

DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A POTATO (SOLANUM TUBEROSUM L.) GRADER FOR VILLAGE-LEVEL OPERATIONS

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ABSTRACT

This study aimed to come up with a functional potato grader for village level operations that will provide a practical means of grading marketable potato tubers by size. The grader operates on the principle of rotating spiral, grading unit, with increasing gaps starting from the inlet. Tubers of smaller minor diameter pass through the gaps.

Machine parameters for the evaluation include the speed of the grading unit (RPM), inclination of the grading unit and feed rate (kg/min). These were tested on potato tubers taking note their influence on grading system efficiency, capacity, damaged tubers and power consumption as independent variables. Data were analyzed and the results indicated that optimum set-up of the grader was at 15 RPM speed of the grading unit, inclination of 100 and feed rate of 30 kg/min. giving a system efficiency of 94.5%, less damaged tubers of 1.85% and low power consumption of 18.1 W-hr.

The cost of the grader is P37, 000.00 with a break-even quantity of 28 tons of tubers in one year. For further improvement of the capacity of the device, consider a larger dimension for the grading unit.

Keywords: Premium price, manual grading, laborious, potato grader, village-level

INTRODUCTION

Manual grading of potato tubers particularly in the village is often inconsistent since quality perception varies from one person to another. Besides, grading tubers by hand is time consuming and stressful job.

Marketable tubers will command a premium price in the market when properly graded. Bringing ungraded tubers in the market will affect marketing system making a delay on the disposal of other products. This causes significant loss due to physiological degradation of the crops as a result of long queue.

Maghirang et. al. (2007) provided a basis on the classification of potato tubers as small, medium and large with minor diameters of 30-3.9 cm, 4.0-7.4 cm and 7.5 cm in above respectively.

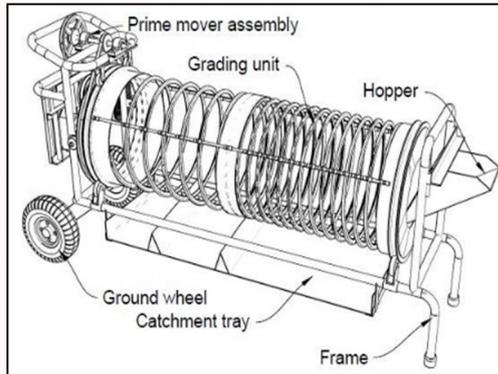
Objectives

The general objective of the study was to designed, fabricate and evaluate the performance of a potato grader. Specifically the study aimed to:

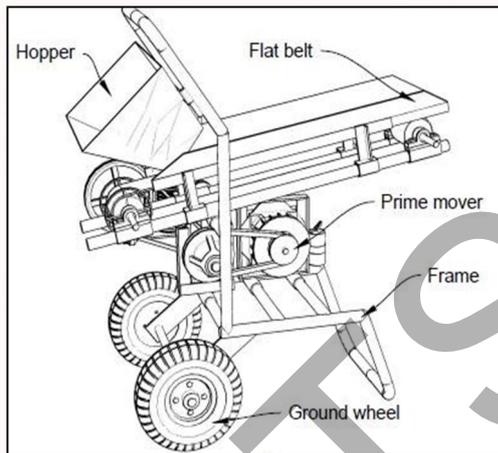
1. design and fabricate a machine for grading potato tubers by size;
2. evaluate the performance of the grading machine in terms of grading system efficiency, capacity and damaged tubers;
3. establish the optimum operating machine parameters such as speed of the grading unit (RPM), inclination of the grading unit (degrees) and feed rate of the device; and,
- 4 . perform a simple cost analysis of the device.

MATERIALS AND METHODS

The setup is composed of two unit, one is the grader (Figure 1a) which is responsible for grading potato tubers and the other is the conveyor (Figure 1b) that feeds the tubers at a uniform rate into the grader.



(A)



(B)

Fig.1. a) Grader, and b) Conveyor

Parts and Description of the device

The grader has a grading unit, catchment tray, side casing, prime mover and power transmission assembly mounted on a portable frame. The materials used included round bar, (7.0 mm and 6.0 mm diameters), cylindrical hinges, (12.7 mm), roller caster, (50.8 mm), rubber wheel, (25.4 cm), Galvanized Iron pipe, (2.0 cm), Galvanized Iron sheet, (gauge # 16), electric motors (1/3 hp with 9 uF), flat belt (5.08 cm) and bolts and nuts.

