Development and Evaluation of Potato Grading Machine

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Abstract

This study presents the performance evaluation of a fabricated potato grader that uses an expanding pitch rods or increasing gaps as small, medium and large potato grades. Response variables were the grading system efficiency in percent and capacity in kg hr^{-1}. These were evaluated on the linear speed of conveying elevator in meters per minutes (m/min) and of inclination angles of the grading unit in degrees. Results of the evaluation showed that the grader had its optimum performance when operated at 25m/min linear speed of the conveyor and inclination of 23 degrees giving a system efficiency of 90.6**%**, and capacity of 1146.0 kg/hr. The total cost of the potato grader was Birr 40,000.00 with an estimated life span of 5 years. It had an annual fixed cost of Birr 8,000.00 and variable operating cost of Birr 15.00/hr. The grader had a break-even point of 1000 ton/year. If available quantity of tubers is greater than the break-even quantity, the use of the grader profit. Otherwise, the device is expensive to use when available quantity is less than the break-even quantity.

Keywords: Angles of Inclination, Conveyor, Efficiency, Grading

Introduction

Potato grading is an important factor in the production and marketing process of potato. Grading helps the potato producers and sellers to determine the price. It reduces the cost of marketing and helping the consumers to get standard potato at fair price. It facilitates the scope to widen the avenue for potato export. Grading has a direct influence on utilization

large sized tubers are preferred for processing purpose. The horticultural product has inherent variability in size at harvest that differentiates them in value. For the ease of buyer it is necessary to grade them according to some objective standard. Therefore it is need of the time to provide facilities at the doorstep of the farming community, so that they may be able to market better quality horticultural products. For most types of fruit and vegetable, bruising is the most common type of post-harvest mechanical injury.

In post-harvest handling, conveying and grading were two most important operations responsible for mechanical injury. Fresh crop and damage free post-harvest handling of fruits and vegetables were considered basic requirements t

According to a study by many researchers large number of factors was limiting our production and export potential of fruits and vegetables. The most common among them were poor farm management practices, lack of adequate social and physical infrastructure such as skill development, extension, transportation, and storage facilities, absence of marketing intelligence, improper storage of seeds, irregularities in domestic and international markets and lack of grading. The normal practice in *Dire Dawa* and *Harar, Haramaya and Kombolcha*, Eastern Ethiopia were to market the ungraded potato tubers and where it was necessary then it was obligatory to be carried out manually by cullers who consider a number of grading factors and separate potatoes according to their physical quality which was tedious, labor intensive, time consuming, slow and non-consistent. Nowadays in world trade organization (WTO) scenario, grading of the horticultural products became basic requirement for national and international marketing system. 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. a basis on the classification of potato tubers was provided as small, medium and large with minor diameters of 30-3.9 cm, 4.0-7.4 cm and 7.5 cm and above respectivel (Anonymous. 2005). This study was then conducted to evaluate the performance of the design developed and fabricated expanding pitch rod-type potato grader in terms of grading system efficiency and capacity percentage; establishing the optimum operating machine parameters such as speed of the conveyer (rpm) and angles of inclination of the grading unit (degrees); and performing simple cost and economic analysis of the device were made. Therefore, the activity was proposed to design, fabricate and evaluate the performance of a potato grader. Specifically as it was aimed in the study, a machine for grading potato tubers by size was designed and fabricated. The performance evaluation of the grading machine in terms of grading system efficiency and capacity was undertaken.

Materials and Methods

Description *of the Study Site*

The potato grader was designed and manufactured at the Fedis Agricultural Research Center Workshop, Oromia Agricultural Research Institute, Ethiopia. The grading experiment was conducted in the Fedis Agricultural Research Center located in the Harar city, which is located in eastern Ethiopia,

Materials

The materials used were the designed and fabricated potato grader and air-cooled diesel engine specified as:

Model: KM178F/FS
Air cooled Diesel Engine
Maximum output power is 3.68 kw

Design of Potato Grading Machine

Potato grader: Shown in figure 1 is the Photo of the grader that was initially fabricated having the overall dimension of 563cm long, 130cm width and 130cm height, respectively. The grader comprises of a feeding trough, conveyer, prime mover, grading unit, catchment bag mounted on a frame. Machine parts were designed using standard formula. The hopper serves as guide for the potato tubers into the elevating conveyer that elevates and feed into the grading unit. The grading unit was a expanding pitch type with increasing gap starting from the inlet. The expanding pitch assembly has three regions: the region for small, medium and large-sized tubers. The first region has gaps that allow only small tubers to pass. The gap of the expanding pitch for this region ranges from 3.0 cm to 3.9 cm. the second region has gaps of 4.0 cm up to 5 cm allowing medium sized tubers to pass. The third is the region for the large tubers with gaps greater than 6 cm. below the expanding pitch were catchment bags for the graded tubers. The bag has three divisions to separate the graded tubers from the regions of the expanding pitch type grading unit.

Figure.1. photo of the potato grade

Key: 1. Hopper, 2. Conveyer 3. Grading Unit 4. Potato Tubers Outlets, 5. Main frame of grading unit, 6. Main frame of conveyer, 7. Pulley, 8. Belt, 9. Engine,

Take-in conveyor

To elevate and convey the potato from feeding trough to the hopper- like space bar and the expanding pitch grading unit, a flight type conveyor was designed. The design of take-in conveyor was made by keeping in view the function to perform, fabrication facilities and skill, simplicity of the design, social acceptability, knowhow of the end users, trend of the local industry, local soil and environmental conditions etc. Raising the incoming product to the grading unit was involved a small drop. Loading capacity, fall height and angle of repose (of the product to be lifted and conveyed) were considered for safe conveying of the produce without any injury to the crop. Take-in conveyor consisted of driving shaft, driving drum, flat belt, frame of the conveyor and power transmission system. The conveyor was powered through a V-belt and pulley arrangement from the main prime mover, the engine. Speed reduction arrangement was also developed to vary the linear speed of the conveyor to change the feed rate.

Capacity of the conveyor

The take-in conveyor was designed to operate at a speed of 20 m/min as suggested by Ragni and Berardinelli (2001). The conveyor of 300 mm width was used with the loading capacity of 10-kg/m length of the conveyor. The capacity of the conveyor was determined by the following formula as suggested by Maghirang et al. (2009).

$$Q = \frac{3600qv}{1000} \tag{1}$$

Where, Q = capacity, tons per hour,

q = weight of the potato per meter length of conveyor, kg/m,

v = linear speed of the conveyor, m/sec, The product was loaded on the conveyor at 10 kg per meter length. By the use of three levels of engine speed it was enabled the take-in conveyor to operate at three linear speeds there by changing the feed rates of the potato to be graded.

Power requirement

Power required to conveying the produce from feeding trough surface to the hopper of the grading unit at height of 1.28 meter, with an inclined conveyor having 2.40-meter length, was worked out by encountering the frictional resistance during elevating and transporting the produce, with the following formula as suggested by More and Saxena (2003).

$N_{fric} = (QL\Omega)/362$ (kW) (2)

Where, N_{fric} = Power to encounter the frictional resistance (kW), Q = Capacity of the conveyor). The power required to elevate the crop to the height H meters was worked out by the following formula as Suggested by More and Saxena (2003).

$N_{eff} = (QH)/362$ (kW) (3)

Where,

N_{eff} = Power required to elevate the crop (kW),

H = Lift height (m)

Q = Capacity of the conveyor (tons /hr)

Since this conveyor performed both functions i.e. conveying and elevating, therefore, total power required (N) for operation of take-in conveyor was determined by the following expression.

$N = N_{eff} + N_{fric}$ (4)

Where, N = Total power required to operate the conveyor (kW). To operate the take-in conveyor at 20-m/min and load rate of 10 kg/m length of the conveyor, as was suggested by [2] and total power worked out was 0.05 kW.

