Development and Evaluation of Engine Driven Corm Grating Machine

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***Abstract*– Enset corm processing, in Ethiopia at present, is labour demanding and time consuming activity which calls for technology to make it efficient and lighten the burden on women. Engine operated inset corm grating machine was developed and the test was carried out at three levels drum speed (2000, 2200 and 2400rpm) for the most dominate three variety (Baladati, Farise and Sharte) at farmers farm. Performance of the machine was evaluated interims of Grating capacity (Kg/hr) and Grating uniformity (%) for all varieties. Grating efficiency (%) and Fuel consumption (Kg/ml) were taken for Baladati variety. Based on the results obtained, the grand mean grating capacity of 1048.3Kg/har (~1ton/hr) is recorded for the prototype. The optimum grating capacity of 1277Kg/hr was observed when the drum was operated at velocity of 2200rpm at Sharte variety; whereas the minimum grating capacity of 604.0Kg/hr was observed when the drum speed was 2000 rpm at Baladati variety. Fuel consumption of 1.32lit/hr was recorded at drum speed of 2400rpm and Baladati variety. The machine can be used by farmers for all varieties at drum speed range of 2200 – 2400rpm.**

***Keywords*– Development, Corm, Evaluation, Grating and Inset**

I. INTRODUCTION

Enset (*Ensetventricosum*) is commonly known as "false banana" and it is a traditional staple crop or co-staple food in the densely populated South and South-Western parts of Ethiopia. It serves as food security for about twelve million people in Southern region of Ethiopia (Brandt *et al.*, 1997). It is a multipurpose crop used as human food, animal feed, to shade other crops like coffee, decoration, is a drought resistant crop which makes it risk avoidance crop. It resembles the banana plant, but is somewhat larger, up to 10 m tall with a pseudo stem up to 1 m in diameter and is produced primarily for the large quantity of carbohydrate rich food found in the false stem (pseudo stem) and an underground bulb (corm).

The major foods obtained from enset are *kocho*, *bulla* and *amicho*. *Kocho* needs a lengthy period of processing and preparation, which is carried out by women. The first stage involves removing the leaf stalks and grading of the corm. *Kocho* is increasingly exported to urban markets. *Bulla* is the unfermented starch of a mature plant, which can be prepared as a pancake or porridge. *Amicho* is the core of a young plant, which is boiled and consumed as other tuber crops. Due to their low protein content these foods are eaten in combination with protein rich products like milk. The fiber is used to make sacks, bags, ropes, mats, construction material and sieves. Fresh enset leaves are used as food wrappers, serving plates and for stall feeding of cattle. There are many other uses, e.g., for medicines.

It is expected that enset can be introduced in many other regions to improve food security. However, this needs further study and work on trial demonstration farms. Further research is needed on: diseases, processing technologies, improvement of the livestock component, and production of protein-rich food crops in enset systems, marketing of *kocho*and sustainability of enset farming under increasing population pressure and marketing.

However, little effort or research is made to improve the processing aspect of the crop especially corm grating and thus traditional processes are predominantly used by farmers. Both men and women are involved in growing and managing enset at field level in most cases, however, there are places where it is most commonly associated with women. Women are mainly responsible for harvesting and processing enset. Enset processing requires more labour and thus it is additional burden for women beside to handling daily house routines. The burden remains as a challenge of women for a long time and this has influence on gender relations at household level. Some enset processing technologies (e.g., scraping and squeezing tools) have been developed by Bako Agricultural Engineering Research Center, Sodo Rural Technology promotion Research Centre and Melkassa Agriculture Research Institution.

However, the technologies that farmers used for corm grating still in the area were traditional. The introduced technologies mainly differ from traditional methods in terms of time and labour taking, and their provided yield of quantities and qualities. The traditional harvesting and post harvesting procedures are cumber some; labour intensive, unhygienic, impose a lot of inconvenience to the working women, and associated with great yield lose. Traditionally 2-3hr per tuber require to grating.

A) Statement of the problem

Women in rural community of Ethiopia have more workload in general as compared to men. The workload is expressed in household, farm and social activities. Almost all the household activities (including child care) are performed by women alone. Therefore, women are busy all the day from very early in the morning to late in the evening. Men do not involve in household activities and in some places, in certain area women are not allowed even to share bread with their husbands in some cases, i.e., women eat what is left from their husbands. Women are also involved in farm operations mainly at planting, weeding and harvesting of different crops. Some crops are more managed by women than men. Such crops include enset, vegetables and spices. Moreover, milking and managing calves is among the daily routines of women. Processing of the staple food source enset is entirely done by women because traditionally men are not allowed to involve on such activities.

