Design, Fabrication and Performance Evaluation of a Potato Grader for Village Level Operations Prototype II

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ABSTRACT

Marketing of potato harvest especially in the arena of global trade requires quality standard as pre requisite to command a premium. In the potato processing industry, uniformly sized tubers contribute to an improved efficiency of the processing line. Along this line, this study dealt with the development of a mechanical potato grader suited under village level operations that provide a cheap and quality approach of grading marketable potato tubers by size. Specifically the study aimed to design and construct a potato grader that grades potato tubers by size, evaluate the performance of the grader in terms of grading system efficiency, capacity, damaged tubers and power consumption, establish the optimum operating machine parameters such as speed of the grading unit (RPM), inclination of the grading unit (degrees) and feed rate (kg/min) of the device and perform a simple cost analysis of the device.

The grader operates on the principle of rotating spiral, grading unit, with increasing gaps starting from the inlet. Tubers with minor diameter smaller than the gaps of the spiral pass through to the collection tray provided under the grading unit. Machine parameters during the evaluation are speed of the grading unit in RPM, inclination of the grading unit in degrees and feed rate expressed in kg/min while the dependent variables, response variables, are the grading system efficiency (GSE), capacity (C), percentage of damage tubers, and power consumption in W-hr.

Results showed that the grader was evaluated on potato tubers taking note of the influence of the machine parameters to the performance of the grader. Careful analysis of the data show that optimum set-up of the grader is at 15 RPM speed of the grading unit, inclination of 10 degrees 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. Consequently, a mechanical potato grader was fabricated and evaluated with the premise that grading potato tubers entails more market price aside from alleviating the pain of manual labor. Optimum set-up for the grader was established at 15 RPM, 10 degrees and 30 kg/min. The cost of the grader is P37, 000.00 with a break-even quantity of 28 tons of tubers/year. The capacity of the device can be improved by considering a larger dimension of the grading unit.

KEYWORDS: *Laborious, manual grading, premium price, potato grader, village-level*

1. INTRODUCTION

Potato tubers are inherently variable in size making it necessary to be graded into homogenous groups prior to marketing. However, manual grading of potato tubers carried by a group of human operators is often inconsistent as quality perception varies from one person to another. Besides, grading tubers by hand is time consuming and stressful job.

Graded tuber offers a variety of advantages. Such is in the potato processing industry, uniformly sized tubers increase the efficiency of the system. Marketable tubers also command a premium price in the market when properly graded. On the other hand, bringing ungraded tubers in the market can affect the whole marketing system making a delay on the disposal of other products. This causes significant loss due to physiological degradation of crops especially those highly perishable one as a result of long queue in the market.

Early in the 1950's a slat grader was developed, potato tubers are scattered on the slat and individually inspected as it manually moves to the bags attached at the end. This pioneering design, although less efficient, gave birth to a more improved device for grading potato tubers. Such improvement includes a chain conveyor belt allowing tubers of smaller size to pass through the chain to the bag provided at the end. However, lack of overall consistency and the aim of minimizing or eliminating constant human intervention in the operation resulted to the search of more improved design.

Meanwhile, potato tubers are said to be best graded by mass as revealed in the study of Shaym[1] and Butler et al.[2]. However, according to Fahardi et al.[3] weigh sizing mechanism are not customary because of being slow and costly. Thus, he conducted a study on the best relating physical characteristics of potato tuber and found out that mass and diameter are related. Similar study was conducted by Tabatabaeefar[4] and found out that there was a strong relationship of the physical attributes of potato tubers between volume and diameters and between diameters and mass among others. Maghirang et al.[5] also conducted the same research and provided a basis on the classification of potato tubers as small, medium and large with minor diameters of 3.0-3.9 cm, 4.0-7.4 cm and 7.5 cm in above respectively.

1.1 Objective

The general objective of the study was to design, fabricate and evaluate the performance of a potato grader for village-level operation.

Specifically the study aimed to:

1. design and construct a potato grader that grades potato tubers by size;
2. evaluate the performance of the grader in terms of grading system efficiency, capacity, damaged tubers and power consumption;
3. establish the optimum operating machine parameters such as speed of the grading unit (RPM), inclination of the grading unit (degrees) and feed rate (kg/min) of the device; and,
4. perform a simple cost analysis of the device.