Conveyor driving shaft

In order to operate the conveyor, power (0.05 kW) was transmitted through a shaft to its belt through the driving drum. In order to drive the conveyor at recommended linear speed, torque (T) required to rotate the driving drum was worked out by using the following formula as described (Annonymouse, 2005).

$$T = \frac{97303 * N}{n} \quad (5)$$

Where, T = Torque required to transmit power kg-cm,

N = Total power required to operate the conveyor, kW,

n = Speed of driving shaft, rpm determined by the following expression.

$$V = r\frac{2 * \pi * n}{60} \quad (6)$$

Where, V is linear speed of the conveyor (m/s)

r is radius of the conveyor drum

n is the rotational speed of the driving shaft (rpm)

Torque (153 kg-cm) was transmitted to the driving drum of the conveyor through shaft at rotational speed of 31.74 rpm to run the conveyor at linear speed of 20 m/min.
The diameter of the shaft was worked out by using the following formula as suggested by Khurmi and Gupta [4]

$$D = \frac{\sqrt[3]{16T}}{Ss\pi} \tag{6}$$

Where, D = Diameter of conveyor driving shaft (cm), T = Torque on shaft kg-cm
Ss = Safe shear stress (Kg/cm2) = U_s/F, Us = 3523 kg/cm^2 (Ultimate stress) (Medium Carbon Steel, 0.15 % to 0.4 % Carbon), F = 8 Factor of safety Stanton, E. and A.B. Wintson [4].

The design diameter of the shaft was12.10 mm and the actual shaft of diameter 25 mm was used to operate the conveyor. Diameter of the shaft used, was larger than the designed diameter of the shaft, hence the design was safe.

Main frame

Mainframe was made with the mild steel square pipe, which was readily available and the most consuming material in farm machinery. To determine the size of mild steel angle bar, dead load and variable loads were considered. There were a weight of dead and variable load was imposed on the machine elements to design its features. For the maximum deflection to be observed, in selected element of the main frame at 4 factor of safety was assumed. This designed load on the square pipe was not enough to produce a mark able deflection in the frame member that may cause any fatigue on the metal of the frame member during operation of the machine.

Grading unit

The grading unit comprises a primary expanding pitch grading unit of the round bars of 10 mm diameter. The conveyor collects the product/potato tubers from the hopper/feeding trough and delivers to the grading unit. Steel bars were cushioned with rubber pipes to cover the exposed hard surface so that the surface may not damage the crop during conveying and grading, Weight of crop on a single bar was worked out as 1 kg. The bending moment 55.3 N-m was determined and thickness of the bar was worked out with the ultimate stress of the material of the bar (4.227× 10^8 N/m^2) and factor of safety (Spinvakovsky and Dyachkov. 1972). The following formula was used to determine the bending moments:

$$M = S.Z \tag{7}$$

Where, S = Safe shear stress,
Z = Section modulus

The bar under load was of round cross section with 10 mm dia., hence the thickness of circular cross section was determined by using following formula:

$$Z = \pi \frac{d^3}{6} \tag{8}$$

Where,
Z is Section Modulus
d is diameter of the bar, mm (known)

Potato Tubers

Size and shape of potato tubers

The common commercial variety of Eastern Hararghe potato tubers was planned to be studied in this experiment. One popular variety was sampled with a total of 50 observations. The mass of each potato was measured to 0.01 g on a digital balance. Its volume was measured by the volume of water displaced. A potato was submerged into the known water volume and the volume of water displaced was measured. Water temperature was kept at 25°C. Specific gravity of each potato was calculated from the potato mass in air times one divided by the mass of water displaced. Three mutually perpendicular axes; *a* (the longest intercept), *b* (the longest intercept normal to *a*), and *c* (the longest intercept normal to *a*, *b*), of potato was measured to accuracy of 0.1 mm by a micrometer (caliper); known by laying on its flat surface and reaching its natural resting position. Primary grading unit was used to separate the product having size less than 39 mm and the remaining crop was transferred by sliding or rolling to next rang of grade size 40 mm to 50 mm, which are categorized as medium sized potato grade next size range from 51 to 65 mm diameter as large and greater than 65 and over are considered extra-large sized potato tubers. The grading unit was designed to divide the product into four sizes. The grading unit was operated at three inclinations and three speed designated as S_1, S_2 and S_3 of the engine which accommodated the different feed rates during operation.

Power transmission system

A pulley and belt arrangement was designed to transfer power at in parallel with velocity ratio 1:7. Because both the shafts input & output were in the same plane having pulleys diameters of 7cm and 48 cm.

Performance evaluation of Potato Grading Machine

The machine has the following components that directly comes in contact with the crop to be graded, the potato tubers

Crop and Machine Parameters

Crop Parameters,

Potato tubers were graded according to size with specified ranges of minor diameter as, 3.0-3.9 cm for small, and 4 - 4.9 cm for medium and greater 5 cm for large sizes. The response variables were the grading system efficiency, GSE (Eq. 9) and capacity, C (Eq. 10).

