tag{6}$$

θ: angle of response, degrees

h_0: height of the maize heap, m

r: radius of the maize heap, m

For primary processing of maize, particularly maize shelling, it is important to determine these physical properties mostly dependent on moisture content. Atere et al. [36] carried out a study on the physical properties of the maize varieties commonly grown in Nigeria. Properties determined included tri-axial dimensions (length, width, and thickness), sphericity, bulky density, true density, porosity, one thousand seed grain weight, and co-efficient of static friction. The data obtained was subjected to analysis of variance (ANOVA) and least significance difference (LSD) tests. The moisture contents of maize in this experiment were 11.35, 11.34, and 11.25%. The ANOVA results showed that maize grain properties of length, thickness, and effective diameter, bulky density, true density, porosity, and response were significantly different ($p < 0.05$) within the three varieties.

3.4 Engineering factors

Engineering properties are divided into frictional and aerodynamic properties and they are used in designing equipment for solid flow, conveying systems, and separation equipment [37]. Frictional properties include the coefficient of friction and angle of response, which can be measured using the angle of response apparatus (**Figure 5**). It consists of a plywood box of 60 mm × 60 mm × 60 mm (a) and a protractor (c) for measuring the angle in degrees and provided with a fixed and adjusted plates [32]. It also has a control (b) for raising and lowering the box during

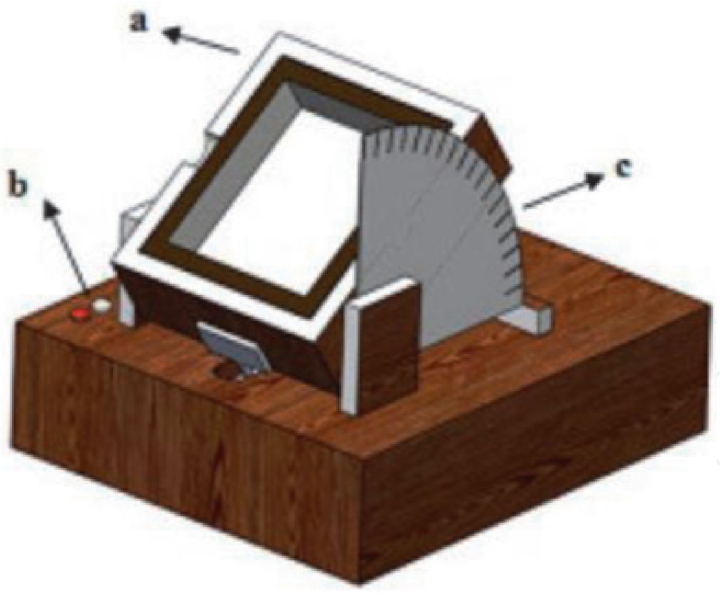

Figure 5.
Angle of response apparatus [32].

measurements. The box is filled with maize and adjustable plate inclined gradually allowing the grains to slide and assume a natural slope. The static coefficient of friction of maize grains on different surfaces can then be determined by this apparatus. Aerodynamic properties include drag coefficient and terminal velocity measured using the terminal velocity apparatus [37].

Identifying the physical and engineering characteristics of grains is important when designing, improving and optimizing the separation and cleaning equipment [34]. The engineering selection and design of grains equipment requires knowledge of these grain properties because they are of great importance in the simulation and design of these equipment. Their influence is more pronounced in problems of conceptual design where a wrong estimation of a property can lead to a design plan that is not feasible. The knowledge of maize properties also gives information about the product quality, its acceptability by different groups of consumers and its behavior in post-production, during storage, and consumption.

4. Designing a maize sheller

To ensure safe food, the equipment used for shelling maize should be designed, fabricated, and tested according to the required food grade design requirements. Mild steel can be used for maize sheller fabrication because it does not contaminate dried foods like maize grains. Besides, mild steel is smooth textured, mechanically stable, easily cleaned, and readily available at a relatively low cost. Bako and Batule [38] used mild steel to construct the shelling drum, spikes, conveyor, sieve, upper casing, hopper, exit cutes, and the frame of the maize sheller. Akoy and Ahmed [39] noted that mild steel can be used to achieve the equipment objective at the lowest cost possible. Designing a maize sheller requires designing the individual parts and then assembling them. These parts include main and other shafts, hopper, power transfer systems, and other parts.