The conveyor has flat belt as a means of conveying the tubers, side casing, hopper, prime mover and a frame with rubber wheel.

Fabrication

The fabrication of the device started with the grading unit. Round bars with diameters of 7.0mm were formed into spiral of increasing gaps. The spiral has a constant diameter of 42.0 cm and was held by three round bars (7.0 mm) as lateral support through 12.7 mm cylindrical hinges. Spirals were coated with chemical hose as shown in Figure 2 & 3. The lateral bars were fixed at both ends on a cylinders. These cylinders were formed out of a flat bar (5.08 cm x 6.35 mm) and was fitted on a guide rim with inside diameter of 42.0 cm. The guide rim was placed over a 5.08 cm roller caster which serves as circumferential rotational path instead of a central axis. All these components were installed on the frame made of Galvanized Iron pipe.

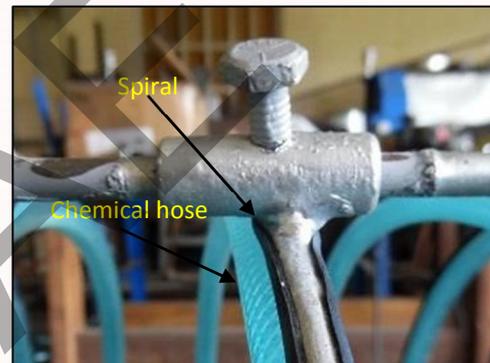


Figure 2. Grading unit



Figure 3. The potato grader

Evaluation

Machine Parameters The independent variables were the speed of the grading unit (10, 15 and 20 RPM), inclination of the grading unit (5, 10 and 15 degrees) and feed rates (20, 30 and 40 kg/min)

Crop Parameters Potato tubers were graded according to size with specified ranges of minor diameter as, 3.0-3.9 cm for small, 4.0-7.4 cm for medium and 7.5 cm in above for large.

The response variables were grading system efficiency, GSE (Eq. 4), capacity, C (Eq. 5), total power consumption and percent damaged tubers.

$$eff_s = \frac{\text{correctly graded small tubers}}{\text{small tubers in the sample}} \times 100 \quad \dots(1)$$

$$eff_m = \frac{\text{correctly graded medium tubers}}{\text{medium tubers in the sample}} \times 100 \quad \dots(2)$$

$$eff_l = \frac{\text{correctly graded large tubers}}{\text{large tubers in the sample}} \times 100 \quad \dots(3)$$

$$GSE = (eff_s \times eff_m \times eff_l) \times 100 \quad \dots(4)$$

$$C = \frac{W}{t} \times 60 \quad \dots(5)$$

Where, *eff_s* is efficiency of small class in percent which is the ratio of the number of correctly graded tubers to the total number of small tubers in the samples, *eff_m* is efficiency of medium class, *eff_l* is efficiency of large class. C is capacity in kg/hr, W is the weight of tubers in kg and t is time in hr.

Test Procedures The grader was tested with the following procedures:

1. samples were procured from the market. Each samples has a weight of 20 kg which was selected at random having small, medium and large size;
2. tubers with initial damaged were discarded.
3. each class in the samples were noted;
4. when the device was ready the samples was fed into the hopper of the conveyor;
5. the time of grading the given sample was recorded;
6. graded tubers in the catchment tray were individually inspected and those that were correctly graded were recorded; finally damaged tubers were also observed. The data was analyzed using factorial in CRD with three speeds of grading unit (RPM), three levels of inclination (degrees) and three feed rates (kg/min) as machine parameters. Least significant difference test (LSD) at 5% level of significance was used to effect treatment means comparisons.

RESULTS AND DISCUSSION

Influence of Speed

Table 1 shows that mean values for the grading system efficiency (GSE) in each machine parameters as influenced by the speed

of the grading unit. The GSE of the grader showed that 15 and 20 RPM are significant from 10 RPM. Lowest speed (10RPM) graded the tubers at a lower rate causing accumulation in the grading unit. While fastest speed (20 RPM) caused aggres-sive re-orientation of the tubers affecting the efficiency. Due to high velocity of tubers in the grading unit, some tubers were observed jumping over several gaps of the spiral.