Enset processing is labour demanding and time consuming activity which calls for technology to make it efficient and lighten the burden on women. It is unimaginable to perform social activities such as wedding, funeral and circumcisions ceremony without active involvement of women. Due to all these workload, women may not have enough time to have adequate care for their child and may not perform the house needs to the satisfaction of men. This at times creates conflict among spouses. In general, the existing enset processing coupled with other farm and household activities has negatively affected the relationship between men and women biasing the work load to women and affecting maternity health (Sodo Rural Technology Promotion Center report document, 2010). Thus, different development programs have introduced enset processing technologies as a solution to lessen the burden on women.

Fig. 1. Traditional method of corm grating

The tubers of enset cannot be stored longer after harvest before decaying, and so processing follows immediately after harvesting. Enset processing leading to size reduction includes decorticating, grating, and squeezing. A typical enset processing plant should therefore consist of units produced to achieve all the stages or steps mentioned above.

Traditional tools used in grating processing was wood with finger type at one end to chip the corm. In this method have low productivities and low hygienic solution to these problems that led to the designing and construction of machines that can grate the corm of enset high quality in a short period of time and reduce human drudgery.

The aim of this paper is therefore to design and construction of engine driven corm grating at a cheaper and more affordable price to our farmers. The design incorporates the used of local raw materials for the construction.

B) Expected Output

The designed corm grating machine is expected to save time and reduce women drudgery and also grate the corm of enset high quality in a short period of time.

Objectives: 1) to develop engine driven corm grater, 2) to evaluate the performance of the developed grater

II. MATERIAL AND METHOD

A) Experimental Site

Construction of the machine was done at Bako Agricultural Engineering Research Center (BAERC), which is located in Western Shoa Zone of Oromia National Regional State, Ethiopia. The Center lies between 90 04'45'' to 90 07'15''N latitudes and 37002' to 37007'E longitudes. The evaluation the machine was done at Toke Kutaye of West Shoa Zone of Oromia.

B) Description of the machine

The machine was consisting basically 3 units; the hopper unit, the grating drum and the delivery channel. All these components are mounted on an angle iron frame. The machine assembly was powered engine of small horse power output (5hp).

C) Design Analysis and Calculations

Design Considerations: The machine should be efficient during use in the household as well as movable (portability) and safely or easily operate.

Hopper Design: The hopper is the receptacle through which corm was admitted into the machine for grating. It has a two trapezoidal structure. Volume of the hopper was:

$$V = (\frac{H_t}{2}(b_{1t} + b_{2t}) + \frac{H_b}{2}(b_{1b} + b_{2b}))L = 0.08m^3$$

Where V = Volume of the hopper, m^3, L = Hoppers' length, m, b_{1t} and b_{2t} = bases' length of top trapezoidal, m, b_{1b} and b_{2b} = bases' length of top trapezoidal, m and H = Hoppers' height of top and bottom trapezoidal, m.

Grating Drum: The grating drum was made of sealed stainless steel sheet of 1.5mm thickness. From 3cm width of 46cm length sheet 1cm isoclase triangles were cut off and bend at 2cm. Twenty three of them were welded on surface drum of 25cm diameter at equal distance spacing which served as the grating.

Shaft Design: The shaft was considered for satisfactory performance is to be rigid enough while transmitting load. To achieve this, a solid circular shaft was considered for analysis of combined torsional and bending stresses. For solid shaft having little or no axial load, the diameter is given by (ASME 1995):

$$d^3 = \frac{16}{\prod S_s} X\left[(K_b M_b)^2 + (K_t M_t)^2\right]^{\frac{1}{2}}$$

Where Mt = torsional moment, Mb = bending moment, Kb = combined shock and fatigue applied to bending moment, Kt = combine shock & fatigue applied to torsional momentum, and Ss = allowable stress.

Determination of belt tensions (T_t and T_s) and torsional moment (Mt) according to Khurmi and Gupta, 2004.

$$\frac{T_t - T_c}{T_s - T_c} = e^{\mu\theta \operatorname{cosec}\frac{\beta}{2}}$$

$$T_t = T_{\max} - T_c$$

$$T_{\max} = \partial a$$

$$T_c = mv^2$$

From the maximum drum speed (2400rpm) and pulley (120mm), drum velocity (m/s):

$$V = \frac{\pi D_1 N}{60} = \frac{\pi x.12x2400}{60} = 15.07 m/s$$

Wrap angle determination was determined) for drum pulley.

$$\theta = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \quad = 2.99\text{rad}$$

$$M_t = (T_t - T_s)\frac{D_1}{2}$$

Where T_t, T_s, Tmax, Tc, ꝺ, a ,m, v, μ, β and θ are the tension at tight side, tension at slack side, maximum tension in belt (N), centrifugal tension of a belts (N), maximum safe normal stress (N/mm2), a is cross sectional area (mm^2), mass per unit length (kg/m) of belts, speed of belt (m/s), coefficient of friction between belt and pulley, groove angle and angle of wrap respectively.