The main shaft of the maize sheller can be designed using a hollow shaft because it has less weight, it is better in absorbing torsional loads and with great strength to weight ratio. Torsion theory [40] as shown by Eq. (7) can be used to calculate the minimum and maximum shaft diameters.

$$\frac{T}{J} = \frac{\tau}{R} \tag{7}$$

where
T: applied external torque, Nm
J: polar second moment of area of the shaft cross section
τ: shear stress at radius R and is the maximum value for both solid and hollow shafts
R: outer radius of the hollow shaft
For hollow shafts J is calculated using Eq. (8) [40].

$$J = \frac{\pi(D^4 - d^4)}{32} \tag{8}$$

where
D: outer shaft diameter
d: inner shaft diameter
Calculation of the Torque generated by the available power required to shell the maize can be done using Eq. (9) [27].

$$P = T\omega \tag{9}$$

where ω is angular velocity in rad/s calculated from Eq. (10) [27].

$$\omega = \frac{2\pi N}{60} \tag{10}$$

where N is shelling speed in rpm
Using a diameter ratio of $d = 0.833D$ and a maximum allowable shear stress $\tau_{\max}$ of 42 MNm^{-2} for a mild steel hollow shaft, the minimum shaft diameters can be calculated [40].

The concept of calculating the volume of the frustum of the pyramid using Eq. (11) can be used to size the hopper [1]. Volume of the frustum (hopper) is the difference between big pyramid volume and the small pyramid volume.

$$V = \frac{1}{3}bh \tag{11}$$

where
V: volume of the pyramid, m^3
b: base area, m^2
h: pyramid height, m
The maximum bending moment $M_{b\max}$ can be obtained by taking moments about any point along the shaft while considering all the forces acting on the shaft and their respective distances from the chosen point [1]. A shear force diagram and bending moment diagram are then drawn from which the maximum bending moment is read.

The torsional moment M_t can be determined using Eq. (12) according to [24, 27].

$$M_t = \frac{P}{2\pi N} \tag{12}$$

where
M_t: torsional moment, Nm

P: power, watts
N: speed, rpm

The bending, load, bending stress (tension and compression) can be calculated from Eq. (13) [24].

$$S_b = \frac{M_b R}{I} \tag{13}$$

But for hollow sections, $I = \frac{\pi(D^4 - d^4)}{64}$ [40].

where
S_b: bending stress, MNm^{-2}
D: outer diameter
D: internal diameter
I: moment of inertia

The torsional stress can be determined using Eq. (14) according to [41].

$$\tau_{xy} = \frac{M_t R}{J} \tag{14}$$

where
τ_{xy}: torsional stress, Nm^{-2}
M_t: torsional moment
R: outer radius of the shaft
J: polar moment of inertia
d: inner diameter of the shaft

Torsional rigidity of the shaft can be based on permissible angle of twist. The amount of twist permissible depends upon the particular application and it can vary from 0.3 m^{-1} for machine tools shaft to 3 m^{-1} for line shafting [41]. Torsional rigidity can be calculated from Eq. (15) according to [41].

$$\theta = \frac{TL}{GJ} \tag{15}$$

where
θ: angle of twist, degrees
L: length of the shaft, m
G: torsional modulus of rigidity, Nm^{-2}

The lateral rigidity of the shaft can be based upon the permissible lateral deflection for proper operation, accurate machine tool performance, shaft alignment, and other factors. The amount of deflection can be calculated by two successive integrals shown by Eq. (16) according to [40].

$$\frac{d^2y}{dx^2} = \frac{M_b}{EI} \tag{16}$$

where
M_b: bending moment, Nm^{-2}
E: modulus of elasticity, Nm^{-2}
I: moment of inertia, m^4

