Comparative evaluation of mechanised and manual threshing options for Amankwatia and AGRA rice varieties in Ghana

Shadrack Kwadwo Amponsah,[1] Ahmad Addo,[1] Komla Dzisi,[1] Jean Moreira,[2] Sali Atanga Ndindeng[2]

[1]Department of Agricultural Engineering, KNUST, Kumasi, Ghana; [2]Africa Rice Centre, Cotonou, Benin

Abstract

Performance of a Yanmar DB 1000 mechanised paddy thresher was comparatively assessed against manual threshing by impact method using a locally-made wooden box for Amankwatia and AGRA rice varieties under farmer's field conditions at Nobewam in the Ashanti Region of Ghana. The mechanised thresher was evaluated at various threshing drum speeds (550 rpm, 600 rpm and 650 rpm) and feeding rates (200 kgh^{-1}, 400 kgh^{-1} and 600 kgh^{-1}). Results showed that threshing was satisfactory at grain moisture content between 16.9% w.b. and 18.0% w.b. for both rice varieties. Threshing efficiency increased from 94.6% to 95.8% with no significant difference observed whereas cleaning efficiency decreased significantly from 84.2% to 81.6% with increasing feed rate irrespective of rice variety. Again, threshing efficiency increased with increasing drum rotational speed, irrespective of feed rate and rice variety. Percentage broken grain and grain loss both increased with increasing peripheral drum speed and paddy feed rate irrespective of rice variety. Average fuel consumption, physical energy requirement and threshing capacity increased significantly with increasing drum speed and feed rate. Crop moisture content and shattering ability influenced the threshing efficiency, threshing capacity, grain loss, broken grain, fuel and physical energy requirement at threshing. AGRA rice variety generally performed better than Amankwatia under both mechanical and manually threshing methods. Mechanised threshing was significantly better at reducing grain loss and physical energy demand whilst yielding over 200% higher threshing capacity than manual threshing by impact using the wooden box. Mechanised threshing was financially rewarding, yielding over 500% higher profit margin than the manual threshing option. Further research on optimum crop moisture content for improved threshing of different rice varieties is suggested.

Correspondence: Shadrack Kwadwo Amponsah, Department of Agricultural Engineering, KNUST, Kumasi, Ghana.
E-mail: skamponsah@hotmail.com

Key words: Amankwatia; drum speed; efficiency; feed rate; mechanised; threshing.

Acknowledgements: the authors wish to acknowledge the financial support from the Africa Rice Centre, through the Support to Agricultural Research for Development of Strategic Crops in Africa (SARD-SC) project. We wish to also express our gratitude to the field staff of the CSIR-Crops Research Institute, Kumasi, Ghana and the rice farmers at Nobewam, Ashanti Region, Ghana who played a part in making the study a success.

Received for publication: 14 February 2017.
Accepted for publication: 8 May 2017.

Journal of Agricultural Engineering 2017; XLVIII:684
doi:10.4081/jae.2017.684

Introduction

Rice is important to Ghana's economy and agriculture, accounting for nearly 15% of the gross domestic product (ISSER, 2000). The crop has become the second most important food staple after maize and its consumption keeps increasing as a result of population growth, urbanisation and change in consumer habit (MoFA, 2009). reported that between 2005 and 2010, Ghana ranked among the top 50 rice producers worldwide, dropping out of the list only in 2007. In addition to being a staple food mainly for high income urban populations, rice is also an important cash crop in the communities in which it is produced (Angelucci *et al*., 2013). Ghana depends heavily on imported rice (Campbell *et al*., 2009; Angelucci *et al*., 2013) with the crop constituting 58% of all cereal imports (Osei-Asare, 2010). It is estimated that the country imports between US$200 million and US$400 million worth of rice annually which accounts for more than 50% of all rice consumed in the country. The amount is said to be one of the major factors that swells the country's import bill, greatly affecting foreign exchange (Okine, 2014).

Harvesting and threshing operations are known as crucial and influential processes on quantity, quality and production cost of rice (Alizadeh and Bagheri, 2009; Alizadeh and Allameh, 2013). A report by Osei-Asare (2010) identified inadequate appropriate harvesting technology/equipment as a major problem that may constrain rice production in Ghana. This has made it difficult for area expansion as far as production is concerned. Khan (1971) and IDRC (1976) added that the problem of harvesting and threshing is worsened with the introduction of more productive rice varieties because of the greater amount of crop that has to be handled. Rice could either be manually or mechanically threshed. In Ghana, threshing is traditionally achieved by beating harvested rice panicles against a wooden box or metal barrel or by beating cut panicles with sticks to detach grains. According to Appiah *et al*. (2011), the output of these manual threshing methods ranges from 0.01 kg to 30 kg of grain per man-hour depending on the variety of rice, condition of rice, the method applied and rice losses recorded. Rickman *et al*. (2013) also reported that the manual threshing method is popular due to its associated low cost; however, quantitative and qualitative losses can be as high as 20-30%.