2. MATERIALS AND METHODS

2.1 Grading unit

The device comprises two units, one is the grading unit Figure 1, which is responsible for grading the potato tubers and the other is a conveyor that conveys the tubers into the grader. The grading unit is an assembly of spiral made out of round bar. The spiral formation of these round bars were installed with increasing gaps beginning from the inlet portion of the unit. The spiral has a constant diameter of 42.0 cm and was held by three lateral round bars through metal tubes. The metal tubes are welded on the spiral where the lateral bar is inserted.

Tubers with minor diameter smaller than the gaps of the spiral pass through for collection. Below the spiral is a catchment tray for the graded tubers. The tray was provided with three divisions to separate the graded tubers coming from the regions of the spiral. The spiral has three regions, the first region having a gap that allows only small tubers to pass. The gap of the spiral for the small region ranges from 3.0 cm to 3.9 cm. The second region has gaps of 4.0 cm up to 7.4 cm allowing medium sized tubers to pass. The third is the region for the large tubers with gaps greater than 7.5 cm.

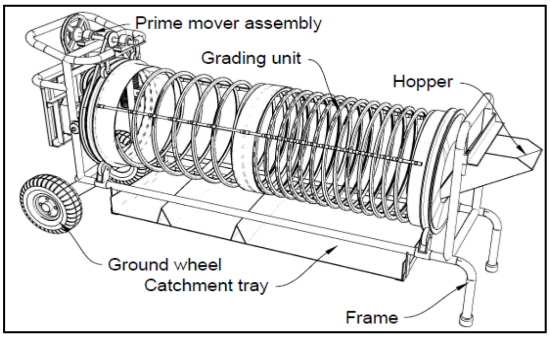

Figure 1. Grading unit

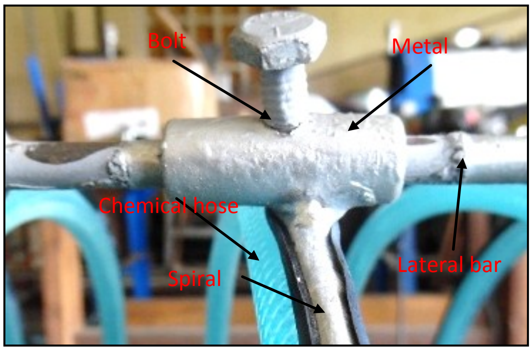

Figure 2. Spiral of the grading unit

As shown in Figure 2, the spiral bar is welded on a metal tube. Inserted in the metal tubes is the lateral bar. The metal tube is bored to allow a bolt in it. The bolt can be driven to tighten the metal tube and the lateral bar. This gives provision in adjusting the spirals into the desired gaps. To prevent the tubers from direct contact with the spiral bars, chemical hose was used as coating.

2.2 Conveyor

The conveyor unit elevates the tubers through the flat belt into the hopper of the grading unit at a regulated rate. Variation of the size of pulley driving the flat belt was made to vary the speed of the flat belt.

Thus three sizes of pulley were used: 15 cm, 20 cm and 25 cm. Each pulley size was initially tested to its equivalent feed rate in kg/min that was used in the final testing. A quantity of 20 kg of tubers were placed into the hopper of the conveyor and the time it takes to fully convey the samples was used to determine the feed rate. Thus three nominal feed rates were used, these are 20 kg/min, 30 kg/min and 40 kg/min.

