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Test and Performance Evaluation of Engine Driven Warqe (*Ensete ventricosum*) Decorticator

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Abstract: Warqe processing is carried out dominantly by women using traditional tools such as a bamboo scraper, serrated wooden tool and metal knife where losses in quality and quantity are exceptionally high. Above all, the traditional way of warqe processing causes physically drudgery among the rural women. In an effort to alleviate the problem, an engine is driven warqe decorticating machine was designed, constructed, tested and evaluated at field conditions. The performance evaluation of the machine was made in terms of decorticating capacity, decorticating efficiency, percentage pulp loss, and fuel consumption. The performance evaluation was carried out at three levels of drum speeds (850, 950 and 1050 rpm), concave clearances (1, 3 and 6 mm) and feeding rates (0.037, 0.056 and 0.074 kg/s, these are based on the feeding rates of 1.00, 1.50 and 2.00 kg/27s) to determine the optimum combination of the same. The experimental design laid was factorial, in the split-split plot. The maximum decorticating capacity of 255.38 kg/hr was obtained at a drum speed of 850 rpm, concave clearance of 1 mm and feeding rate of 0.074 kg/s. The decorticating efficiency and percentage un-decorticated pulp highly depended on concave clearance rather than other factors. Maximum decorticating efficiency 98.97% and minimum pulp loss of 1.03% were achieved at drum beater speed of 850 rpm and concave clearance of 1mm. The production cost of the decorticator was found to be 28,322.00 Birr. The total operating cost of the decorticator estimated to be, 48,925.38 Birr and the payback period and benefit-cost ratio of the prototype decorticating machine were estimated to be 0.90 years and 1.64, respectively.

Keywords: Benefit-cost Ratio, Decorticating Capacity, Decorticating Efficiency, Fuel Consumption, Leaf Sheath, Payback Period, Warqe

1. Introduction

Warqe (*Ensete ventricosum*) belongs to the order *Scitamineae*, the family *Musaceae* and the genus *Ensete*. *Warqe* is banana like herbaceous monocarpic plant with underground corm, a bundle of leaf sheaths that form a pseudostem and large leaves. Enset, however, is usually larger than a banana, with the largest plant up to 10 m tall and with a pseudostem up to one meter in diameter [3].

One of the high yielding potential plants in Ethiopia is warqe and Cassava that yields more than 300 and 250 quintal/hectare/year, respectively [15, 16] however, the shelf-life of Kocho is by far better than Cassava if handled properly. Due to its drought tolerance and high productivity, Ensetis regarded as a priority food security crop in Ethiopia [17, 18] where it makes a major contribution to food security of the country.

Warqe is grown at an altitude ranging from 1,100 to more than 3,000 meters above sea level. Variation among the species with altitude, soil and climate have allowed the widespread cultivation of the crop in the mid to highlands [11] and Western Arsi, Bale, the Southern Nations Nationalities and Peoples Regional State (SNNPRS) and Western Oromia including West Shewa, Jimma, Ilubabora and Walegga.

Warqe is a traditional staple crop in central and southern parts of Ethiopia and co-staple food in the densely populated areas too [5]. The plant products include a carbohydrate-rich food source (*kocho, amicho* and *bulla*). It serves as a food security crop for about 50% of the Ethiopian population [2]. In 1991 the Ethiopian government declared the crop as a national crop [3]. It is a multipurpose crop used as human food, animal feed, shade to other crops like coffee, ornamental, and is a drought tolerant; hence, it is risk avoidance crop.

Warqe provides fiber (30% of Ethiopia's fiber need), as a byproduct of the decortication process of the leaf sheaths [12]. *Warqe* fiber has excellent structure, and its strength is equivalent to the fiber of *abaca*, a world-class fiber crop [8]. The fiber is used to make sacks, bags, ropes, mats, construction materials, and sieves.