Ghana has made serious efforts in the recent past to introduce few rice harvesting technologies from Asia to help boost the rice sector (Rickman *et al*., 2013). Between 2007 and 2010 alone, the government through the Agricultural Engineering Services Directorate, MoFA imported 30 rice reapers, 30 rice threshers and 39 rice combines to be supplied to smallholder farmers across the country (MoFA SRID, 2011). Unfortunately, these efforts have not really achieved expected results because, aside the fact that such machinery are unaffordable and in most cases unavailable to these resource-poor farmers, they are not well suited to local conditions (Osei-Asare, 2010). Hand and pedal threshers (500 kgd^{-1} capacity) have been widely adopted in Burkina Faso, Guinea, Liberia, Madagascar and Sierra Leone. According to Rickman *et al.* (2013), these threshers can now be built locally for use by small-scale farmers and seed producers. However, due to the high amount of physical energy required to operate these threshers, there has been an increased desire within the region for mechanised threshers. Similarly in Ghana, the low quality of rice produced through the use of traditional threshing methods, labour shortage, reduced turn-around time and use of high yielding varieties have forced farmers to shift to mechanised grain threshing (Akolgo *et al*., 2015).

Since its introduction to Ghana in 2009 from Japan, the Yanmar DB 1000 thresher has only been evaluated on Jasmine 85 rice variety to assess the extent and causes of grain loss (Akolgo *et al*., 2015). There's the need to further assess the thresher under varying field and crop conditions in comparison to existing manual threshing methods. Such information on technical and economic performances of existing rice threshing systems will not only offer farmers the opportunity to access different mechanisation options but is also crucial in facilitating future improvement on technology design and overall efficiency. This will consequently ensure acceptability and promote better adoption of improved harvesting technologies by smallholder rice farmers. Studies by Špokas *et al.* (2008) indicated that the design and technological parameters of the threshing apparatus influence grain losses. Ajav and Adejumo (2005) assessed the performance of an Okra thresher by taking moisture content, cylinder speed and feed rate as independent parameter to obtain the maximum threshing efficiency. Research by Gol and Nada (1991) showed that speed of operation and condition of crop are important factors affecting the efficiency of a mechanical threshing or stripping unit. Drum peripheral speed and feed rate has also been found to significantly influence threshing capacity and paddy grain loss (Akolgo *et al*., 2015; Olaye *et al*., 2016).

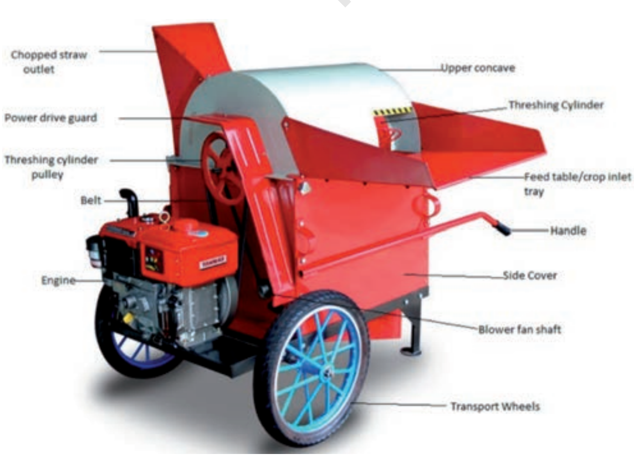

Figure 1. Labelled pictorial view of the Yanmar DB 1000 mechanised rice thresher.

Objectives of study

The main objective of this study was to evaluate the performances of mechanised and manual threshing methods for two rice varieties under farmer's field conditions. Specific objectives of the study were to: i) assess the effect of drum rotational speed and feed rate on threshing efficiency, cleaning efficiency, threshing (output) capacity and fuel consumption of the mechanised thresher; ii) determine the percentage broken grains, percentage grain loss, threshing capacity and level of drudgery associated with both mechanised and manual rice threshing methods for AGRA and Amankwatia rice varieties; iii) assess the economic feasibility of using the mechanised and manual rice threshing options.

Materials and methods

Study location and rice variety

The study was conducted at Nobewam in the Ejisu-Juaben municipality located in the Ashanti Region of Ghana under farmer's field conditions. The field was planted to both *Amankwatia* and AGRA rice varieties using seedling-transplanting method.

Machine specification

Figure 1 illustrates a labelled pictorial view the Yanmar DB 1000 mechanised thresher (Yanmar Co., Ltd., Osaka, Japan). Prior to field evaluation, the following technical parameters/condition of the machine were determined; overall dimensions and weights, power source, details of feeding arrangements, details of threshing unit, type of sieve(s), details of fan(s), method of transport and safety arrangements.

Table 1 presents the technical details and specifications of the Yanmar DB 1000 mechanised paddy thresher.

Table 1. Technical specifications of the Yanmar DB 1000 mechanised paddy thresher.

Parameter	Specification
Model	DB 1000 Yanmar paddy thresher
Dimensions: length×width×height (mm)	1034×1200×1462
Engine model	Diesel engine TF55H-di
Engine output (kW/rpm)	4.0/2200
Net weight (kg)	130
Feeding type	Throw-in
Feeding desk height (mm)	944
Threshing teeth type	Swirl
Threshing cylinder type	Axial-flow
Concave clearance (mm)	15-25
Diameter of threshing drum (mm)	500
Length of threshing drum (mm)	1000
Shaft rotation speed (rpm)	550-650
Cleaning mode	Fan blast
Fan type	Agricultural centrifugal type
Screen type	Steel square bar
Threshing capacity (kgh^{-1})	1000

Manual threshing

Paddy was manually threshed by impact method with the help of a locally-made wooden box. The wooden box (both ends open) is square in top cross-section and tapers down to the other square cross-section bottom. A tarpaulin or plastic sheet is usually spread out on the threshing floor and the wooden box placed on it to ensure that grains that will fall outside the box are safely captured. The farmer holds the crop and beats the panicles severally on the inside of the wooden box (Figure 2). Detached grains end up inside the box, which are later collected when the box is full and the threshed crop thrown away.