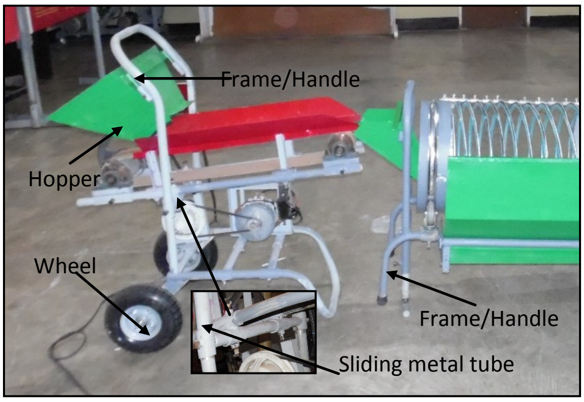

Figure 3. Fabricated conveyor

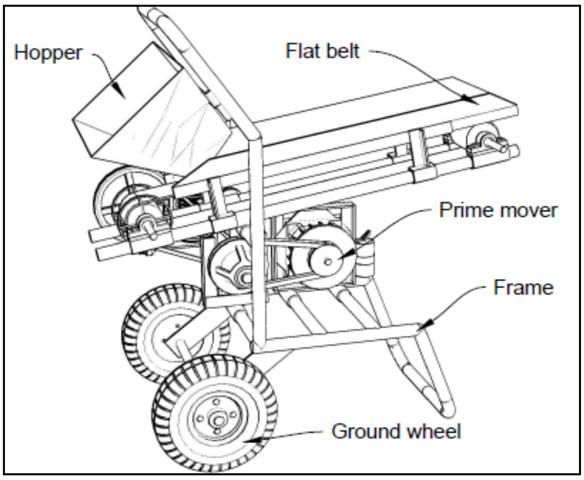

Figure 4. Conceptual design of the conveyor unit

The conveyor has several components such as side casing, hopper, prime mover and a frame with rubber wheel shown in Figure 3. Another set of prime mover with the same size as the grader was installed through the frame of the conveyor. Prior to the fabrication of the conveyor, a conceptual design was first made as shown in Figure 4.

The frame assembly of the conveyor was fabricated in a way that height and inclination of the conveyor is adjustable. This was made through sliding metal tubes inserted to the vertical component of the frame. The metal tubes were provided with bolts. These tubes were welded to the frame holding the flat belt. Thus, the metal tubes could be moved up or down with the flat belt to a desired level. Inclination of the conveyor was arbitrarily set at around 5 degrees as observed during the pre-testing. Higher inclination caused the tubers to slide back to the hopper base.

2.3 Catchment tray

The collection tray provided under the grading unit was made of Galvanized Iron sheet (gauge # 16). It was covered with soft materials to prevent tubers from bruising when dropped from the grading unit. It had three regions for the sizes of the graded tubers, the regions for the small, medium and large sized tubers.

The region for the small sized tubers had the longest length as shown in Figure 5. A very limited length of this region decreases the chance of tubers to interact with the gaps since this contains all the samples during the start of the operation.

Figure 5. Fabricated potato grader

2.4 Frame

Galvanized Iron pipe (20.0 mm) was made for the framing of the grader and the conveyor. Installed at the end of the frame was a pair of rubber wheels (25.0 cm) which enable transportability of the device. Extended length of the frame was bent and served as handle and at the same time support post when the grader is in horizontal position during operation. Between the handle is adjustable metal tube to incline the grading unit.

The frame was also designed to place the grader into a vertical position for convenience in storage after the harvest season as shown in Figure 6.

Figure 6. Potato grader in upright position

2.5 Prime mover

The grader is powered by a ¼ hp electric motor coupled with a reducer mounted upon the frame. Pulley combination was made through a 50 mm shafting supported by a pair of pillow block bearing. The pulley at the other end of the shaft is replaceable to vary the RPM of the grading unit as shown in Figure 7.

Rotational power is then transferred to the secondary pulley through the shafting. A V-belt was connected from the secondary pulley to a guide rim, 40 cm in diameter, which eventually the final mode of power to the spiral assembly. The guide rim serves as circumferential rotation of the spiral assembly in place of a central shafting. Inscribed in this guide rim is a cylinder (10 cm x 6.35 mm thick) which the three lateral bars are welded at three equidistant point around its circumference.