The exact number of people depending on *Warqe,* as sources of income and means of food security, is not known. However, based on the year 2014 agricultural sample survey report of the Central Statistics Agency of Ethiopia [4] and the 2012 population projection, it was estimated that about 35% of Ethiopians were living in areas where *Warqe* is predominantly cultivated as a food crop.

Estimation of yield (kg/ha) is usually difficult due to the very fact that ages of plants, in most cases, are not known, plant spacing changes with time, and at various points, in time they are interspersed with other species and differently sized *warqe* plants [8]. A numbers of the study were reported that *warqe* yield varied with the type of clone, growing area, growth stage, and cultural management. Most *warqe* growing farmers reported that the amount of *kocho* obtained from one *warqe* plant ranged from 15.00 to 61.00 kg [1]. Similar, study made in Emdibir, Kambata and Sidama areas on *warqe* production indicated that the yield of *kocho* per plant ranged from 8 to 70 kg at a farm level.

Decortication is a process used to separate the pulp from the fiber of the stem. This processing activity is carried out dominantly by rural women using traditional tools such as bamboo scrapers, serrated wooden tools, and metal knives. The process is, in general laborious, tiresome and unhygienic [13]. During harvesting, old and young leaf sheaths are removed from the plants manually. The internal leaf sheaths (usually up to two meters of length) are separated from the pseudostem down to the true stem, which is about 20 cm between corm and pseudostem.

Traditionally, a bamboo scraper is used to decorticate leaf sheath tied with rope on an inclined wooden plank that leans at an angle of 40° against a vertical pole. A woman sits in front of the plank keeping a pseudostem piece with its convex side against the plank and securing it in position by putting her foot on it as high as possible [6].

Though the crop has considerably contributed to the food security of the country, the processing practice of *warqe* as food remained extremely traditional and backward [14]. *Warqe* processing is carried out dominantly by women using traditional tools such as a bamboo scraper and a wooden plank, and the process is laborious, tiresome, and unhygienic. In view of these problems encountered with the processing of *warqe*, recently the decorticating machine was designed and developed at Bako Agricultural Engineering Research Center. Hence, this study was initiated to test and evaluate the performance of engine driven warqe decorticating machine and also determine the economic importance, thereby recommend the best performance operational parameters at different field conditions.

2. Materials and Methods

2.1. Performance Evaluation of the Prototype Machine

Prior to the actual testing and performance evaluation of the decorticating machine, a preliminary test was made and observations recorded. Test runs were made under no load and load conditions. Under no load conditions, no defect was observed on any component part of the machine. Three drum speeds (850, 950 and 1050 rpm), three concave clearances (1, 3 and 6 mm) and thee feeding rate (0.037, 0.056 and 0.074 kg/s) were considered as test parameters.

2.2. Experimental Design

The experiment was laid in split-split plot design where drum speeds, concave clearances, and feeding rates are the main plot, sub-plot, and sub-subplots, respectively with three replications as a block. The design had the form of 3^3 factorial combinations with three replications as a block, which resulted in 81 total number of test runs.

2.3. Measurement Machine Parameters

2.3.1. Decorticating Efficiency

Decorticating efficiency is the capability of the decorticator to separate the pulp from fibers with minimum loss. It was determined by taking samples of decorticated pulp and un-decorticated pulp. The weight of each decorticated and un-decorticated samples was determined. Un-decorticated samples were decorticated and reweighed separately. The decorticating efficiency of the machine was determined by using Eqn. (1) [7].

$$\text{Decorticating efficiency (\%)} = \left(\frac{Q_{dp}}{Q_{dp}+Q_{up}}\right)\times 100 \quad (1)$$

where:-

Q_{up}=quantity of un-decorticated leaf sheath (kg);

Q_{dp}=quantity of decorticated pulp by the machine (kg)

2.3.2. Percentage of Pulp Loss

During the performance evaluation of the machine the un-decorticated pulp left on the fiber was decorticated manually, the weight was observed and recorded separately at each level of the samples. The percentage of pulp loss was determined using Eqn. (2) [7].