Crop condition

The test condition of crop (variety, duration of crop, grain/straw ratio, grain/straw moisture content, grain size, percentage of damaged grain and crop height) were determined using appropriate procedures according to Smith *et al.* (1994).

Moisture content

From each harvested field to be threshed, 3 samples of approximately 0.5 kg each were randomly taken. The samples were placed in sealed plastic containers and taken to the laboratory where the grains and straw were separated by hand. The straw and grains from each sample were kept paired. After weighing with a sensitive electronic scale, the samples were oven dried at 130°C for at least 15 h and then reweighed. The moisture content (% w.b.) was calculated using Equation 1:

$$\text{Moisture content} = \frac{\text{weight of wet sample} - \text{weight of dry sample}}{\text{weight of wet sample}} \times 100 \quad (1)$$

Grain/straw ratio

After determining the weight of the dry samples, the result of the paired samples was used to calculate the mean grain/straw ratio using Equation 2:

$$\text{Grain/straw ratio} = \frac{\text{weight of dry grain}}{\text{weight of dry straw}} \quad (2)$$

Size of grains

From a representative sample of the test material, grain and straw were separated by hand and the size (grain diameter and length) of 50 grains measured. The average grain diameter and length was determined using a digital Vernier caliper with an accuracy of +/–0.02 mm. Grains were also inspected for damage and the damage calculated as a percentage of the total number of grains sampled.

Machine field test procedure

With the thresher set up in accordance with the manufacturer's instructions and threshing mechanism properly adjusted, runs were made at various threshing drum speeds (550 rpm, 600 rpm and 650 rpm) and feeding rates (200 kgh^{-1}, 400 kgh^{-1} and 600 kgh^{-1}). For each experimental run, bundles of harvested crop were manually fed into the threshing chamber at uniform rates and the time requirement for threshing was recorded. Any time for stoppages was recorded with the total testing time. Observations on factors affecting the operation of the machine were also recorded together with any adjustments and repairs. At the end of each test run, the machine was operated idle for 2 to 3 min to clear residue from respective outlets.

A digital tachometer (TA-114) was used to define the various drum speeds (rpm). Tests were carried out to determine the following parameters during threshing; grain quality (rubbish content, damage to grains, grain loss), rate of work (threshing efficiency, cleaning efficiency and output capacity). Fuel consumption and the level of physical energy requirement associated with threshing under each experimental run were also determined as described below.

Grain quality assessment

For each treatment (variable threshing drum speed and feed rate), three 500 g rice samples were collected from a larger amount of grain by placing the sample bottle in the stream of grain, which is entering the sacks at the grain outlet. The coning and quartering technique, according to NRI (2000), was used to collect representative samples for grain quality assessment. Whole grains and rubbish were separated by hand in the laboratory. Similarly, threshed grain samples after manual threshing with the wooden box were collected for grain quality assessment.

Damaged/broken grains

For damaged/broken grains assessment, three samples of 100 grains were randomly taken from the separated grain sample and manually checked for signs of fissure with the help of a magnifying glass. The percentage damaged/broken grain was then calculated using Equation 3.

$$\text{Broken grains (\%)} = \frac{\text{number of damaged/broken grains}}{\text{total number of grains in sample}} \times 100 \quad (3)$$

Grain loss

For grain loss assessment, grains collected through thresher main outlet were weighed and recorded as total grain input. All whole, broken and un-threshed grains from sieve and chaff outlets were collected and weight recorded. Scattered and blown grains were recovered by sweeping and gathering grains around the thresher. The percentage grain loss was calculated using Equation 4 according to Smith *et al.* (1994).

$$\text{Grain loss (\%)} = \frac{\text{lost grains from chaff and sieve outlet (kg)}}{\text{total grain input (kg)}} \times 100 \quad (4)$$

Figure 2. Paddy threshing by impact method using the wooden box.

For manual threshing, all grains, which fell outside the wooden box, were collected after threshing and loss calculated as a percentage of total grain yields.

Rate of work

Threshing efficiency

The net threshed grain received at main outlet with respect to total grain input expressed as percentage by weight is termed as threshing efficiency. The threshing efficiency was calculated using Equation 5 by Smith *et al.* (1994).

$$\text{Threshing efficiency}(\%) = 100 - \left[\frac{\text{unthreshed grains at all outlet per unit time (kg)}}{\text{total grain input (kg)}} \times 100\right] \quad (5)$$

Cleaning efficiency

Cleaning efficiency is the ratio of whole grains to whole material at thresher main outlet per unit time expressed as percentage by weight and was determined using Equation 6.

$$\text{Cleaning efficiency}(\%) = \frac{\text{whole grains at main grain outlet per unit time (kg)}}{\text{whole material at main outlet per unit time (kg)}} \times 100 \quad (6)$$