The sheller main shaft speed and the engine shaft speed can be related by power transfer equation shown by Eq. (17) according to [24].

$$N_1 D_1 = N_2 D_2 \tag{17}$$

where
N_1: speed of the driver pulley, rpm
D_1: diameter of driver pulley, m
N_2: speed of the driven pulley, rpm
D_2: diameter of the driven pulley, m

5. Economic feasibility of maize shelling as a business

Most fabricators, wholesalers, and retailers of maize shellers in many countries do not have definite capacity building and after-sale services to the maize sheller users [42] and no adequate instructions on equipment maintenance. Hence the entrepreneurs mostly learn on their own the operation and maintenance of their maize shellers. As a result, the economic lives of maize shellers become shorter and cause a financial loss to entrepreneurs. Thus, determining the key indicators relating to the financial feasibility of a maize shelling business is of greater importance before getting into the maize shelling business. These indicators include benefit–cost ratio and payback period [43]. The payback period is the period within which the initial investment will paid. It can be estimated using Eq. (18) according to [24].

$$P = \frac{I}{NA} \tag{18}$$

where
P: payback period, years
I: investment cost, USD
NA: net annual returns, USD

The benefit–cost ratio can be defined as the comparison of the present worth of the costs with the present worth of the benefits [42]. The benefit–cost ratio can be calculated using Eq. (19) according to [24] and it is recommended to be greater than one for the shelling business to be financially viable.

$$BC = \frac{DB}{DC} \tag{19}$$

where
BC: benefit–cost ratio
DB: discounted benefits
DC: discounted costs

$$\text{Discounted Benefits} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t}$$

$$\text{Discounted costs} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

B_t: returns for year t, USD
C_t: cost for year t, USD
t: economical life, years
r: discounted rate

6. Modification and improvement of mobile maize shellers

Modification of maize shellers can lead to improvement of the existing shellers for better performance. Most engineering designs are classified as systems created by human effort and did not exist before or improvements on the existing ones. These designs do not suddenly appear from nowhere. They result from merging technologies to meet or solve existing problems from time to time. Modification of maize shellers can be aimed at improving the performance of the existing shellers by adjusting mechanisms to certain working conditions [44]. Abagissa and Befikadu [45] noted that modification of maize shellers can result in causing no damage to maize kernels at all. Their study further revealed that the shelling efficiency was 99.67% at a moisture content of 14.7%. The evolution of motorized mobile maize shellers is a result of modification of the immobile motorized maize shellers to solve the power and transportation problems.

6.1 Case study 1: multi-purpose farm vehicle mobile maize sheller

According to [1], a study was conducted to evaluate the performance and optimize the shelling operation of the multi-purpose farm vehicle shelling technology. The study was aimed at: (i) improving the available market maize sheller and evaluate its performance and (ii) optimizing the shelling operation of the multi-purpose farm vehicle using the modified sheller. At present, transportation of maize shellers and engines (power source) from place to place is a big challenge in maize shelling. In Uganda, shellers and engines are transported on motorcycles, which not only require an extra cost, but also extra time and energy. In an effort to improve maize shelling in the country, a multi-purpose farm vehicle with a provision for hitching a maize shellers was developed to solve the power and transport problems faced by maize farmers. The three-wheeled vehicle can be used for water pumping, maize shelling, rural transport, and phone charging. This technology involves use of a multi-purpose farm vehicle power take off (PTO) power to run the maize shellers using a V-belt and a pulley. The multi-purpose farm vehicle was evaluated using a motorized market sheller and the mean broken percentage of the shelled maize was 8.43%, which was higher than the 2% recommended [20]. As a result, the holes of the concave were increased to 15 mm from 12 mm so that maize grains could easily fall through, a hollow shaft was used instead of the solid shaft for the main shelling shaft, the clearance between the concave and the spikes was modified from 22 to 25 mm which was just enough to allow the grain from being detached from the cob without damaging them and the number of the fun blades was increased from 4 to 8 [1]. The modified maize sheller was evaluated (**Figure 6**) to assess if the results were satisfactory. One way analysis of variance (ANOVA) was done using R-studio. The economic feasibility of the shelling technology was also conducted.