According to standard table Khurmi and Gupta (2005) the value of ꝺ, a, m, μ, β and θ are 2.1 N/mm^2, 2mm^2, 0.189 kg/m, 0.3 and 40° respectively. From above equations T_t, T_s, Tmax, Tc and Mt are 297.81N, 139.47N, 340.73N, 42.92N and 9.50 N-m respectively:

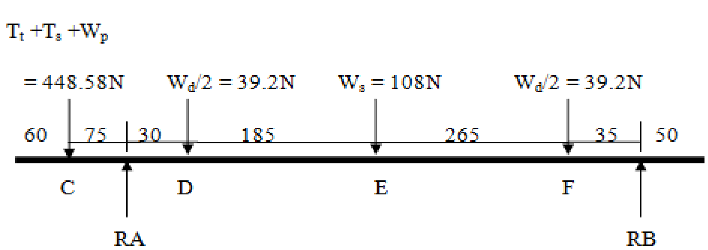

Fig. 2: Free body diagram of the drum shaft and all dimensions are in millimeters

The diameter of the shaft was calculated as follow. The maximum bending moment of 33.67Nm was obtained at point A. Assume K_b = 1.5 and K_b = 1 and $\tau_{\max}$ = Allowable Stress; 40MPa (for steel shaft with keyway).

$$d^3 = \frac{16}{3.14 \times 40MPa}\left[(1.5 \times 33.67)^2 + (9.5)^2\right]^{\frac{1}{2}}$$

= 18.7mm but by taking 1.5 safety factor, 25mm diameter of shaft was selected.

Selection of pulley: The speed ratio of the larger pulley on the machine shaft to the smaller pulley on the engine is givens as (Khurmi and Gupta, 2004):

N1 D1 = N2 D2

Where N1 = speed of engine, N2 = speed of machine driving shaft, D1 = diameter of engine pulley, and D2 = diameter of machine drive pulley.

Let N1 = Speed of the driver in r.p.m. = 1500rpm and D1 = 192mm; Nd = maximum speed of the driven in r.p.m. = 2400rpm

1500 x 192 = 2400 x D2

D2 = 120mm

Based on availability and cost aluminum pulley was selected.

Selection of belt: Length of belt was calculated by Equation (Khurmi and Gupta, 2004),

$$L_p = 2C + 1.57(D_p + d_p) + \frac{(D_p - d_p)^2}{4C}$$

Where: L_p**:** effective length of belt (mm), C: center distance (mm), D_p**:** pitch diameter of large pulley (mm), d_p**:** pitch diameter of small pulley (mm)

Assume C = 460mm based on the height of frame.

Lp = 2x460 +1.57(192+120) + ((192-120)^2)/4*460

= 1412.66mm

Based on the driven and driving pulley diameter and the closest belt length B – 56 (1422mm) belt type was selected.

D) Performance Evaluation

Series of tests were conducted using the machine. Three variety Enset tubers, Baladati, Sharte and Farise, were used. Those names were taken from the farmers' local calling. They told us baladati is the hardest while processing, specially the corm and inner part. But it has the best yield and preferred quality other than those two varieties. Sharte was the least hard during processing when they compare to other, but the same yield with Farise. The test was carried out at three levels drum speed (2000, 2200 and 2400rpm) for all varieties. Those drum speeds are at ideal operating machine. The time taken for each treatment was accurately checked and recorded.

The following parameters were taken to determine the performance of the machine:

$$GC = \frac{W_{tg}}{T_g}$$

$$\eta g = \frac{W_r}{W_f} x100\%$$

Where GC – Grating capacity, kg/hr, W_{tg}–Total weight grate, kg, T_g – Grating time, hr, η_g = Grating efficiency, %, W_r = Total weight recovered, kg, and W_f = Total weight fed in, kg.

$GU = \frac{W_{ns}}{W_s} x100\%$ W_{ns} = Weight of sample that can't pass 0.5x0.5mm sieve hole, kg, and W_s = Weight of sambled in, kg.

E) Statistical Analysis and Interpretation

The experimental was conducted in a factorial experimental analysis of variance. It was made using Statistix 8 statistical software. All significance pairs of treatment means were compared using the Least Significant Difference Test (LSD 5%).

III. RESULT AND DISCUSSION

The performance of the machine was evaluated in terms of Grating capacity (Kg/hr), Grating uniformity (%), Grating efficiency (%) and Fuel consumption (Kg/ml).

