Performance Evaluation of Motorized Maize Sheller

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Abstract. Maize is the major food crop, with highest yield and production in Ethiopia. At the same time, postharvest losses in maize production are very high. Maize shelling is one of the main stages of postharvest loss in maize production. The traditional method of maize shelling is tedious, time consuming and less productive. Hence, this research project focuses on modifying and evaluating the Bako maize sheller for better performance. In doing so, evaluation site and participant farmers were selected, and the performance tests were conducted according to FAO standard test procedures. The experiments were conducted with two commonly grown varieties of maize, BH661 and LIMU (P3812W), at two different moisture contents each. In addition, farmers' opinion about the evaluated sheller and the traditional method of shelling was assessed. The results show that the capacity of the modified sheller improved by 29% without compromising any other performance parameter of the original design. Moreover, higher shelling capacity has been recorded at lower moisture content for both maize varieties. As the moisture content decreased by 2.7% for BH661 and 3.5% for Limu, the shelling capacity increased by 326.2 kg/h and 543.333 kg/h, respectively. There is no significant variation in shelling efficiency, grain damage and cleaning efficiency for both varieties among treatments. Scattering losses are increased significantly as the moisture content of the maize kernel decreased.

Keywords: Maize sheller · Shelling performance · Shelling efficiency

1 Introduction

Maize is Ethiopia's leading cereal in production, with 7.8 million metric tons (t) produced in 2016 cropping season by 10.9 million households from 2.14 million hectares of land [1]. According to the report of Ethiopian central statistical agency (CSA), out of the total cultivated area in 2016, 81.27% was covered by cereals, from which teff, maize, sorghum, and wheat covered 24%, 16.98%, 14.97% and 13.49%, respectively. Cereals contributed 87.42% of the total grain production from which maize, teff, wheat and sorghum accounted for 27.02%, 17.27%, 15.63% and 16.36%, respectively. The national annual average production of maize, teff, wheat, and sorghum in the same season was 3.7, 1.7, 2.7 and 2.6 t/ha, respectively [1]. Compared to other cereals, maize has the highest potential yield per unit area. This shows that maize has become Ethiopia's major and strategic crop among cereals to improve farmers' livelihood.

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Smallholder farmers mostly produce maize for subsistence, with 75% of the production being consumed by the farming household. According to International Food Policy Research Institute (IFPRI) 2010, maize is the cheapest source of calorie intake in Ethiopia, providing 20.6% of per capita calorie intake. Thus, it can be said that maize is an important crop for overall food security.

Maize is consumed as "Injera," Porridge, Bread and "Nefro." It is also consumed roasted or boiled as vegetables at green stage. The leaf and stalk are used for animal feed and dried stalk & cob are used for fuel. Moreover, it also supported the growing demand for industrial use [2].

In the Ethiopian context, the common methods of shelling maize under small-scale farmers' conditions are manual. This shelling activity can be done by stripping with fingers, rubbing two cobs against each other, rubbing cob on rough stone, and/or beating cobs or bagged cobs with sticks. All these traditional maize shelling methods are highly tedious, inefficient, require a lot of labor, and have outputs of a few kilograms an hour. Moreover, kernel damages in the form of bruises, cracks and/or breakage are inevitable with these shelling methods. Such kernel damage facilitates the infestation of pests during storage. Hence, maize shelling is one of the main problems encountered by the farmers in maize production and postharvest handling. To solve this problem, so many attempts have been made by governmental and non-governmental institutions to develop and introduce different types of maize shellers for smallholder farmers [3–5]. Even though attempts to introduce different types of maize shellers for farmers have been made, it has not been adopted until recent times. In some areas, adoption of motorized maize shellers is increasing, and maize producers are very keen to get shelling service through hiring [6].

Thus, there is a need to design, develop, and introduce appropriate maize shellers that reduce postharvest loss, increases labor and time productivity, and reduces drudgery. Hence, this research project focuses on modifying the Bako maize sheller to improve performance, and evaluating the sheller with farmers for further promotion and modification activities. This will facilitate the adoption of the technology by smallholder farmers.