It was noted that the output capacity, cleaning efficiency, and grain damage percentage of the modified maize sheller was significantly different ($P < 0.05$) from the values obtained by the market maize sheller (**Table 1**). However, there was no significant difference between the shelling efficiency of the modified maize sheller and the market maize sheller. Hence in terms of shelling efficiency, both the market maize sheller and the modified maize sheller were good since their values were all above 97%.

The results of the benefit–cost analysis of the modified maize sheller powered by the multi-purpose farm vehicle are presented in **Tables 2** and **3**.

The benefit–cost-ratio and pay back period of the modified maize sheller were 1.07 and 1.37 years, respectively (**Table 3**). These results were in agreement with [42] who obtained a benefit–cost ratio of 2.34 for a maize sheller for which it

Figure 6.
Operational view of the modified multi-purpose vehicle maize sheller [1].

Performance indicator	Units	Market maize sheller	Improved maize sheller	*p*-values
Output capacity	kg/h	608.0	1581.0	$P < 0.05$
Shelling efficiency	%	97.4	98.0	$P > 0.05$
Cleaning efficiency	%	18.4	98.3	$P < 0.05$
Grain damage percentage	%	8.4	0.7	$P < 0.05$

Table 1.
Market maize sheller versus modified maize sheller [1].

Particulars	Cost, USD
Fixed cost (cost of the sheller)	577.0
Annual variable cost	2982.9
Annual gross income from shelling	3405.4
Annual net returns	422.6

Table 2.
Various costs for the modified maize sheller [1].

Particulars	Details
Payback period (years)	1.37
Benefit–cost ratio	1.07

Table 3.
Payback period and benefit–cost ratio of modified maize sheller [1].

required to be greater that one. In addition, the modified sheller investment would pay back the initial investment within 1.5 years or approximately three maize growing seasons. Hence the maize shelling operation of the modified maize sheller powered by the multi-purpose vehicle is a profitable venture for entrepreneurs.

6.2 Case study 2: two-wheel tractor mounted mobile maize sheller

According to [9], a study was conducted to develop a cost effective two wheel tractor mounted mobile maize sheller for small-scale farmers in Bangladesh in South Asia. Two-wheel tractor (power tiller) is a common tillage tool in Bangladesh agriculture because it can easily access fragmented land that is affordable to small scale farmers. Traditionally, maize shellers need to be carried from place to place by hooking with two-wheel tractor (2WT) and set it up again for shelling operation. This takes longer time for preparation of maize shelling.

To consider this problem and constraint, a small cost-effective mobile maize sheller was developed, which is mounted on the front side of the two-wheel tractor (**Figures 7** and **8**).

So, the driver of the 2WT carry and move the sheller along in the 2WT driving position. The engine of 2WT is used as a power source for operating the maize sheller.

The mobile maize sheller eradicates the transportation problem and can start shelling operation instantly at any place since it is attached together with 2WT. It is counter clockwise rotating cylinder, axial flow type sheller and grain separated with a resistance between spike tooth and the concave. The maize sheller is attached with nuts and bolts in front of the engine base of 2WT. The operating power of the sheller comes from the fly wheel of the engine of the tractor through a V-belt and a pulley.

The shelling performance of the mobile maize sheller is shown in **Table 4**. The shelling capacity, shelling broken kernel and cylinder loss of the mobile maize sheller were 2100 kg/h, 2.3 and 0.35%, respectively. The efficiency of the mobile maize sheller was 97%.

Effective operating hours of mobile maize sheller is more than that of the traditional maize sheller (**Table 5**). This is because shelling unit of the mobile maize sheller is assembled with the transportation power unit and service providers freely carry the maize sheller to different farmers' home yards in assembly position. This therefore, reduces the maize sheller installation and starting time. The effective operating hours/day were 6.5 and 4.5 hours for the mobile maize sheller and immobile maize sheller, respectively. Mobile maize sheller saves 2 hours/day that is this sheller can be used for an additional 2 hours in day compared to the immobile maize sheller. The shelling cost for mobile maize sheller was 0.0026 USD/kg of grain which was lower than 0.012 USD/kg for the immobile maize sheller (**Table 6**).