$$\text{Pulp loss (\%)} = \left(\frac{\text{wieght of re-decortic ated pulp (kg)}}{\text{Weight of pulp (kg)}}\right)\times 100 \quad (2)$$

2.3.3. Percentage of Fiber Yield

The byproduct of the decortication process, the fiber was weighted and recorded for every observation after re-decorticating of pulp left on the fiber safely without damaging it. The percentage of the fiber yield was determined using Eqn. (3).

$$\text{Percentage of fiber extracted (\%)} = \left(\frac{Q_t - Q_p}{Q_t}\right) \times 100 \quad (3)$$

where: -

Q_t=mass of leaf sheath fed into the cylinder (kg);

Q_p=quantity of recovered pulp plus re-decorticated manually (kg)

2.3.4. Measurement of Fuel Consumption

Measurement of fuel consumed was made for different factor combinations. Amount of fuel consumed was used to estimate cost operation under varying conditions. The fuel tank was filled to its maximum capacity and machine was operated for each factor. The tank was refilled using a graduated cylinder and funnel to estimate fuel consumed (ml/kg) during each test run.

2.4. Cost Analysis

Economic analysis of the prototype decorticating machine such as cost of operation, payback period and benefit-cost ratio of the machine and construction material cost were analyzed and economic return was estimated.

2.4.1. Cost of Operation

The cost of operation of *warqe* decorticating machine includes fixed and variable costs. The fixed cost included depreciation, interest on investment, insurance, taxes, and housing. The operating cost included the cost of repair and maintenance, fuel /electricity costs and labor wages [9]. Total processing or operational cost=Fixed cost + Operating cost.

2.4.2. Payback Period

The payback period was estimated using the following formula [10].

$$\text{Payback period} = \frac{I}{E} \quad (4)$$

where: - I=investment cost, birr

E=net annual return

2.4.3. Benefit-cost ratio

Benefit-cost ratio is the comparison of the present worth of cost with present worth of benefits. The benefit-cost ratio was calculated using the following formula [10].

$$\text{Benefit cost ratio} = \frac{\text{Discounted return}}{\text{Discount cost}} \quad (5)$$

The total production cost of *warqe* decorticator=Cost of raw material + Cost of labor for fabrication + Cost of machine work were determined and equaled to 28,321.50 Birr. To determine the cost of operation the following assumptions were made,

1. Useful working hours=3000
2. Useful life years=5
3. No. of labors per day=1
4. No. of working hours per year=704 hours (*warqe* decortication takes place during the months of September to December)
5. Salvage value=10% of initial investment
6. The rate of interest on fixed capital=15% of the initial investment
7. Taxes per annum=2% of initial investment
8. Housing=1% of the initial investment
9. Repair and maintenance=8% per annum of initial investment

The total fixed cost of the machine was the sum of machine cost, depreciation, interest, taxes, housing and repair and maintenance which is 36,606.19 Birr. Operating cost of the machine (variable costs), Total operation (variable) cost of the machine was 14,655.76 ETB. Total processing / operation cost=Fixed cost + Operating (variable) cost=34,269.62+ 14,655.76=48,925.38 Birr

$$\text{hourly cost of operation} = \frac{\text{Total operation cost}}{\text{number of working days per year} \times \textit{working} \text{ hours per day}} = \frac{48{,}925.38}{88\ \text{d}ays \times 8hr/day} = 69.50\ \text{Birr/hr} \quad (6)$$

The maximum decorticating capacity of 255.38kg/hr was determined. Expected Cost of decorticating,

$$\text{Expected cost of decorticating} = \frac{\text{hourly cost of operation}}{\text{capacity of the machine}} = \frac{69.50}{255.38} = 0.27\ Birr/\text{kg}$$

Assume cost of decorticating for custom hiring as 0.6 Birr/ kg.