2 Materials and Method

2.1 Participant Farmers' Selection

This participatory evaluation was conducted in North Western Ethiopia, at the Amhara region in Bure Woreda, Wadra Kebele, where most of the farmers grow maize as a major crop. To conduct the experiment with farmers' participation, one Farmers Research Group (FRG) was organized in collaboration with village level development agents. Gender, accessibility for demonstration sessions in the farm and willingness to use the maize sheller were considered as selection criteria from the FRG members. Ten farmer households were selected, from which four of them were female headed.

2.2 Description of the Maize Sheller

The sheller was initially made by Bako Rural Promotion Centre, for shelling maize. The average capacity of the maize sheller is 4,100 kg/h, with shelling efficiency of 98.3%. The average grain breakage and unshelled grain is 4.99% and 1.73%, respectively. The sheller uses 14 horse power (HP) diesel engine and the fuel consumption is 3.125 L/h [3, 4]. In order to improve the performance of the sheller, slight modification were made. The major modification was to increase the torque of the sheller drum by increasing the pulley size (both in diameter and weight). In the previous model the diameter of the pulley was 450 mm and in the modified model it was 500 mm.

The modified version of sheller also uses 14 horse power (HP) diesel engine. The main components of the sheller include: feeding hopper, shelling drum with perforated concave, blower, grain discharging auger, power transmission system and diesel engine. The sheller operates on the principle of axial flow movement of material. Shelling is done by the impact between a high-speed cylindrical drum and a perforated concave, equipped with three radial arranged bars at 120° along the axis mounted on its periphery. At the one end of the cylindrical drum the profile of the radial bars is changed to eject the shelled cob through the shelled cob outlet. The shelled grain and fine chaffs pass through the perforated concave and the air coming from the blower removes the chaff and other lighter materials. The clean grain falls to the lower chamber, and the grain discharging auger moves the grain through the outlet.

Sheller operation requires a total of 10 operators. Seven are required to feed the hopper with unshelled cobs, two work on the grain outlet, and one on the cob outlet side.

2.3 Assessing the Common Method of Maize Shelling in the Study Area

The common method of maize shelling in the study area was assessed through interview, observation and measurements of grain breakage. Average labor requirement and general demographic information (gender, age and role in the household) of each operator was recorded for this study.

2.4 Participatory Performance Evaluation of the Sheller

Performance evaluation tests were conducted for two common hybrid varieties of maize grown in the area: LIMU and BH661. The performance of the sheller was evaluated on shelling efficiency, cleaning efficiency, grain damage, unshelled grain, scattering loss and fuel consumption. FAO test procedure for evaluating maize shellers was used [7]. During evaluation, ease of handling, adjustment of working parts, and overall performance under farmers' opinion was recorded. Group and individual discussions were made with farmers.

Samples were taken according to [7] to determine grain parameters and sheller performance. Two digital balances, with measurement range of 0–40 kg ± 0.001 kg and 0–5 kg ± 0.0001 kg were used to measure grains and cob samples before and after shelling process. A digital optical tachometer with an accuracy of 0.04% ± 2 was used to measure the rotational shaft speeds of the sheller. Fuel consumption was measured by filling the engine fuel tank completely at the start and end of each time-recorded period and weighing the quantity of fuel added using graduated cylinder with an accuracy of ±1 ml.

Maize grain parameters, variety, moisture content (MC), grain cob ratio (GCR), maize grain per cob (MGC), cob length (CL) and diameter (CD), were determined.

Oven dry method was used to determine the moisture content of maize in dry basis (DB). Vernier caliper with an accuracy of ±0.05 mm and steel measuring tape with an accuracy of ±1 mm were used to measure the cob diameter and length, respectively. Each test was conducted for two minutes and replicated three times for each variety, for two different moisture contents (Table 1).

Table 1. Crop parameters under experimentations.