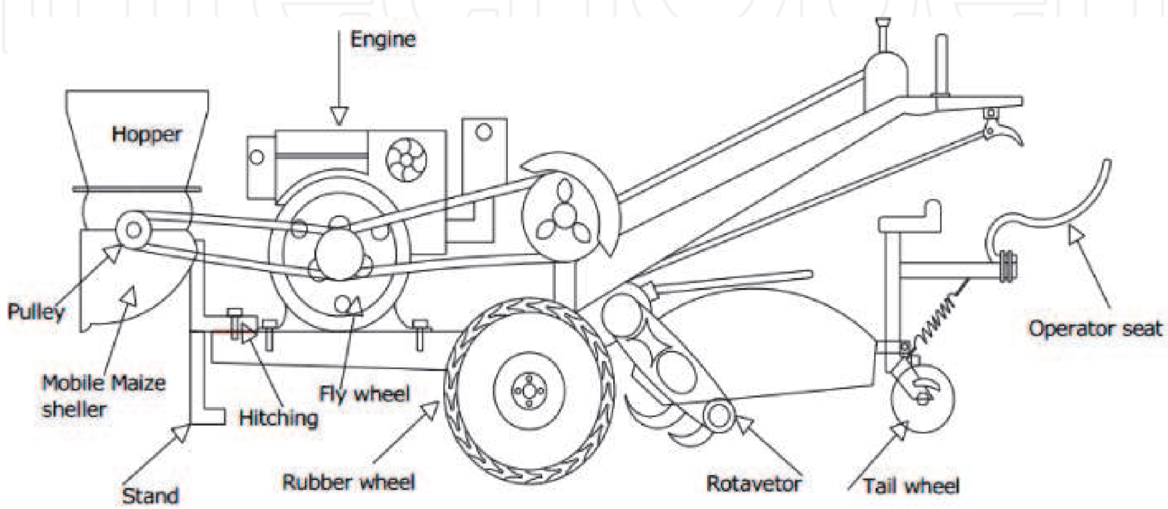

Figure 7.
Side view of the two-wheel tractor with the mobile maize sheller [9].

Figure 8.
Operational view of the two-wheel tractor mobile maize sheller [9].

Performance parameter	Units	Measured value
Cylinder speed	rpm	1250
Throughput capacity	kH/h	3150
Average shelling capacity	kg/h	2100
Cylinder loss	%	0.35
Separating loss	%	0.40
Broken kernel	%	2.20
Shelling efficiency	%	97

Table 4.
Shelling performance of the mobile maize sheller [9].

Maize sheller name	Average effective use, hours/day	Time saving, hours/day
Mobile maize sheller	6.5	2
Immobile maize sheller	4.5	—

Table 5.
Effective use hours of mobile maize sheller versus immobile maize sheller [9].

Maize sheller types	Shelling cost, USD/kg	Shelling cost, USD/year	Net return, USD/kg	Net return, USD/year	BCR
Mobile maize sheller	0.0026	3.416.72	0.012	17,646.94	5.16
Immobile maize sheller	0.012	—	—	—	—

Table 6.
Shelling cost of the mobile and immobile [9].

The lower shelling cost of the mobile sheller can be attributed to the extra two hours that it can operated per day compared to the immobile maize sheller. The benefit–cost ratio (BCR) of the mobile maize sheller was 5.15.