$$\text{Expected return per year} = \text{Capacity} \times \text{No. of working hours per year} \times \text{Cost for decorticating} = 255.38\ \text{kg} \times 704\, hr \times 0.6\, Birr/kg = 107{,}872.00\ \text{Birr} \quad (7)$$

$$\text{Profit} = \text{Return per year - total operating cost per year} = 107{,}872.00 - 48{,}925.38 = 58{,}946.62 \text{ Birr per year}$$

The production cost of the decorticator was found to be 28,322.00 Birr. The total operating cost of the decorticator was determined to be 48,925.38 Birr. The expected useful life of the decorticating machine was assumed to be 5 years. The discount rate for the decorticator is taken at 12.00%. It is assumed that there is a 2.00% increase in the operation cost due to maintenance and repair cost. Cost economics of the decorticating machine was determined using (Table 1). The expected cost of operation and expected return are assumed based on the available economics of the machine.

Table 1. *Cost economics of warqe decorticating machine.*

Life in Years	Estimated Cost (Birr)	Discount cost at12%(ETB)	Estimated Return (Birr)	Discounted Return at 12%	Net Return
0	28,322	28,322.00	-	-	-
1	28,888.44	24,923.36	58,946.62	52,630.91	30,058.18
2	29,466.21	21,932.56	60,125.55	46,315.20	30,659.34
3	30,055.53	19,300.65	61,328.06	40,757.38	31,272.53
4	30,656.64	16,984.57	62,554.62	35,866.49	31,897.98
5	31,269.78	14,946.42	63,805.72	31,562.51	32,535.94
Total	178,658.60	126,409.56	306,760.58	207,132.49	12,8101.98
Mean	29,776.43	21,068.26	61,352.12	41,426.50	31,575.68

The payback period was determined using Eqn. (75);

$$\text{Payback period} = \frac{28322.00\ \text{Birr}}{31{,}575.68\ \text{Birr/yaer}} = 0.90\ year$$

Benefit-cost ratio was calculated using Eqn. (76),

$$\text{benefit cost ratio} = \frac{\text{Discounted return}}{\text{Discount cost}} = \frac{207{,}132.49}{126{,}409.56} = 1.64$$

The benefit-cost ratio of the decorticating machine was 1.64.

3. Results and Discussion

A prototype *warqe* leaf sheath decorticating machine was designed, manufactured, tested and the performance of the same was evaluated at Bako Agricultural Engineering Research Center. The decorticating machine consisted of scratching and scraping units as a major component since the leaf sheath required scratching and scraping to separate pulp and fiber. The performance of the decorticating machine was assessed in terms of output, efficiency, and cost against feed rate, cylinder speed, and concave clearance. The data collected at each test run at different combinations of feed rate, cylinder speed, and concave clearance was subject to ANOVA to determine the level and extent of the effect of the variables on the machine performance.

3.1. Measurement of Crop and Machine Parameters

During the process of decortication, the machine was operated under different combination of drum speeds, concave clearance and feed rates.

Table 2. *Mean of decorticating capacity (kg/hr) of the prototype machine at different drum speeds, concave clearances, and feed rates.*

Treatments Feeding rate (kg/sec)					
Drum speeds (rpm)	**Concave clearance (mm)**	**0.037**	**0.056**	**0.074**	**Means**
850	1	127.70	191.60	255.40	191.54
	3	115.00	178.80	240.50	178.12
	6	97.91	157.60	218.90	158.16
950	1	127.30	191.30	254.20	190.93
	3	111.60	171.10	229.00	170.56
	6	93.60	153.90	208.10	151.90
1050	1	126.50	190.70	254.60	190.59
	3	109.90	172.20	223.60	168.55
	6	98.84	153.80	209.34	153.99
Means		112.04	173.44	232.64	-
LSD	13.19				
CV%	2.33				
SD	4.02				

Source: Own computation (2019)

LSD: Least significant difference; CV: coefficient of variation; SD: standard deviation; at 5% level of probability

3.2. Performance of Decorticating Machine

The effect of drum speeds, concave clearance and feeding rates on the performance of the prototype decorticating machine such as decorticating capacity (DC) kg/hr, decorticating efficiency (DE) in percent, pulp loss (PL) in percent and fuel consumption (FC) lit/kg were assessed as presented below.