Meanwhile, analysis of variance on the influence of machine parameters to grading system efficiency showed significant effect. Shown in Table 2 is the summary of grading system efficiency at different classification. Small class contributed the greatest error of 60.72% while 30.18% for the medium and 15.60% for the large class. Potato tubers in the region of the small class was observed to have multilayering limiting the chance of other tubers to interact with the gaps of the spiral.

The capacity of the grader using speed of 15 and 20 RPM is significantly higher than using a speed of 10 RPM. Highest speed (20 RPM) induces more velocity to the tubers causing them to travel along the unit at a faster rate. However, there velocity resulted to insufficient resident time for the tubers to interact with the spiral.

This explains why efficiency is lower at high speed. Conversely, lowest speed (10 RPM) resulted to slow material flow in the grading unit resulting to longer time of operation which caused lower capacity. Damaged tubers was found to be minimal at a speed of 15 and 20 RPM. Highest damaged of 2.26% at 10 RPM could be due to large accumulation of tubers in the unit creating significant impacts as a results of weight of the large quantity of tubers. Abrasion of tubers resulted not only with the high RPM of the grader but also due to large quantity of tubers. The combined effect of the speed of the grading unit and the heavy weight of tubers causes greater impact to the tubers.

Power consumption is lowest at 20 RPM. The grader operates at a faster rate causing shorter time of operation.

Although power consumption is very minimal, the differences on the mean values are significant. Lowest speed (10 RPM) resulted to more power consumption. Tubers stayed longer time in the unit causing more power inputs.

Table 1. Comparison among mean values of the grading system efficiency, capacity, damaged tubers and power consumption as influenced by the speed of the grading unit

MACHINE PARAMETERS	SPEED (RPM)		
	10	15	20
GSE (%)	77.07 ^a	83.81 ^b	78.20 ^b
Capacity (kg/hr)	490.86 ^a	534.80 ^b	539.41 ^b
Damaged Tubers (%)	2.26 ^a	1.99 ^b	1.99 ^b
Power Consumption (W-hr)	20.7 ^a	19.0 ^b	18.8 ^c

Means having the same letter along row are not significant

INFLUENCE OF INCLINATION

Table 2 shows that the grading system efficiency of the grader was highest at an inclination of 10 degrees. Extreme inclination (15 degrees) causes immediate movement of the tubers over the gaps. This also reduce the time of operation causing significantly high capacity of 553.84 kg/min while lowest inclination (5 degrees) resulted to lower efficiency.

This position causes the tubers to move at a significantly lower time. The efficiency is affected when continues fed of tubers at faster rate than the grader it could process, accumulation is formed which also explains why high damage is incurred at 5 degrees.

When tubers are process at a longer time, this results to more power consumption. High inclination encourage the tubers to roll at a faster rate making the time of travel a bit shorter than when the grade is not inclined. However, to fast movement of tubers affects the efficiency when the tubers were not given enough residence time.

Table 2. Comparison among mean values of the grading system efficiency, capacity, damaged tubers and power consumption as influenced by the inclination of the grading unit

MACHINE PARAMETERS	INCLINATION (degrees)		
	5	10	15
GSE (%)	79.67 ^a	85.20 ^b	73.73 ^c
Capacity (kg/hr)	490.63 ^a	520.61 ^b	553.84 ^c
Damaged Tubers (%)	2.20 ^a	2.07 ^b	1.97 ^b
Power consumption (W-hr)	20.7 ^a	19.5 ^b	18.3 ^c

Means having the same letter along row are not significant

Influence of Feed Rate

The system efficiency of the grader at 20 and 30 kg/min feed rate shown in Table 3 is

signifi-cant at 40 kg/min. Highest feed rate introduce large quantity of tubers in the grading unit. The efficiency is affected when the unit could not process at a rate faster or equal to the feed.

Whenever the feed rate was very high, tubers tends to accumulate in the unit. This creates heavier impact to the tubers underneath causing abrasion to the tubers. Power consumption is significantly lower at 40kg/min. Tubers were immediately introduced in the unit at a shorter time compared to the other feed rate. Although, the grader takes some time to grade the tubers it always accomplish the grading in a shorter time. This results to low power consumption.

Damaged tubers was significant from each feed rate. Lowest damage was observed at 1.87 kg/min. Lowest feed rate introduce tubers at a rate the grader could process unlike for higher feed rates which causes accumulation of tubers. The resulting weight of tubers in the unit created impact to the tubers.