Trial #	Variety	Mean MC (%)	Mean MGC	Mean GCR	Mean CL (mm)	Mean CD (mm)
1	LIMU	12.8 ± 1.0	0.84	4.7	180.5	48.0
2	LIMU	16.3 ± 0.7				
3	BH661	12.4 ± 0.9	0.84	5.3	201.8	46.3
4	BH661	15.1 ± 0.8				

The following measurements were also recorder: feed rate of cobs per unit time, weight of shelled grains at all outlets per unit time, weight of shelled grains at main outlet per unit time, weight of grain and residue mixture per unit time, weight of shelled damaged grains at all outlets per unit time, weight of shelled and unshelled grains at cob outlet per unit time, fuel consumed per unit time and rotational speed of the shelling drum and the input shaft with load and without load. Using mean values of the replications, shelling capacity (SC), shelling efficiency (SE), cleaning efficiency (CE), percent grain damage (GD) and percent scattering loss (SL) were estimated.

$$SC = \frac{Wa}{St} \tag{1}$$

$$SE(\%) = 100 - Ug(\%) \tag{2}$$

$$Ug(\%) = \frac{Wu}{TWK} * 100 \tag{3}$$

$$CE(\%) = \frac{Wm}{Wr} * 100 \tag{4}$$

$$Gd(\%) = \frac{Wd}{Wm} * 100 \tag{5}$$

$$SL = \frac{Wc}{TWK} * 100 \tag{6}$$

Where,

– St - shelling time
– Wa - weight of shelled grain per unit time at all outlet
– Ug - percent unshelled grain

– Wu - weight of unshelled kernel
– Wm - weight of shelled grain per unit time at main outlet
– Wr - weight of grain & residue mixture per unit time at main outlet
– Gd - percent grain damage
– Wd - weight of damaged grain
– Wc - weight of grain collected at dust and cob outlet
– TWK - total weight of kernel fed in to the hopper

2.5 Collecting Feedback from Participating Farmers

Farmers who participated during demonstration were encouraged to give their opinions about the maize sheller, based on observed performance, ease of handling and transportation, and their own selection parameters. Feedbacks were collected through semi-structured interviews and focus group discussions. Some of the issues discussed with the farmers during the discussions were:

- Quality of work in their observation, these include seed and cob breakage, shelling loss, cleaning efficiency in comparison to traditional shelling method and other mechanized sheller if they have previous acquaintance
- Threshing performance in comparison to traditional shelling method and other mechanized sheller if they have previous acquaintance
- Suggestions for future improvements of the demonstrated maize sheller
- Their willingness to use the technology

The figure below shows the event of on farm evaluation of the motorized maize sheller with participant farmers (Fig. 1).

Fig. 1. Motorized maize sheller during on farm evaluation

2.6 Data Analysis

Measurements were taken for crop and operating parameters. Multivariate analysis were performed on the experimental data collected using SPSS version 17 computer-based software. Mean difference between treatments were done using the LSD at 5% level of significance. Narrative summary and descriptive statistics were used.

3 Result and Discussion

3.1 Common Method of Maize Shelling in the Study Area

In the study area the common method of maize shelling is rubbing cob on rough stone and beating cobs with sticks. The majority of shelling activity was done by women and children. This method of maize shelling is tedious, time consuming and less productive. Moreover, higher grain damages, on average 7.1% for grain moisture content of 12.5% (DB), was observed. Farmers prefer to use the method of beating cobs with sticks when more than 1,500 kg of maize will be shelled. According to the response of the farmers, it requires 4 to 5 man-day to shell 1,600 to 2,000 kg of maize with average composition of 1–2 adult men, 2 children, 1–2 women.

Recently, mechanical shellers were introduced by service providers through custom hiring, with rate of 20ETB for 100 kg of shelled maize. As it has been expressed by farmers, using these threshers the grain damage and cob breakage is higher. They use the cob as a fuel for cooking food; hence, they prefer whole cob. As mentioned, by women farmers, as the grain damage increases, the processing quality of the grain is generally decreased.

Maize is mainly used to prepare a local beverage called '*tella*'. The first step in this process is roasting the maize. The broken grain will roast faster, and the unbroken grain will roast slower. Hence, it becomes difficult to get optimum level of roasting. Even though, the introduced shellers have limitations, as expressed above, it was observed that farmers were interested to use these mechanized shellers, but the supply is limited, hence there was too much waiting.

3.2 Shelling Performance of the Evaluated Maize Sheller

Estimated marginal mean shelling performance parameters were analyzed under two different moisture contents for BH661 (Table 2) and Limu (Table 3).