Machine parameters

The *machine parameters* were the two independent variables:

- the speeds of the conveyer shaft S_1, S_2 and S_3 in rpm,
- inclination of the grading unit (A_1, A_2 and A_3 degrees)

Two machine parameters were used during the evaluation. These were the linear speed of the conveyer (15 20 and 25 m/min) and the angles of inclination of the grading unit (23, 26 and 29 degrees). 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 and capacity (C) in kg/hr. The grading system efficiency was determined by taking the products of the efficiencies of small, medium and large regions as shown in Eq. 9, 10, 11, and 12. Where eff_s is the efficiency, in decimal, of the small region of the grader to classify the small tubers, eff_m was the efficiency of the medium region and eff_l was the efficiency of the large region.

$$GSE = \left(eff_S * eff_M * eff_L\right) * 100 ; \% \qquad (9)$$

Samples preparation

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district at vegetable producing area on the 5th November, 2017. Tubers with initial damages such as scratches, abrasion, decay and greening were not considered in the sample. Thus, there was no initial damage during the testing of the device. The samples were divided into 27 groups with 5 kg each containing small, medium and large. On the average, each group had 28% small, 52% medium and 20% large-sized tubers. Each tuber was manually measured with digital Vernier caliper to determine the size and was given a label to easily distinguish after grading.

Operation & & &

The principle of operation of the device began with the linear motion of the elevating conveyer through the prime mover, the diesel engine. Tubers with minor diameters pass through the gaps during rolling or sliding down over the expanding pitch dropping into collection bag hung to the outlets provided below the grading unit.

Test run

A test runs of 27 were used in the study with 9 treatment combination and 3 replications. Each replication used 5 kg of potato tubers as it was initially prepared. Evaluation procedures: As it was initially prepared, each 5kg of potato tubers were loaded into the feeding trough while the conveyer dropping on the expanding pitch grading unit was inclining down. After the grading operation, tubers that dropped on the appropriate region were counted and recorded. This was used to determine the grading efficiency of each region as shown in Eq. 10, 11 and 12. The time, in seconds, it took to grade the samples were also recorded.

$$eff_S = \frac{GradedSmallTubers}{TotalSmallTubersInSample_s} \qquad (10)$$

$$eff_m = \frac{GradedMediumTubers}{TotalMediumTubersInSample} \qquad (11)$$

$$eff_l = \frac{GradedLargeTubers}{TotalLargeTubersInSample} \qquad (12)$$

The capacity of the grader was determined by considering the time it takes to grade the given quantity of tubers. In this study 5 kg of tubers were used. The capacity was expressed in kg/hr as shown in [Eq.13], where W is the weight in kg and t is time in seconds.

$$C = \frac{\mathrm{W}}{\mathrm{t}} ; kg/hr \qquad (13)$$

Test Procedures

The grader was tested using the following procedures:

1. Samples were procured from the known potato producing family farmers. Each sample has a weight of 5 kg which was selected at random having small, medium, large and extra large sizes;
2. Tubers with initial damaged were discarded.
3. Each class in the samples was 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 bag were individually inspected and those that were correctly graded were recorded (weight, minor, intermediate and major diameters); finally damaged tubers were also observed.

Instrumentation and Measurements
Measuring instruments used were:
Digital balance ACS-30

Max. Weight {30kg), Min. weight (20g), Graduation (5g) and Best Accuracy + or 0.1g

Digital tachometer

Model: UNI- T UT371, Technical specification, Measurement 10 to 99, 999 RPM,
Best Accuracy 0.04% + or 2dgt

Data Analysis
The data was analyzed using factorial experimental design in strip plot design with three levels of speeds for elevating conveyer (rpm) and three levels of inclination (degrees) as machine parameters. Least significant difference test (LSD) at 5% level of significance was used to conduct treatment means comparisons.

Economics of the potato grader:
Break-even point of the device was considered in this study which is expressed in terms of the amount of tubers needed to be grade per year. The analysis included the actual cost of the device, custom rate, annual cost, depreciation, insurance and tax and repair and maintenance or the fixed and variable cost. Break even cost of the device is given by [Eq. 14] where CR is the custom rate, AFC is the annual fixed cost and VC is the variable cost.

$$BEP = \frac{AFC}{CR - VC} \qquad (14)$$

Results and Discussion

The physical properties such as major, minor, intermediate diameter, mass, volume measured of *bubu* variety was shown in Table 1.