A) Grating Capacity (Kg/hr)

The analysis of variance of the main effects of the variety, drum speed, feeding batch, combination of variety and drum speed, drum speed and feeding batch and variety, drum speed and feeding batch were significantly affected grating capacity at 1% level (Table I).

Table I: Analysis of variance on performance of prototype corm grater indicators

Source of Variation	df	F Value Grating Capacity
REP	2	
Variety	2	125.84**
Speed	2	113.35**
VRT*SPD	4	17.17**
Grand Mean 1080.7Kg/hr	CV 7.13 %	

*** Highly significant at 1% level; * significant at 5% level; ns, non-significant; df, degrees of freedom.*

B) Combination Effect of variety and drum speed on grating capacity (Kg/hr)

The overall grand mean grating capacity of the prototype is 1048.3Kg/har (~1ton/hr). Maximum and least grating capacity was recorded at Sharte and Baladati variety for each drum speeds, respectively. Additionally, as we observed from the Table II, for all varieties the grating capacity has increasing trend while the drum speed increase from 2000 to 2200rpm and then decline. The optimum grating capacity of 1277Kg/hr was observed when the drum was operated at velocity of 2200rpm at Sharte variety; whereas the minimum grating capacity of 604.0Kg/hr was observed when the drum speed was 2000 rpm at Baladati variety.

Table II: Variation effect

Source of Variation				
Combination Effect (Vrt X V)				
Velocity (rpm)	Variety			Grand mean
	Baladati	Farise	Sharte	
2000	604.0^{G}	992.5^{E}	1052.9^{DE}	
2200	1154.9^{BC}	1176.8^{B}	1277.0^{A}	
2400	831.2^{F}	1093.2^{CD}	1251.9^{A}	1048.3
SE (M)	36.85			
LSD (5%)	73.94			
CV (%)	7.46			

Traditionally, adult women can grate three corm per a day for corm of 40kg. Also it is tedious and has high hygiene problem. Compare to the machine, the machine can grate 26 inset corm of 40kg per hour. Generally, the machine has high significant advantage over traditional corm processing.

Fig. 3: Manual grated

Fig. 4: Machine grated

In addition to the corm part, the machine can grate the inner part of inset which is not decorticated.

Fig. 4: The inner part of inset

C) Effect of variety and drum speed on grating capacity

The main effect, variety, revealed that the difficulty of processing certain their confirmation. The grating capacity of the machine for each variety depends on their hardness for size reduction. This means, the hardest take long time to pulverize than the less soft.

Table III

Source of Variation			
Main Effects			
Velocity (rpm)	Mean	Variety	Mean
2000	883.1^{A}	Baladati	960.5^{A}
2200	1202.9^{B}	Farise	1087.5^{B}
2400	1058.8^{C}	Sharte	1193.9^{C}
		21.273	
LSD (5%)	42.687	42.687	

D) Grating Uniformity

It was evaluated interims of the size reduction produced after grating for each drum speed and Baladati variety. Grating uniformity of the machine at 2000rpm was 91.63% under 0.5x0.5mm^2 sieve. But it is 100% at 2200 and 2400rpm. High size reduction made them to drain the liquid state easily for Bulla preparation and facilitate the fermenting process due to its uniformity from farmers' perspective. From traditional corm processing we obtained 36.8% of grating uniformity. To make greater percentage it takes labor intensive and long time that is why they did not do.

E) Grating Efficiency of the Machine

There is no loss of corm due to the machine during processing, so grating efficiency of the machines is 98%. This was because of the delivery unit is assembled at the bottom of the hoper to prevent the splashing after grating.

Fig. 5: Manual grated

Fig. 6: Machine grated

F) Fuel Consumption

It was determined for maximum drum speed (2400rpm) and Baladati variety. Fuel consumption of 1.32lit/hr was recorded at this operation

IV. CONCLUSION AND RECOMMENDATIONS

Conclusion: Enset processing, in Ethiopia at present, is labour demanding and time consuming activity which calls for technology to make it efficient and lighten the burden on women. Engine operated inset corm grating machine was developed and evaluated for the most dominate three variety (Baladati, Farise and Sharte) at farmers farm.

Based on the results obtained, the grand mean grating capacity of 1048.3Kg/har (~1ton/hr) is recorded for the prototype. Regarding to these, it can be concluded that the machine can solve current problem of the farmers.

Recommendation: Even though, the machine was developed for the corm part and effective, it can grate almost the whole parts of the inset except some leaf sheet at outer parts. So, I recommend, incorporation of decorticating part which has its own hoper at side of corm grating hoper.

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