Shelling Capacity. The previous model Bako maize sheller has a shelling capacity of 4,100 kg/h to 5,000 kg/h for different variety of maize at different moisture content [3, 4]. The current modified model has a shelling capacity of 5,800 kg/h to 7,000 kg/h. This shows that shelling capacity was improved by 29% without compromising any other performance parameters.

The results show that, higher shelling capacities were recorded at lower moisture contents for both varieties. As the moisture content decreased from 15.1% to 12.4% for BH661 variety, the shelling capacity increased by 326.2 kg/h. The results show that this mean difference is significant at 0.05 level of significance (Table 4). Similarly, for Limu (P3812W) maize variety, as the moisture content decreased from 16.3% to 12.8%, the shelling capacity increased by 543.333 kg/h, and this increment is significant at 0.05 level of significance (Table 5). Similar results have been reported previously [8, 9].

Table 2. Estimated marginal means shelling performance parameters for BH661

Dependent variable	Moisture content (%)	Mean	Std. error	95% confidence interval	
				Lower bound	Upper bound
Shelling capacity (kg/h)	12.4 ± 0.9	6343.23	77.87	6127.03	6559.43
	15.1 ± 0.8	6017.03	77.87	5800.83	6233.23
Shelling efficiency (%)	12.4 ± 0.9	99.83	0.03	99.74	99.93
	15.1 ± 0.8	99.67	0.03	99.57	99.76
Grain damage (%)	12.4 ± 0.9	2.30	0.07	2.09	2.51
	15.1 ± 0.8	2.07	0.07	1.86	2.27
Cleaning efficiency (%)	12.4 ± 0.9	98.93	0.14	98.55	99.32
	15.1 ± 0.8	98.77	0.14	98.38	99.15
Scattering loss (%)	12.4 ± 0.9	9.00	0.22	8.40	9.60
	15.1 ± 0.8	4.30	0.22	3.70	4.90
Fuel consumption (L/h)	12.4 ± 0.9	3.07	0.11	2.76	3.38
	15.1 ± 0.8	3.01	0.11	2.71	3.32

Table 3. Estimated marginal means shelling performance parameters for LIMU

Dependent variable	Moisture content (%)	Mean	Std. error	95% confidence interval	
				Lower bound	Upper bound
Shelling capacity (kg/h)	12.8 ± 1.0	6888.23	69.96	6693.99	7082.48
	16.3 ± 0.7	6344.90	69.96	6150.66	6539.14
Shelling efficiency (%)	12.8 ± 1.0	99.77	0.07	99.56	99.97
	16.3 ± 0.7	99.50	0.07	99.29	99.71
Grain damage (%)	12.8 ± 1.0	1.90	0.05	1.77	2.03
	16.3 ± 0.7	1.83	0.05	1.70	1.96
Cleaning efficiency (%)	12.8 ± 1.0	98.77	0.11	98.45	99.08
	16.3 ± 0.7	98.93	0.11	98.62	99.25
Scattering loss (%)	12.8 ± 1.0	9.03	0.25	8.33	9.74
	16.3 ± 0.7	6.27	0.25	5.56	6.97
Fuel consumption (L/h)	12.8 ± 1.0	3.00	0.11	2.69	3.30
	16.3 ± 0.7	3.05	0.11	2.75	3.36

Table 4. Mean difference between treatments for maize variety of BH661

Dependent variable	Mean difference (I-J)	Std. error	Sig.[a]	95% confidence interval for difference[a]	
				Lower bound	Upper bound
Shelling capacity (kg/h)	326.200*	110.124	0.041	20.447	631.953
Shelling efficiency (%)	0.167*	0.047	0.024	0.036	0.298
Grain damage (%)	0.233	0.105	0.091	−0.059	0.526
Cleaning efficiency (%)	0.167	0.197	0.446	−0.381	0.714
Scattering loss (%)	4.700*	0.306	0.000	3.852	5.548
Fuel consumption (L/h)	0.057	0.156	0.735	−0.376	0.490

*. The mean difference is significant at the 0.05 level.
a. Least significant difference (equivalent to no adjustments).