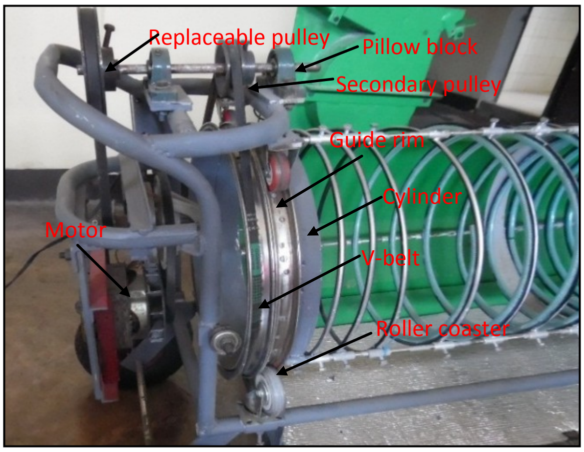

Figure 7. Prime mover assembly of the grader

2.6 Evaluation Parameters

2.6.1 Machine Parameters

The machine parameter has three factors. Each factor has three levels. These are the speed of the grading unit (10, 15 and 20 RPM), inclination of the grading unit (5, 10 and 15 degrees) and feed rate (20, 30 and 40 kg/min).

2.6.2 Crop Parameters

In the earlier practices, potato tubers were graded by mass. However, since the size through its minor diameter and mass of potato are related, grading by mass is inconvenient that operators need to use weighing scale to get the mass of each tuber. Local farmers practice was to grade their product according to size. Several standards both abroad and local provide ranges on the minor diameter of tubers for each grade. Nonetheless this study used 3.0-3.9 cm for small, 4.0-7.4 cm for medium and 7.5 cm in above for large.

2.6.3 Equations

Eq. (1) relates the efficiency of the region of the grading unit responsible for grading small tubers from the sample. Hence, eff_s stands for efficiency for small. It is the ratio of the number of small tubers correctly graded to the total number of small tubers from the sample in percent. Similarly, Eq. (2) is the efficiency of the grader for the medium classification. It is the ratio of the correctly graded medium tubers to the total number of tubers from the samples. While Eq. (3) is the efficiency for the large classification in percent, it is the ratio of the number of correctly graded large tubers to the total number of large tubers in the sample.

Taking the product of eff_s, eff_m and eff_l in decimal gives the Grading System Efficiency (GSE) of the grader in percent as shown in Eq. (4).

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

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

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

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

2.6.4 Evaluation Procedure

The grader was primarily tested for modification and adjustment of the several components. After which it was finally evaluated on potato tubers with the following steps:

1. A total of 540 kg potato tubers were procured from the market and was divided into 27 sub-samples at 20 kg each. Each sub-samples was selected at random having small, medium and large size;
2. The samples during the procurement were manually inspected and those with initial damages such as bruises, decayed surface, greening skin and cracks were discarded;
3. The proportion of small, medium and large tubers in each sub-sample was noted. This was to compare the graded product if it has the same number of tubers for each size with the sample prior to grading;
4. The samples were loaded into the hopper of the conveyor and conveyed it to the grading unit. Each machine set-up evaluated at three replication, 9 set-ups, used 20 kg of potato tubers which was initially prepared. Each set up was replicated three times having 27 test at all;
5. The time of grading each sub-sample was recorded beginning from the loading of the tubers to the conveyor until the last tubers in the grading unit had fallen to the catchment tray;
6. Graded potato tubers were individually inspected and the correctly graded tubers for each size-small, medium and large were recorded; and
7. Finally damaged tubers caused by the machine were also noted.

3. RESULTS AND DISCUSSION

The grader was evaluated on potato tubers using three machine parameters. Each machine parameter had three levels. These were the speed of the grading unit (10, 15 and 20 RPM), inclination of the grading unit (5, 10 and 15 degrees) and feed rate (20, 30 and 40 kg/min) with three replications. The influence of these machine parameters to the performance of the machine during the evaluation was observed. Machine performance, response variables, was indicated by the grading system efficiency (GSE) in percent, capacity (C) in kg/min, percent damage tubers and power consumption in W-hr. Analyzed data showed that these machine parameters have no interaction effect on the performance of the grader. However, each machine parameter significantly affected the performance of the grader.