Table1: Physical properties of potato variety

Item no.	Physical attributes	Mean
1	Major diameter (mm)	65.01
2	Intermediate diameter (mm)	55.3
3	Minor diameter (mm)	45.5
4	Mass (g)	110.6
5	Measured volume (cc)	98.0

The physical properties of the ungraded potatoes tubers shown in tab.1 the average major, intermediate and minor diameters were 65.01, 55.3 and 45.5mm respectively. The average weight (g) and measured volume (cc) were also 110.6 and 98.0, respectively. Whereas the averages of small, medium and large sized grades with their sizes and weights, collected catchment bag individually inspected and those that were correctly graded and recorded data (weight, minor, intermediate and major diameters) were shown in table 2 below. As shown in the table 2 physical properties for the small sized grade potatoes the averages of major, intermediate and minor diameters were 61.41, 45.57and 35.19 mm respectively, having an average weight of 57.53 grams. The physical properties of medium sized grade potatoes the averages of major, intermediate and minor diameters were 66.9350.33 and 41.35mm respectively, having an average weight of 86.68grams. The average physical properties of large sized potato tubers having major, intermediate and minor diameters were 71.32, 54.58 and 46.0 mm, respectively, with an average weight of 112.25grams.

Table 2: The averages of collected catchment bag individually inspected and those that were correctly graded and recorded data

No.	Size (grade) categories	Major Diameter (mm)	Intermediate Diameter (mm)	Minor Diameter (mm)	Weight (g)
1	Small sized grade (G1)	57.40	40.39	31.76	57.53
2	Medium sized grade (G2)	66.93	50.33	41.35	86.68
3	Large Sized grade (G3)	71.32	54.58	45.21	112.25

Table 3: Shows the influence of speed and inclination on the performance of the grader in terms of capacity (kg/hr) and grading system efficiency (GSE %)

Speed (m/min)	Slope of grading sieve Angle A , (degrees)	capacity (kg/hr)	GES (%)
$S_{1\,(15)}$	A1 (20°)	779.8	75.1
	A2 (23°)	1037.0	77.2
	A3 (26°)	1106.8	73.2
$S_{2\,(20)}$	A1	763.4	84.8
	A2	891.5	84.2
	A3	961.6	75.8
$S_{3\,(25)}$	A1	1031.4	87.1
	A2	1070.5	90.6
	A3	1146.0	77.4

Table 4: Analysis of variance (ANOVA) table for the capacity (kg/hr)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	458282.1	8	57285.27	10.63	< 0.0001
A-speed	199402.9	2	99701.43	18.49	< 0.0001
B-Inclination	190801.7	2	95400.87	17.70	< 0.0001
AB Interaction	68077.52	4	17019.38	3.16	0.0394
Error	97045.24	18	5391.402		
Total	555327.4	26			
Std. Dev.					73.4
Mean					976.5
C.V. %					7.5
LSD					125.955

Influence of speeds and angles of inclination combination on grading capacity and grading system efficiency

Grading capacity

Means separation for the treatment combination of the linear speeds (15, 20 and 25m/min) of the conveyer at three levels and angles of inclination of grading unit at (A_1 = 23, A_2 =26 and A_3= 29) this can be shown in the two way table of means of the speeds and angles of inclinations combined in table 3 below.

Table 5: shows the means of capacities (kg/hr) resulted from the combination of speeds and angles of inclination

Speeds (m/min)	**Inclination (degree)**		
	A_1	A_2	A_3
S_1	779.8	1037.0	1106.8
S_2	763.4	891.5	961.6
S_3	1031.4	1070.5	1146.0

The capacity of the grader increases with the increasing of the angles of inclination. In table 3 it is shown that the grading capacity increased from 779.8 kg/hr to 1106.8 kg/hr as the angles of inclination increased from 23° to 29° whereas the speed of the conveyer kept constant at the minimum speed S_1which is 15m/min. Similarly, it was shown the grading capacities continued increasing starting from 763.4 kg/hr to 961.6 kg/hr when operated at the fixed conveyer speed 20m/min. In the same way it can be shown that the grading capacity increases as the angles of inclinations.