Threshing capacity

Threshing capacity (output capacity) is the weight of grains (whole and damaged) threshed and received per hour at the main grain outlet. At the end of each test, total threshed grain was collected from the main grain outlet. Similarly, for manual threshing, output capacity was determined by collecting and weighing all threshed grains within the wooden box. The threshing capacity was calculated using Equation 7 according to Smith *et al.* (1994).

$$\text{Threshing capacity (kg/h)} = \frac{\text{threshed grains at main outlet (kg)}}{\text{duration of test run (min)}} \times 60 \quad (7)$$

Fuel consumption

Fuel consumption was measured by filling the engine fuel tank completely at the start and finish of each harvesting period and recording the quantity of fuel added (Smith *et al*., 1994; Amponsah *et al*., 2014). A graduated measuring cylinder was used for the refilling. Fuel consumption was calculated on the basis of litres of fuel consumed per hour of machine operation.

Figure 3. The Polar (RS 800) watch and chest strap as worn by a person.

Harvesting drudgery

A Polar heart rate sensing device (RS 800) was used to obtain the heart rate of the operator during experimental trials with the Yanmar DB 1000 paddy thresher and manual threshing with the wooden box. Figure 3 shows the Polar heart rate (RS 800) watch and how the chest strap (with heart beat sensor) should be worn before an activity (Amponsah *et al*., 2014).

Before and after each physical activity, the person is allowed 10-min period of rest so the heart rate could be stabilised which are referred to as the rest and recovery periods respectively. Using the mean heart rate obtained for a specific physical activity to trace for a corresponding energy consumption value on the heart rate-energy conversion chart (Jones, 1988), the gross energy consumed (Watts) was determined.

Economic feasibility assessment

The cost of threshing (both mechanised and manual methods) was calculated by considering the fixed and variable costs. Fixed (ownership) costs include depreciation, interest, taxes, insurance, and shelter. Operating costs on the other hand, include repairs and maintenance, fuel, lubrication and operator charge. Total cost of the machine is the sum of its total fixed costs and total variable costs. Depreciation on mechanised thresher was calculated using the straight line method according to Hunt (1983) using Equation 8 whilst the interest on machine ownership was calculated using Equation 9.

$$\text{Depreciation} = \frac{\text{Purchase price} - \text{salvage price}}{\text{Economic life}} \quad (8)$$

$$\text{Interest} = \text{Rate}\left(\frac{\text{Purchase price} + \text{salvage price}}{2}\right) \quad (9)$$

Taxes, insurance and shelter are usually 1.0% of purchase price. Where 0.5% each of purchase price is allocated to insurance and shelter and 0% of purchase price for taxes (Hunt, 1983). Fuel cost depends on thresher's fuel consumption (Lha^{-1}), cost of fuel ($US\$l^{-1}$), threshing capacity ($kgh^{-1}$) and working hours per year. Lubricant cost is usually calculated as 15% of fuel cost unless lubricant consumption (Lha^{-1}) is otherwise stated (Kepner *et al*., 1982). Repairs and Maintenance (R&M) cost is usually 5% of machinery purchase cost per annum while labour cost depends on the number of farm hands required to complete a specific harvesting task and the rate charged per hectare (Hanna, 2001).

Based on calculated total cost of threshing and assumed per hour hiring cost, the expected revenue, profit and break-even cost were determined for each threshing method as used in (Fairhurst, 2012).

Experimental design

The results of paddy threshing trials and field measurements were statistically analysed as a split plot layout in randomised complete block design with 3 replicates, using GenStat Discovery Edition 3 (VSN International, 2011). In the comparative assessment of both manual and mechanised threshing options, main plot treatment was the threshing method and rice variety was the subplot treatment. However, in the analysis of the mechanised thresher performance, the main plot treatment was the rice variety whereas drum speed or feed rate was the subplot treatment. The least significant difference was used at the $P<0.05$ level of probability to test difference between treatment means. Analysis of variance was performed to determine the effects of drum speed and feed rate and their interaction on threshing quality and rate of work.

Results and discussion

Crop condition

Table 2 shows details of crop condition for Amankwatia and AGRA rice varieties before mechanised and manual threshing operations.

From Table 2, it could be seen that except for percentage grain damage, Amankwatia variety recorded greater values for all other parameters (grain moisture, straw moisture, grain-straw ratio, grain diameter, grain length and crop height) than AGRA rice variety.

Performance evaluation

Graph in Figure 4A shows the mean threshing and cleaning efficiencies of the Yanmar DB 1000 mechanised paddy thresher at varying feed rates. Threshing efficiency increased from 94.6% to 95.8% with increasing paddy feed rate from 200 kgh^{-1} to 600 kgh^{-1} with no significant ($P<0.05$) difference observed irrespective of drum peripheral speed and rice variety.

This could be explained based on the fact that with an increase in feed rate, more paddy gets into the machine's threshing unit to be threshed per unit time. This trend agrees with studies by Abo-El-Naga *et al*. (2015) on evaluation of a lentil thresher. Conversely, cleaning efficiency decreased significantly from 84.2% to 81.6% as feed rate increased from 200 kgh^{-1} to 600 kgh^{-1}. This could be due to the reason that increased feed rate poses extra pressure on the machine's blower unit causing substantial amount of materials other than grain coming out into the main grain outlet. This agrees with studies by Singh *et al*. (2015) on evaluation of a multi millet thresher.