Table 1. Performance of the grader as influenced by the speed of the grading unit

Machine parameters	Speed (RPM)		
	10	15	20
GSE (%)	74.07[a]	83.81[b]	79.20[b]
Capacity (kg/hr)	490.86[a]	534.80[b]	539.41[b]
Damaged Tubers (%)	2.26[a]	1.89[b]	1.99[b]
Power Consumption	20.7[a]	19.0[b]	18.8[c]

Means having the same letter along row are not significant

The data showed that the grader was 83.81% efficient in separating the tubers when operated at 15 RPM and was comparable to 79.20% at 20 RPM. While 10 RPM had a significantly lower efficiency of 74.07%. Tubers was observed, when the grader was operated at 10 RPM, to accumulate in the grading unit due to slow speed causing multi-layering, hence some tubers passed over several gaps. In some instances small tubers were layered to the larger one and carried either into the medium region or even at the large region. The fastest speed (20 RPM), on the other hand caused aggressive re-orientation of the tubers. Due to high velocity of tubers in the grading unit, some tubers were observed to jump over several gaps of the spiral. This affected the efficiency especially when small tuber jumped over to the region of medium or large selection of the spiral.

The capacity of the grader using speed of 15 and 20 RPM was significantly higher than at 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 was lower at high speed. Conversely, lowest speed (10 RPM) resulted to slow material flow through the grading unit resulting to longer time of operation that caused lower capacity. However, the very slow movement of tubers in the spiral caused accumulation of tubers which formed multi-layering. In this situation, small tubers were carried over by the layer to the region of next classification. This affected the efficiency and capacity of the grader as well.

Damaged tubers was minimal at 15 and 20 RPM while highest damaged of 2.26% was observed at 10 RPM. Slow speed (10 RPM) caused accumulation of tubers in the grading unit that induced greater impacts as a result of their weight. The combined effect of the speed of the grading unit and the heavy weight of tubers caused more impact to the tubers especially those that at the first layer.

Power consumption was lowest at 20 RPM. The grader operated at a faster rate causing shorter time of operation. Lowest speed (10 RPM) resulted to more power consumption. Tubers stayed at a longer time in the unit causing more power inputs.

3.2 Influence of Inclination

Table 2 shows the mean values for the machine parameters as affected by the inclination of the grading unit. Highest grading system efficiency of 85.2% was observed at an inclination of 10 degrees. Whereas lowest efficiency was obtained at an inclination of 15 degrees. Extremely high inclination caused immediate movement of tubers to the next several gaps as influence by gravity plus the effect of the rotation of the spiral. Tubers in this scenario, especially the smaller ones at the first region jumps to the next selection region without passing to the primary region.

Table 2. Performance of the grader 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	20.7^{a}	19.5^{b}	18.3^{c}

Means having the same letter along row are not significant

Same trend of data was observed for the capacity of the grader in which 15 degrees had the highest capacity of 553.84 kg/hr. High inclination of the grading unit facilitated faster movements of tubers along the spiral reducing the time of operation which eventually led to high capacity. Lowest inclination (5 degrees) on the other hand caused the tubers to move at significantly longer time which resulted to the lowest capacity of 490.63 kg/hr.

Lowest inclination (5 degrees) of the grading unit caused accumulation of tubers especially when feeded at a rate faster than the grader could process. The accumulated tubers when rotated caused impacts and was responsible for a more skin damage. This mechanical reaction was observed to decrease at higher inclination.

High inclination encouraged the tubers to roll at a faster rate making the time of travel a bit shorter than at lower inclination. However, fast movement of tubers affected the efficiency when the tubers were not given enough residence time.

3.3 Influence of Feed Rate

Mean values for the different machine parameters as influenced by the feed rate are presented in Table 3. The system efficiency of the grader at 20 and 30 kg/min feed rate were comparable and was significantly higher at 40 kg/min. Highest feed rate introduces large quantity of tubers in the grading unit. The efficiency was highly affected when the grader could not process at a rate faster or equal to the feed.

Table 3. Performance of the grader as influenced by the feed rate of the grading unit

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	23.2^{a}	18.5^{b}	16.9^{c}

Means having the same letter along row are not significant

Potato tubers tended to accumulate inside the unit at extremely high feed rate. This creates heavier impact to the tubers underneath causing abrasion on the skin of tubers. Thus, significantly high damage of 2.15% was observed at 40 kg/min.