3.2.1. Decorticating Capacity (DC kg/hr)

The mean decorticating capacity was presented in Table 2. The statistical analysis, ANOVA, clearly indicated that the decorticating capacity of the machine was significantly ($P < 0.05$) affected by drum speed, concave clearance, and feeding rate. The effects of drum speed and concave clearance and that of concave clearance and feed rate were significant while drum speed and feeding rate, and the cross effect of the three factors were not significant at $p < 0.05$. The maximum decorticating capacity of 255.38 kg/hr was obtained at a drum speed of 850 rpm, when the concave clearance was 1 mm and the feeding rate was 0.074 kg/s. Nonetheless, the decorticating capacity of the prototype machine decreased with increasing concave clearance and increased with increasing feeding rate.

3.2.2. Decorticating Efficiency

The effects of drum speeds, concave clearances and feed rates on the decorticating efficiency of the prototype machine are presented in Table 3. The highest decorticating efficiency of 98.97% was obtained at a drum speed of 850 rpm, concave clearance of 1 mm and feed rate of 0.074 kg/s while the lowest decorticating efficiency of 72.41% occurred at a drum speed of 950 rpm, concave clearance of 6 mm and feed rate of 0.037kg/s. The mean decorticating efficiency with respect to the feeding rates of 0.037, 0.056 and 0.074 kg/s were 86.77, 89.41 and 89.91%, respectively.

Decorticating efficiency decreased with increasing speeds and increasing concave clearance. This was manifested by an increasing amount of un-decorticated pulp. The decorticating efficiency was almost the same for the same concave clearance at drum speeds of 850, 950 and 1050 rpm, i.e. at given concave clearance the effect of drum speed was almost negligible.

The decorticating efficiency increased with increasing the feed rate and decreased with increase in concave clearances and nearly constant for drum speeds. The decorticating efficiency increased by decreasing concave clearance. The concave clearance of 6 mm resulted in minimum decorticating efficiency at all drum speeds. The statistical analysis, ANOVA clearly indicated that the decorticating efficiency of the machine was significantly ($P < 0.05$) affected by the combined effect of concave clearance, feeding rate, and drum speed.

Table 3. *Mean of decorticating efficiency of the prototype machine at different drum speeds, concave clearances, and feed rates.*

Treatments	**Feeding rate (kg/sec)**				
Drum speeds (rpm)	**Concave clearance (mm)**	**0.037**	**0.056**	**0.074**	**Means**
	1	98.66^{a}	98.92^{a}	98.97^{a}	98.85
850	3	90.47^{dac}	92.02^{bac}	92.37^{ba}	91.62
	6	75.42^{de}	81.32^{bdec}	84.67^{dec}	80.47
	1	98.52^{a}	98.58^{a}	98.74^{a}	98.61
950	3	86.20^{bdec}	88.10^{bdac}	88.22^{bdac}	87.51
	6	72.41^{f}	79.29^{de}	80.30^{dec}	77.33
	1	98.07^{a}	98.50^{a}	98.57^{a}	98.38
1050	3	85.03^{bdec}	88.77^{bdac}	86.43^{bdec}	86.75
	6	76.17^{de}	79.22^{de}	80.92^{bdec}	78.77
Mean		86.77	89.41	89.91	-
LSD	4.04				
CV (%)	2.15				
SD	1.91				

Source: Own computation (2019)

LSD: Least significant difference; CV: coefficient of variation; SD: standard deviation; Means followed by same letters are not significantly different at 5% level of probability

Table 4. *Mean of pulp loss (%) of the prototype decorticating machine at different drum speeds, concave clearances, and feed rates.*