Table 5. Mean difference between treatments for maize variety of LIMU

Dependent variable	Mean difference (I-J)	Std. error	Sig.[a]	95% confidence interval for difference[a]	
				Lower bound	Upper bound
Shelling capacity (kg/h)	543.333*	98.940	0.005	268.633	818.034
Shelling efficiency (%)	0.267	0.105	0.065	−0.026	0.559
Grain damage (%)	0.067	0.067	0.374	−0.118	0.252
Cleaning efficiency (%)	−0.167	0.160	0.356	−0.611	0.277
Scattering loss (%)	2.767*	0.359	0.002	1.770	3.763
Fuel consumption (L/h)	−.057	0.156	0.735	−0.490	0.377

*. The mean difference is significant at the 0.05 level.
a. Least significant difference (equivalent to no adjustments).

Shelling Efficiency, Grain Damage and Cleaning Efficiency. The results show that, the mean difference between treatments on shelling efficiency, grain damage and cleaning efficiency have slight variations for both varieties. These variations are not statistically significant at 0.05 level of significance, except for shelling efficiency of BH661 variety (Tables 4 and 5).

Scattering Loss (%). The results show that, higher percentages of scattering losses have been recorded at lower moisture contents for both varieties. As the moisture content decreased from 15.1% to 12.4% for BH661 variety, scattering loss increased by 4.70%. Similarly, for Limu (P3812W) maize variety, as the moisture content decreased from 16.3% to 12.8%, the scattering loss percentage increased by 2.767%. These increments were significant at 0.05 level of significance (Tables 4 and 5). These losses were collected at dust and cob outlet. This is because as the moisture content decreases, the weight of the grain decreases, thus some grain will be blown with the dust.

Fuel Consumption. The results show that no significant difference was observed in fuel consumption for both trials among treatments. The average fuel consumption for BH661 and LIMU varieties were found to be 3.04 L/h (Table 4) and 3.03 L/h (Table 5), respectively. Moreover the average fuel consumption without load was found to be 1.14 L/h.

Engine and shelling drum rpm. The average rotational speed of the shelling drum with load and without load was 600.85 ± 4.58 and 619.42 ± 0.86 respectively. The average rotational speed of the engine with load and without load was 3193.08 ± 22.74 and 3211.69 ± 6.32 respectively.

Table 6. Mean fuel consumption, shelling drum and prime mover speed

Parameters	Units	Without load	With load
Average fuel consumption	L/h	1.14	3.04
Average drum speed	rpm	619.42 ± 0.86	600.85 ± 4.58
Average prime mover speed	rpm	3211.69 ± 6.32	3193.08 ± 22.74

3.3 Farmers' Opinion About the Evaluated Maize Sheller

Farmers who participated during the demonstration were encouraged to give their opinions about the maize sheller, based on observed performance, ease of handling and transportation, and their own selection parameters. According to their response, they are satisfied with the quality of work performed by the sheller. Excellent performance was observed by participant farmers regarding seed and cob breakage, shelling loss, cleaning efficiency. Nevertheless, farmers observed that the portability of the sheller has some limitations. It was observed that transporting the sheller from place to place is very difficult. Hence, farmers have suggested to incorporate a wheel and animal harnessing system to be pulled by draft animals to transport easily from place to place.

4 Conclusion

From this participatory evaluation research, the following conclusions can be made:

- The shelling capacity of the modified model is improved by 29% from the previous Bako model maize sheller without compromising any other performance parameters.
- Shelling capacity increased significantly, as the moisture content of the maize kernel decreased.
- Shelling efficiency, grain damage and cleaning efficiency has shown no significant difference as the moisture content of the maize varies from 12.4% to 16.3%
- Scattering losses increased significantly, as the moisture content of the maize kernel decreased.
- Traditional maize shelling is less productive, requires 4 to 5man-day to shell 1,600 kg to 2,000 kg of maize, and drudgeries. Hence, farmers have showed interest for mechanical threshers.
- For the farmers, the evaluated maize sheller has excellent performance in shelling maize regarding seed and cob breakage, shelling loss, cleaning efficiency, shelling capacity and efficiency. The sheller has some difficulties to transport from place to place. Hence farmers have suggested that to incorporate wheel and animal harnessing system to be pulled by draft animals.

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