Figure 4B is a graph showing threshing efficiency of the Yanmar DB 1000 mechanised paddy thresher at varying drum rotational speed.

The greatest significant ($P<0.05$) threshing efficiency of 96.5% was recorded at a drum speed of 650 rpm while the least (93.8%) was recorded at a drum speed 550 rpm. The threshing efficiency increased with increasing drum rotational speed, irrespective of feed rate and rice variety. This could be attributed to the fact that with higher drum rotational speed, there's high impact from threshing teeth ensuring more grains are threshed per unit time. This trend agrees with studies by Olaye *et al*. (2016) on evaluation of an axial-flow rice thresher, El-Haddad (2000) on evaluation of simple grain threshers and Singh *et al*. (2015) on the evaluation of a multi millet thresher.

Table 3 illustrates the mean percentage grain loss by weight recorded by the mechanised thresher under varying drum speed and paddy feed rate. The mechanised thresher recorded the greatest significant ($P<0.05$) grain loss of 7.07% at a drum speed of 650 rpm whereas the least (4.80%) was at 550 rpm, irrespective of rice variety.

Similarly, the greatest significant grain loss (6.93%) was recorded at a paddy feed rate 600 kgh^{-1} whilst the least (4.95%)

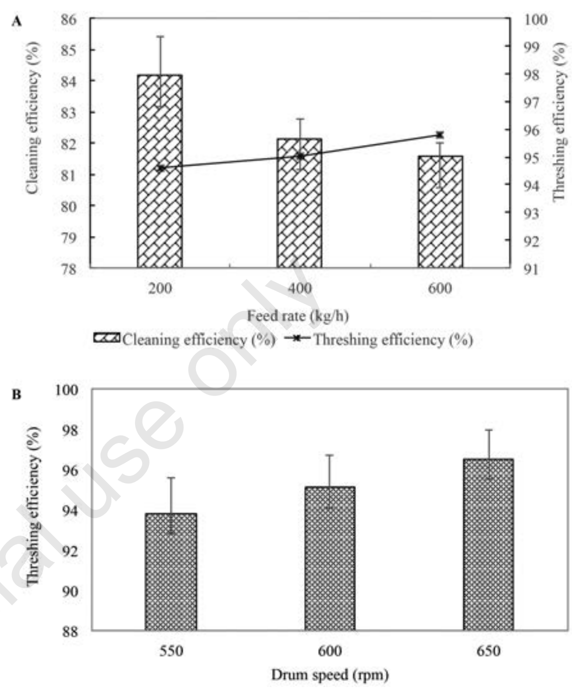

Figure 4. A) Threshing and cleaning efficiencies of the mechanised thresher at varying feed rates; B) Threshing efficiency of the mechanised thresher at varying drum speed.

Table 2. Crop condition at threshing.

Parameter/crop variety	Amankwatia	AGRA
Grain moisture content (% w.b)	18.0	16.9
Straw moisture content (% w.b)	20.5	19.6
Grain-straw ratio	1.27	1.23
Grain diameter (mm)	2.69	2.57
Grain damage (%)	0.10	2.15
Grain length (mm)	9.87	9.39
Crop height (cm)	127	126

Table 3. Mean grain loss (%) and mean fuel consumption as influenced by drum speed and feed rate.

Drum speed (rpm)	Grain loss (%)	Fuel consumption (Lh^{-1})	Feed rate (kgh^{-1})	Grain loss (%)	Fuel consumption (Lh^{-1})
550	4.80^{c}	0.37^{c}	200	4.95^{c}	0.31^{c}
600	5.90^{b}	0.42^{b}	400	5.86^{b}	0.40^{b}
650	7.07^{a}*	0.46^{a}*	600	6.93^{a}	0.54^{a}
LSD	0.68	0.03	LSD	0.68	0.03
CV (%)	21.9	26.7	CV (%)	22.3	13.3

*Values followed by the same letter in the same column are not significantly different at P<0.05. LSD, least significant difference; CV, coefficient of variation.

was at 200 kgh^{-1}. Studies by Akolgo *et al*. (2015) recorded an average grain loss of 9.4% during loss evaluation of the Yanmar DB 1000 paddy thresher for Jasmine 85 rice variety.

Graph in Figure 5 depicts the percentage broken grains and grain loss by weight as influenced by drum rotational speed and paddy feed rate for the Yanmar DB 1000 mechanised thresher.

The percentage broken grain and grain loss both increased significantly ($P<0.05$) with increasing drum speed for all feed rate levels. This is because as drum speed is increased, there is increased impact force on the grains to aid threshing which causes significant breakage on some of the grains. Also, more power is delivered to the blower unit with increased drum speed so as to generate more air stream. The increased air stream blows some of the grains away through the sieve outlet, causing significant losses.

Similarly, percentage broken grains and grain loss increased steadily with increasing feed rate, irrespective of drum speed and rice variety. Again, percentage broken grains ranged from 0.06% to 2.5% across various drum speeds and feed rates. Akolgo *et al*. (2015) recorded percentage broken grains ranging from 0% to 2.2% during evaluation of the Yanmar DB 1000 thresher for Jasmine 85 rice variety. It must be stated that there was no significant difference ($P<0.05$) in percentage grain loss at various feed rates. Conversely, there were significant differences in percentage broken grains at various feed rates. This trend might be due to the fact that more seed received impact from cylinder teeth and blower impeller as crop throughput was increased resulting in an increase in internal friction and number of blown or lost grains respectively. The trend of increasing broken grains and grain loss with increasing feed rate and drum speed agrees with studies by Olaye *et al*. (2016), Akolgo *et al*. (2015) and Emara (2006).