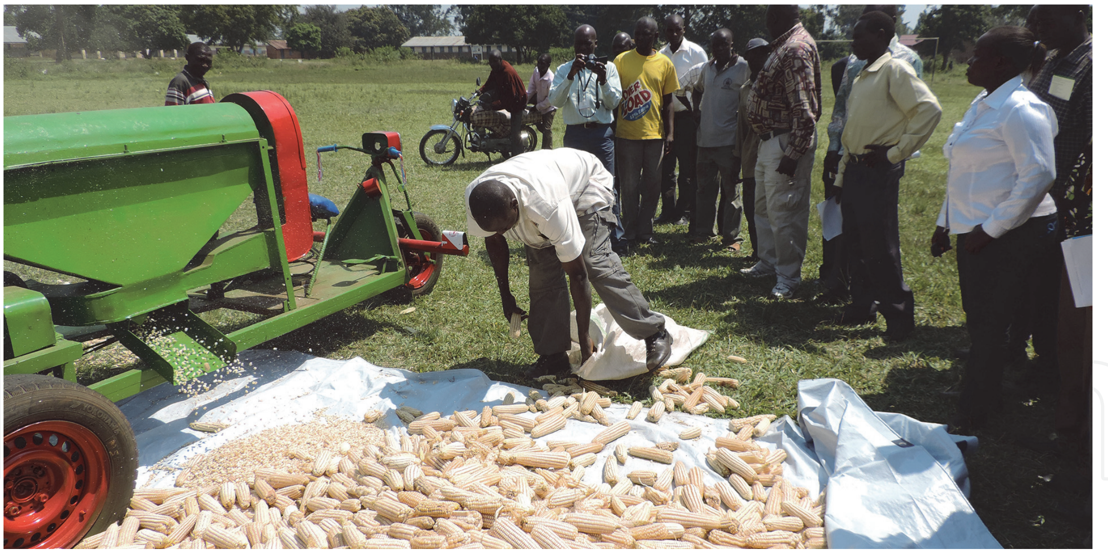

Figure 9.
Operational view of the Munyegera Agro-Machinery mobile maize sheller [10].

6.3 Case study 3: Munyegera Agro-Machinery mobile maize sheller

The last case study is from [10] about a mobile maize sheller (**Figure 9**) designed and fabricated by an enterprising fabricator Munyegera Agro-Machinery in Eastern Uganda with encouragement, advice, training, and initial funding from Non-Government Organization (NGO) Sasakawa 2000.

Although there is not much scientific information on its design, fabrication, and evaluation, it can be noted that this mobile maize sheller capacity is 2000–3000 kg/h [10] which is higher than most motorized immobile maize shellers. This can be attributed to the bigger shelling unit of the mobile maize sheller compared to the motorized immobile maize shellers. Operation of this mobile maize sheller requires three to four workers. Hence, whether a self-employed agent or large-scale farmer service enterprise like the Bugiri Agribusiness Initiative Development Association, youth are typically hired to operate and maintain the maize shellers which has contributed to rural enterprise growth and job creation.

Feed the Future Uganda Commodity Production and Marketing (CPM) initially cost-shared 70 these mobile maize shellers in 2015, particularly with large traders and farmer organizations linked to village agents to demonstrate the benefits of this technology [10]. On observing the benefits, some traders started buying the mobile shellers and have their village agents operate them. Apex farmer organization also purchased the mobile maize shellers to provide the mobile maize shelling service to their members. As of March 2016, many CPM clients acquired 280 mobile maize shellers [10]. CPM worked with Munyegera Agro-Machinery to train more than 200 operators in operations and maintenance, as well as maize quality control with an idea that shellers will be offering premium prices on behalf of their buyers.

7. Conclusion

This book chapter's main aim was to describe the maize shelling operations in low developing countries with focus on the need for a paradigm shift from immobile maize shellers to mobile maize shellers. Compared with immobile maize shellers, mobile maize shellers have the potential to solve the power problem as well as sheller transportation problem and the extra energy required to lift the maize shellers up and down during the shelling process. In addition, mobile maize shellers save time hence increasing their effective use hours in the field. To maximize the shelling operation, it is recommended that the moisture content of maize is maintained between 12 and 13% at a shelling speed of 880 rpm. Also, the clearance between the spikes and the concave should always be designed depending on the maximum and minimum diameters of the maize cobs.

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Conflict of interest

The authors declare that there is no conflict of interest.

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†Dedicated to the author Noble Banadda who passed away while this book chapter was being prepared.

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