Treatments	**Feeding rate (kg/sec)**				
Drum speeds (rpm)	**Concave clearance (mm)**	**0.037**	**0.056**	**0.074**	**Means**
850	1	1.34^{f}	1.08^{f}	1.03^{f}	1.15
	3	9.53^{dfc}	7.98^{df}	7.63^{df}	8.38
	6	24.58^{ba}	18.68^{bdac}	15.33^{bdc}	19.53
950	1	1.48^{f}	1.42^{f}	1.26^{f}	1.39
	3	13.80^{ebdc}	11.90^{edfc}	11.78^{edfc}	12.49
	6	27.60^{f}	20.72^{bac}	19.70^{dbac}	22.67
1050	1	1.93^{f}	1.49^{f}	1.43^{f}	1.62
	3	14.96^{ebdc}	11.23^{edfc}	13.56^{ebdc}	13.25
	6	23.83^{ba}	20.78^{bac}	19.08^{ebdac}	21.23
Means		1.39	11.38	21.14	
LSD	4.04				
CV (%)	16.87				

Source: Own computation (2019)

LSD: Least significant difference; CV: coefficient of variation; SD: standard deviation; Means followed by same letters are not significantly different at 5% level of probability

3.2.3. Percentage of Pulp Loss (PL%)

The effect of drum speed, concave clearance and feed rate on pulp loss during *warqe* decortication is presented in Table 4. The maximum pulp loss of 27.60% occurred at drum speed 950 rpm, concave clearance 6 mm and feed rate 0.037 kg/s while the. Lowest loss of 1.03% was recorded at drum speed 850 rpm, concave clearance 1 mm and feed rate 0.074 kg/s. The mean pulp losses at feed rates of 0.037, 0.056 and 0.074 kg/s were determined to be 13.23, 10.59 and 10.09%, respectively. From Table 4 it can be noted that the loss of pulp increased with increasing drum speed and concave clearance, and decreases with increasing feed rate.

The pulp losses at feeds of 0.037, 0.056 and 0.074 kg/s are given in Table 4. At all feed rates, pulp losses increased as concave clearance increased from 1 mm to 6 mm, without significant effect of variations in drum speeds. This clearly indicated that concave clearance has a dominant effect on percent pulp losses. The ANOVA indicated that effect of drum speed and concave clearance and concave clearance and feed rate on pulp losses are significant at 5% level while the combined effect of drum speed, concave clearance, and feed rate is not significant at 5%.

Table 5. *Mean of fuel consumption (ml/kg) of the prototype decorticating machine at different drum speeds, concave clearances, and feed rates.*

Treatments		**Feeding rate (kg/sec)**			
Drum speeds (rpm)	**Concave clearance (mm)**	**0.037**	**0.056**	**0.074**	**Mean**
850	1	11.73[a]	14.53[f]	16.17[g]	14.14
	3	9.67[b]	12[c]	12.33[a]	11.33
	6	9.73[b]	11.37[a]	13.03[a]	11.38
950	1	12.13[c]	14.1[f]	16.77[g]	14.33
	3	10.5[d]	13.4[f]	14.53[f]	12.81
	6	9.8[d]	12.53[c]	13.67[a]	12.00
1050	1	11.57[a]	14.33[f]	16.57[g]	14.16
	3	10.03[d]	11.8[a]	13.83[a]	11.89
	6	10.9[d]	12.27[c]	13.83[a]	12.33
Mean		10.5	14.13	16.29	
LSD	0.75				
CV%	6.35				

Source: Own computation (2019)

LSD: Least significant difference; CV: coefficient of variation; SD: standard deviation; Means followed by same letters are not significantly different at 5% level of probability

3.2.4. Fuel Consumption (FC)

A machine should be technically viable, economically feasible and socially acceptable for its acceptance by farmers. Hence rate fuel consumption becomes one of the important parameters used in the determination of economic viability of innovations and technologies. Concave clearance and feed rate had a statistically significant effect on fuel consumption; fuel consumption increased with increasing feeding rate and decreasing concave clearance as shown in Table 5. The highest fuel consumption of 16.77ml/kg was observed at drum speed 950 rpm, feeding 0.074kg/s and concave clearance 1 mm, as can be seen from Table 5.