Table 3 illustrates also the mean fuel consumption at varying drum speed and feed rate during mechanical threshing with the Yanmar DB 1000 paddy thresher for the two rice varieties.

From Table 3, the highest fuel consumptions of 0.46 Lh^{-1} and 0.54 Lh^{-1} were respectively recorded at 650 rpm drum speed and 600 kgh^{-1} feed rate; whereas at 550 rpm drum speed and 200 kgh^{-1} feed rate, the least fuel consumptions of 0.37 Lh^{-1} and 0.31 Lh^{-1} were respectively recorded. Again, it was realised that fuel consumption increased significantly ($P<0.05$) with increasing drum speed and feed rate, which is in agreement with studies by Olaye *et al*. (2016), Abo-El-Naga *et al*. (2015) and Emara (2006). This trend could be explained based on the fact that at higher drum speeds and crop throughput, threshing power requirement increases, translating into increased fuel required by the engine to provide the needed power.

Figure 6A depicts the physical power requirement for mechanised threshing with the Yanmar DB 1000 paddy thresher at varying feed rates. The greatest significant ($P<0.05$) power requirement of 672 W was recorded when operating the thresher at a feed rate of 600 kgh^{-1}, while the least (580 W) was realised at a feed rate of 200 kgh^{-1}.

Again, power requirement increased with increasing feed rate. This is because increasing crop throughput results in higher physical power consumption due to increased heart rate.

Figure 6B presents the mean threshing capacity for the Yanmar DB 1000 mechanised thresher at varying crop feed rate and drum speed.

At a drum speed of 550 rpm, threshing capacity increased from 73.4 kgh^{-1} to 216.1 kgh^{-1} as feed rate increased from 200 kg/h to 600 kg/h. Again, at 600 rpm drum speed, threshing capacity increased from 82.8 kgh^{-1} to 235.1 kgh^{-1} with increasing feed rate from 200 kg/h to 600 kg/h. Lastly, at 650 rpm drum speed, threshing capacity increased from 90.1 kgh^{-1} to 257 kgh^{-1} with increasing feed rate from 200 kg/h to 600 kg/h.

From graph in Figure 6B, it could be deduced that irrespective of drum speed, threshing capacity increased significantly with increasing feed rate. Similarly, threshing capacity increased with increasing drum speed at all feed rate levels. The increasing threshing capacity with increasing feed rate and drum speed could be attributed to the fact that at higher rotational speed and crop throughput, there is increased impact on grains and quantity of crops in the machine's threshing unit respectively. Consequently, more grains can be threshed per unit time. This trend agrees with studies by Badway (2002) and Olaye *et al*. (2016).

Table 4 illustrates the performance of the Yanmar DB 1000

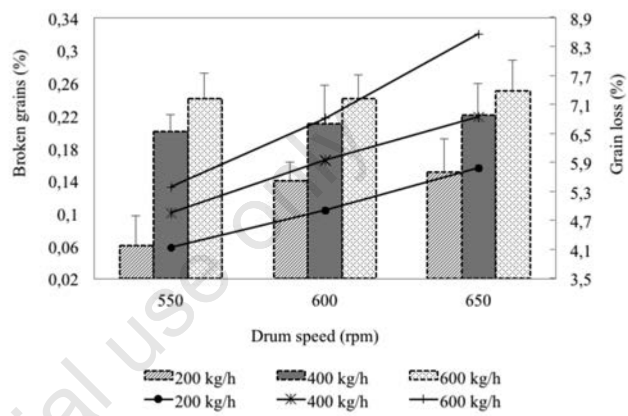

Figure 5. Mean broken grains (%) and grain loss (%) at varying drum speed and feed rate.

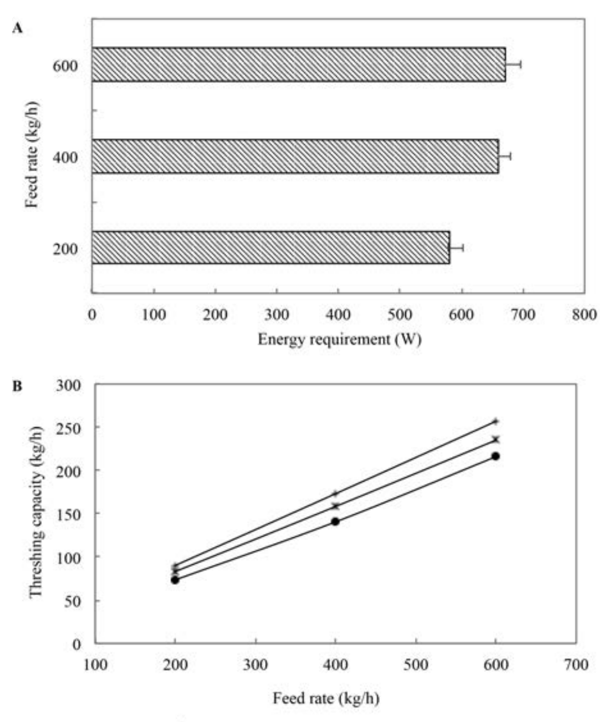

Figure 6. A) Physical power requirement for mechanised threshing at varying feed rate; B) Threshing capacity as influenced by crop feed rate and drum speed.

paddy thresher for Amankwatia and AGRA rice varieties at manufacturer's operating recommendation (600 rpm drum speed and 400 kgh^{-1} feed rate).