Power consumption was significantly lower at 40kg/min. Tubers were immediately introduced in the unit at a shorter time as compared to the other feed rate. Although, the grader took some time to grade the tubers it always accomplished the grading in a shorter time. This results to low power consumption.

3.4 Economics of the Grader

The total cost of the potato grader was P 37, 000.00 with an estimated life span of 5 years. It had an annual fixed cost of P 9906.75 and variable operating cost of P72.25/hr. Assumptions include: interest, 10%, tax, insurance and shelter, 3%, repair and maintenance, 15%, operation per day, 8 hr, annual use, 600hr and custom rate P0.5/kg. The grader had a break-even point of 28ton/year. Shown in Figure 8 is the cost curve emphasizing the break-even point of the potato grader. If available quantity of tubers is greater than the break-even quantity, the use of the grader will result to profit. Otherwise, the device is expensive to use when available quantity is less than the break-even quantity.

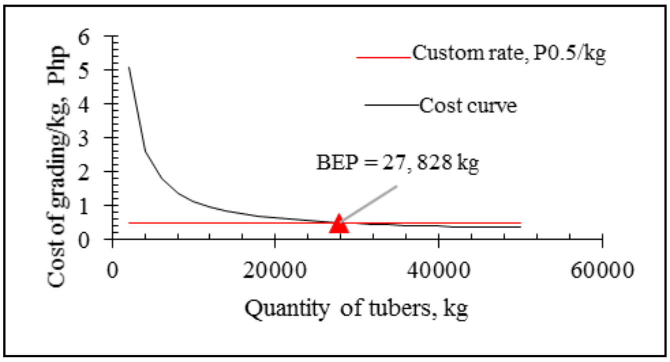

Figure 8. Break-even curve of the potato grader

4. SUMMARYAND RECOMMENDATION

4.1 Summary

This study was conducted to help local potato farmers in the province of Benguet, Philippines in response to prevalent challenges in the market. One of the important value-adding processes in potato farming is the grading of the harvest prior to marketing. However, due to lack of grading device in the village, farmers just settle selling their harvest unsorted at a relatively lower market price resulting to a narrow profit margin or worse income losses.

The general objective of the study aimed to fabricate a device that provides a practical way of grading potato tubers for farmers' use in the village. This prototype design of potato grader was fabricated at the College of Engineering and Applied Technology, Benguet State University, La Trinidad, Benguet.

The newly developed potato grader was finally evaluated after preliminary testing. The response variables were the grading system efficiency (GSE), capacity, power consumption and damaged tubers. The independent variables were the speed of the grading unit in RPM, inclination of the grading unit in degrees and feed rate in kg/min.

Data were analyzed using factorial in CRD and least significant difference test (LSD) was used to establish significances among the differences on the effects of the treatment combinations.

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 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.

4.2Recommendations

The designed, fabricated and evaluated potato grader is recommended to be used by the local farmers at La Trinidad, Benguet to 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 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 observed 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 that the average harvest of an individual farmer is 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

REFERENCES

[1] M. Shaym. “Criteria for separating potato tubers in to different size- grades,” *Journal of Agricultural Engineering.* 19 (4): pp. 77-83, 1982.

[2] G. P. Butler, T. Bernet, and K. Manrique, “Mechanization of potato grading on small scale farms: A case study from Peru,” *Experimental Agriculture*., pp. 41:81-92, 2005.

[3] R. Farhadi and D. Ghanbarian, (2004). "Potato mass modeling with dimensional attributes using regression and artificial neural networks,” *Trakia Journal of Sci*., No 1, pp 47-54, 2004. Available: http://tru.uni-sz.bg/tsj/N%201,%20Vol.12,% 202014/R.Farhadi.pdf

[4] A. Tabatabaeefar. “Size and shape of potato tubers,” *Int. Agrophysics.* pp. 301–305, August 24, 2002. Available: www.ipan.lublin.pl/int-agrophysics

[5] R. G. Maghirang, G. S. Rodulfo and B. Kebasen. 2009. Potato Poroduction Guide. Info. Bull. No. 272/2009. College of Agriculture, University of the Philippines, Los Baños (UPLB) College 4031, Laguna.