Table 3. Comparison among mean values of the grading system efficiency, capacity, damaged tubers and power consumption as influenced by feed rate

MACHINE PARAMETERS	FEED RATE (kg/min)		
	20	30	40
GSE (%)	82.47 ^a	84.26 ^a	72.36 ^b
Capacity (kg/hr)	431.90 ^a	539.81 ^b	593.37 ^c
Damaged Tubers (%)	1.87 ^a	2.12 ^b	2.25 ^c
Power consumption (W-hr)	23.2 ^a	18.5 ^b	16.9 ^c

Means having the same letter along row are not significant

Economics of the Grader

The device has an initial cost of P37, 000.00 with an estimated life span of 5 years. With basic assumptions and current market practice the annual cost of operating the device is P9906.75. Assumptions include: interest, 10%, tax, insurance and shelter, 3%, repair and mainten-ance, 15%, operation per day, 8 hr, annual use, 600hr and custom rate P0.5/kg.

The grader needs to grade a quantity of 28 tons of potato tubers in one year to break-even the cost of fabrication. Figure 4 shows the cost curve emphasizing the break-even quantity. If available quantity of tubers is greater than the break-even quantity, the use of the grader will result to profit. Otherwise, the machine is expensive to use when available quantity is less than the break-even quantity.

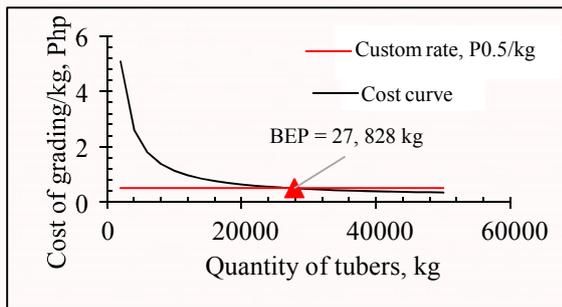


Figure 4. Relationship of the cost of operation of the grader and the quantity of tubers for grading

CONCLUSIONS

A mechanical potato grader, powered by electric motor, was designed, fabricated and evaluated. The device operates with the principle of rotating spiral as grading unit. The grading unit was formed by shaping round bars in spiral pattern with increasing spaces thereby promoting size differentiation of potato tubers being conveyed along the length, inside the spirals

The grader was devised with mechanism to vary the speed of the rotating spiral, degree of inclination of the grading unit and feed rate. The speed (RPM) impart velocity on the tubers causing them to move along the gaps of the spiral. Inclination of the grading unit facilitate the flow of tubers inside the spiral.

The performance of the fabricated grader was evaluated on potato tubers. Grading system efficiency, capacity, damaged tubers and power consumption were observed. The optimum operating parameters for the machine was established at a speed of 15 RPM, inclination of 10 degrees and feed rate of 30 kg/min giving a system efficiency of 94.52%, capacity of 550 kg/hr, less damaged tubers of 1.85% and a low power consumption of 18.1 W-hr. The initial cost of the grader is P36, 750.25 (P37, 000) and is expected to last for 5 years. The annual use of the grader in the village is approximately 600 hrs. Cost of operating the machine is affected by several factors such as: depreciation, tax, insurance and shelter, repair and maintenance at a current custom rate of P0.50/kg, the grader has an annual fixed cost of P9906.75 and variable operating cost of P72.25/hr. A quantity of 27,828 kg (28 tons) of tubers is needed to be graded by the device in one year to break-even the cost.

RECOMMENDATIONS

The designed, fabricated and evaluated potato grader is recommended to be used by the local farmers at La Trinidad, Benguet to immediately address prevailing problems on long queues due to slow manual grading in the market area.

The prototype design can also be adapted for fabrication taking note, however, on the following recommendations based on the observations noted during the evaluation:

1. Consider the use of larger diameter for the spiral to increase the capacity;
2. Constructing the device with higher vertical clearance from the ground for convenience in the collection of graded product;
3. Designing the hopper which can accommodate larger volume so it will not require constant attention of the operator;
4. Lengthening the regions for small-and medium-sized classifications since multi-layering and crowding of potato tubers were observe at that region;
5. Redesigning the grading unit to have shorter overall length to make the device more portable, accessible and easy to store; and
6. Furthermore, considering the average harvest of an individual farmer of 4 tons per cropping and the break-even point of 28 tons, it is suggested that the ownership should be in group of farmers or cooperatives to maximize utilization of the machine. The option of individual ownership is also possible provided however that it will be engaged in custom servicing.

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