From Table 4, it could be seen that AGRA rice variety recorded significantly greater values for cleaning efficiency, threshing efficiency and threshing capacity than Amankwatia. Conversely, Amankwatia variety was associated with significantly greater ($P<0.05$) levels of grain loses, broken grains, fuel and physical power requirements than AGRA rice variety. This situation could be attributed to the fact that at the time of threshing (from Table 2), grain-straw ratio and crop moisture for Amankwatia was relatively higher than AGRA. Besides, it was realised from field observation that AGRA variety was easier to shatter than Amankwatia under similar conditions. Studies by FAO (1976) indicated that threshing is affected by grain shatterability and moisture content. Singh *et al*. (2015) reported a decrease in threshing efficiency at higher crop moisture content. Higher cleaning efficiency at lower crop moisture was also reported by Bansal and Lohan (2009).

Table 5 illustrates the performance of manual paddy threshing by impact method using the wooden box for threshing Amankwatia and AGRA rice varieties. Average broken grains after threshing ranged from 0.16% to 0.18% for AGRA and Amankwatia rice varieties respectively with no significant difference in percentage broken grains between rice varieties. Average grain loss showed significant difference between rice varieties while ranging from 6.06% to 8.35% for AGRA and Amankwatia respectively.

This was because Amankwatia naturally has poor shattering properties than AGRA rice, thus it was easier with few beatings on the wooden box to separate grains for AGRA than Amankwatia. Moreover, crop moisture at threshing for Amankwatia was higher than AGRA rice variety, thus some grains still remained on the panicles after threshing, causing the substantial amount of loss realised for Amankwatia. The above reasons could as well justify the significantly ($P<0.05$) lower threshing capacity and the relatively higher physical power demand in threshing Amankwatia than AGRA rice variety. However, unlike threshing capacity, physical power demand for threshing showed no significant difference ($P<0.05$) between AGRA and Amankwatia rice varieties in the range of 728 W to 767 W respectively. Better efficiency of manual threshing is achieved with the AGRA rice variety than Amankwatia.

Table 6 depicts the percentage broken grains and grain loss by weight, average physical power demand and threshing capacity for manual threshing by impact using the wooden box and the mechanised threshing with the Yanmar DB 1000 paddy thresher.

Results in Table 6 shows that mechanised threshing was significantly ($P<0.05$) better at reducing grain loss and physical power demand whilst yielding higher threshing capacities (more than twice) than manual threshing by impact using the wooden box. However, in terms of reduction in average broken grains, manual threshing by impact with the wooden box was significantly ($P<0.05$) better than mechanised threshing with the Yanmar DB 1000 paddy thresher. This could be attributed to the lower impact

Table 4. Performance of the Yanmar DB 1000 paddy thresher as influenced by rice variety at manufacturer's recommended drum speed and feed rate.

Variety	Evaluation parameter						
	Cleaning efficiency (%)	Threshing efficiency (%)	Grain loss (%)	Broken grains (%)	Threshing capacity (kgh^{-1})	Fuel consumed (Lh^{-1})	Power required (W)
AGRA	87.9	96.3	5.05	0.18	170.3	0.38	615
Amankwatia	77.4	94.0	6.79	0.20	146.8	0.45	672
LSD	1.47	0.83	0.72	0.02	8.60	0.03	12.0
CV (%)	3.4	1.1	21.9	36.4	42.5	26.7	7.4

LSD, least significant difference; CV, coefficient of variation.

Table 5. Performance of manual threshing by impact method (using the wooden box) for Amankwatia and AGRA rice varieties.

Variety	Evaluation parameter			
	Broken grains (%)	Grain loss (%)	Power requirement (W)	Threshing capacity (kgh^{-1})
AGRA	0.18	6.06	728	120.5
Amankwatia	0.16	8.35	767	102.9
LSD	ns	1.79	ns	9.66
CV (%)	32.6	19.8	5.1	9.3

LSD, least significant difference; CV, coefficient of variation; ns, not significant.

Table 6. Comparative evaluation of manual and mechanised paddy threshing methods.

Threshing method	Evaluation parameter			
	Broken grains (%)	Grain loss (%)	Power requirement (W)	Threshing capacity (kgh^{-1})
Manual	0.13	8.46	834	64.9
Mechanised	0.21	5.95	660	158.4
LSD	0.06	1.79	91.2	9.66
CV (%)	27.7	18.7	9.2	6.5

LSD, least significant difference; CV, coefficient of variation.

on grains against the wooden surface of the box compared to the metallic cylinder and concave in the case of mechanised threshing. This confirms the fact that mechanised paddy threshing options generally offer better solution to reducing production cost and enhancing labour productivity than manual threshing methods which agrees with report by Alizadeh and Allameh (2013).