3.2.5. Multiple Regression Analysis Factor Combinations

Multi regression analysis was carried out to establish relationships between drum speed, concave clearance, and feed rate and that of decorticating capacity, decorticating efficiency, pulp losses, and fuel consumption, and to estimate correlation coefficients.

As can be seen from Table 6, decorticating capacity, decorticating efficiency, the percentage of pulp loss and fuel consumption are dominantly affected by concave clearance and feed rate while the effect of drum speed appears to be negligible.

Table 6. *Multiple regressions equations of decorticating capacity, decorticating efficiency, pulp loss and fuel consumption upon drum speed, concave clearance, pulp loss, and fuel consumption.*

Regression equations	**Coefficient of determination (R^2)**
$DC = 38.95 - 0.02S - 7.16C + 120.60F$	0.96
$DE = 108.13 - 0.01S - 3.90C + 3.14F$	0.83
$PL = -8.13 + 0.01S + 3.90C - 3.14F$	0.69
$FC = 5.95 + 0.003S - 0.43C + 3.85F$	0.61

Source: Own computation (2019)

where: - DC=decortication capacity, kg/hr; DE=decortication efficiency (%); PL=pulp losses (%), FC=fuel consumption (ml/kg); S=drum speed (rpm), C=concave clearance (mm), and F=feed rate (kg/s)

As can be seen from Table 6, concave clearance has positive effect on pulp loss (i.e. increased clearance leads to increased pulp loss) while it has negative effect on decorticating capacity, decortication efficiency and fuel consumption (i.e. increased clearance reduces decorticating capacity, decortication efficiency and fuel consumption). Feed rate has positive effect on decorticating capacity, decortication efficiency and fuel consumption while it has negative effect on pulp loss (i.e. increased feed rate increases decorticating capacity, decortication efficiency and fuel consumption and decreases pulp loss).

4. Conclusions and Recommendations

4.1. Conclusions

Testing and performance evaluation was made to quantify the effects of drum speed, concave clearance and feed rates on decorticating capacity, decorticating efficiency, pulp loss, and fuel consumption. The optimum operating conditions were determined on the basis of measurements made and analysis affected. Accordingly, the following conclusions were made:

(1) Drum speed of 850 rpm, concave clearance of 1 mm and feed rate of 0.074 mm are considered to be optimum combination.
(2) The decorticating efficiency and percentage pulp loss highly depend on concave clearance rather than the other factors. Maximum decorticating efficiency 98.97% and minimum pulp loss of 1.03% were achieved at a drum speed of 850 rpm and concave clearance of 1mm.
(3) Drum speeds did have any significant effect on the performance of the prototype decorticating machine; feeding rate was underestimated, as observed during actual repetitive field tests.
(4) Generally, the machine has acceptable performances; hence, it can be used to alleviate problems associated with *warqe* processing using the machine.

4.2. Recommendation

The traditional method of decorticating *warqe* which is full of drudgery, unhygienic and consuming much time, needs to be modernized through the introduction of appropriate technology. Therefore, the need for a decorticating machine is high. Nonetheless, the prototype machine appears to be expensive though the performance is acceptable.

Thus, the following recommendations are made:

(1) The low income should think of buying and owning the machine jointly, or custom use and/or service provision must be thought of.
(2) To minimize the cost of the machine, the use of materials other than stainless steel must be sought (plastic, aluminum, etc).
(3) The performance the prototype machine was high at a concave clearance of 1 mm, the concave clearance beyond this is not recommended.
(4) Drum speed greater than 850 rpm is not required to

decorticate *warqe*.

(5) The machine was highly recommended to the end users with the current status.

(6) The capacity of the prototype decorticating machine appears to be low and the levels of feeding rates selected were small in general this calls for further testing and re-evaluation of the prototype machine other than the predetermined values.

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