Economics of manual and mechanical threshing

Table 7 shows the total cost of mechanised threshing using the Yanmar DB 1000 paddy thresher and manual threshing using the wooden box based on relevant assumptions. At an investment cost of US$ 2000.00, mechanised threshing offered a total annual cost of US$ 1287.00 while the manual threshing option, at an investment cost of US$ 100.00, yielded a total cost of US$ 746.00 per annum. Making reference to threshing capacity values in Table 6, the total cost per kilogram of threshed paddy for mechanised and manual threshing options were estimated at US$ 0.008 and US$ 0.011 respectively.

Figure 7 illustrates the break-even chart for mechanised threshing and manual threshing methods using the Yanmar DB 1000 thresher and the wooden box respectively. Break-even calculation was based on the assumption that cost of threshing was US$ 3.00 and US$ 1.00 per hour for mechanised and manual options respectively for a maximum of 1000 h of work per annum. Cost of paddy threshing values used were prevailing service charges within the study location as at September, 2016.

Mechanised threshing offered greater total annual cost and revenue than the manual threshing option. At 1000 h of annual use, the mechanised Yanmar DB 1000 paddy thresher is yielding total revenue of US$ 1712.72 as compared to US$ 253.75 for manual threshing with the wooden box. The break-even for manual threshing was at 73 h of machine use (equivalent to 4.74 metric tonnes of threshed paddy) as compared to mechanised threshing at 190 h (equivalent to 30.10 metric tonnes of threshed paddy). However, the profit margin for the mechanised threshing was over 500% higher than the manual threshing option.

Conclusions

The following conclusions based on set objectives could be drawn from the study:

- Threshing efficiency increased significantly from 94.6% to 95.8% while cleaning efficiency decreased from 84.2% to 81.6% with increasing feed rate irrespective of rice variety. Again, threshing efficiency increased with increasing drum rotational speed, irrespective of feed rate and rice variety.
- Percentage broken grain and grain loss both increased with increasing peripheral drum speed and paddy feed rate irrespective of rice variety. Average fuel consumption and threshing capacity increased significantly with increasing drum speed and feed rate. Similarly, physical energy requirement for threshing increased with increasing paddy feed rate, irrespective of rice variety.
- Crop moisture content and shattering ability had an influence on the threshing efficiency, threshing capacity, grain loss, broken grain, fuel and physical energy requirement at threshing. AGRA rice variety generally performed better than Amankwatia under both mechanical and manually threshing methods.
- Mechanised threshing was significantly better at reducing grain loss and physical energy demand whilst yielding over 200% higher threshing capacity than manual threshing by impact using the wooden box.
- Mechanised threshing was financially rewarding, yielding over 500% higher profit margin than the manual threshing option.

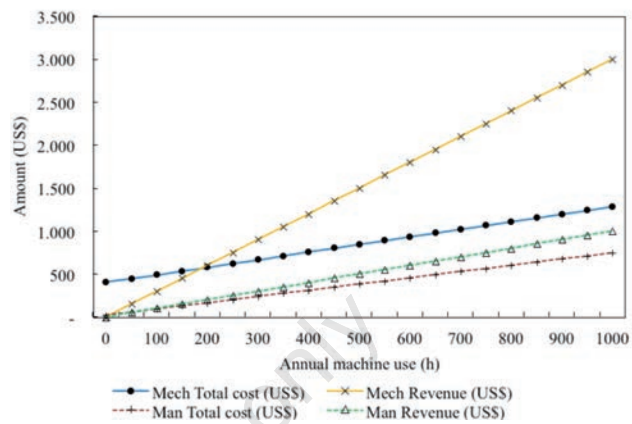

Figure 7. Break-even chart for mechanised (Mech) and manual (Man) paddy threshing options.

Table 7. Total cost for mechanised and manual paddy threshing options.

Item	Unit	Mechanised thresher	Wooden box
Purchase price	US$	2000	100
Salvage value	US$	200	10
Economic life*	y	5	5
Depreciation	US$y^{-1}	360	18
Interest	US$y^{-1}	22	1.1
Insurance	US$y^{-1}	10	0.5
Tax	US$y^{-1}	0	0
Shelter	US$y^{-1}	10	0.5
Total fixed cost	US$y^{-1}	402	20.1
Fuel (Diesel) cost	US$l^{-1}	0.91	-
Fuel consumption	l/h	0.42	-
Annual machine use	h	1000	1000
Lubricant consumption	Lh^{-1}	0.01	-
Lubricant cost	US$l^{-1}	4.25	-
Worker's salary	US$	75	75
Number of workers		1	2
Fuel	US$h^{-1}	0.38	-
Lubricant	US$h^{-1}	0.04	-
Repairs and maintenance	US$h^{-1}	0.10	0.01
Labour	US$h^{-1}	0.36	0.72
Total variable cost	US$h^{-1}	0.89	0.73
Total variable cost	US$y^{-1}	885	726
Total cost	US$y^{-1}	1287	746
Total cost	US$kg^{-1}	0.008	0.011

*Estimation was based on survey data provided by rice farmers within the study location.

Recommendations

The following recommendations are suggested:

- Further research to determine the optimum crop moisture content for improved rice threshing should be conducted for different varieties.
- Rice breeding programmes should focus future work on releasing more varieties like the AGRA rice that can facilitate threshing.
- Government and other private sectors should consider investing into mechanised threshers to improve productivity and facilitate national self-sufficiency in rice production.

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