Means Separation and Comparison

In table 6 the mean difference of S_1A_3 and S_1A_2 is less than the least significant different obtained which is 125.955, so that the two means of potato grading machine capacities of S_1A_3 and S_1A_2 treatment combinations are not significantly different. Whereas the differences of the means values of the speed of the engine S_1 at A_3 and A_1 the angles of inclination of the grading unit is 327 which is greater than the least significant difference, LSD is 125.955 indicating that there is significant different between the two means.

Table 6. The means of the capacity in the descending order when the inclination is combined with the lowest speed of the conveyer.

Speeds (m/min)	**Angle of Inclination**		
	A_3	A_2	A_1
S_1	1106.8[a]	1037.0a[a]	779.8[b]

Similarly, there is a mean difference value between means of capacities of the means S_1 at A_2 and A3 which is 257.2 also greater values than the **LSD** value of 125.955. Therefore in these treatment combinations S1A3 is the best.

Table 7. Comparisons between the means of S2 at A1, A2 and A3 angles of inclinations of grading unit of the machine.

		Inclination (degrees)		
		A_1	A_2	A_3
Speed (m/min)	S_2	961.6[a]	891.5[a]	763.4[b]

The means differences in table 7 above between: S_2A_3 and S_2A_2 is 70.1 this value is less than the LSD value obtained 125.955 indicating the treatment combination is not significantly different. Whereas the means differences between S_2A_3 and S_2A_1 and S_2A_2 and S_2A_1 are, 198.2 and 128.1, respectively. These means difference values of the speed and angles of inclination of the grading unit of the grader machine are greater than the LSD (0.05) value obtained 125.955. Therefore these later mean values are significantly different.

Table 8. Means comparisons between the means of S_3 at A_2, A_3 and A_1 angles of inclinations of grading unit of the machine.

	Inclination (degrees)		
Speed (m/min) S_3	A_3	A_2	A_1
	1146.0[a]	1070.5[a]	1031.4[a]

The difference between means values of the (S_3A_2, S_3A_3), (S_3A_2, S_3A_1) and (S_3A_3, S_3A_1) are 75.5, 114.6 and 39.1, respectively. These difference values between means are less than the LSD $_{\alpha(0.05)}$ value obtained. Therefore the differences between these means are not significantly different.

Table 9: Analysis of variance ANOVA table (GSE %) for selected factorial model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
A-speed	443.6	2	221.8	31.80	< 0.0001
B-Inclination	327.7	2	163.8	23.49	< 0.0001
AB	94.5	4	23.6	3.39	0.0312
Pure Error	125.5	18	7.0		
Cor Total	991.3	26			
Std. Dev.	2.640919				
Mean	80.37574				
C.V. %	3.285716				
LSD	4.53				

Means separation of grading system efficiency, GSE (%) of the potato grading machine
Table 10: shows the means of **GSE (%)** resulted from the combination of speeds and angles of inclination

Speeds (m\min)	Inclination (degrees)		
	A1	A2	A3
S_1	75.1	77.2	73.2
S_2	84.8	84.2	75.8
S_3	87.1	90.6	77.4

a) Mean Comparisons

The Means Comparisons of the responses grader system efficiency of the obtained by the treatment combination of the angles of inclination of the grading unit and the speeds (rpm) of the conveyor was made during the data analysis and result interpretation. The means Comparisons were undertaken by taking one at a time and combining against the three angles of inclination as shown in table 11 below.

Table11. The means of the grading system efficiency in the descending order when the inclination is combined with the lowest speed of the conveyer.

Treatment combination	Angles of Inclination (degrees)		
	A2	A1	A3
Speed (rpm) S_1	77.2^a	75.1^a	73.2^a

In table 11 the mean difference of S1A2 and S1A1 is less than the least significant different obtained which is 4.53, so that the two means of potato grading machine efficiencies of S1A2 and S1A1 treatment combinations are not significantly different. The means difference values between S1A2 and S1A3 are 4 which is less than the LSD $_{(0.05)}$ value obtained which is 4.53, indicated that the treatments combination was not significant. Similarly, the means difference value between S_1 (A_2, A_1), S1 (S2, A3) and S_1 (A1, A3) are 2.1,4 and 1.9 respectively. These all the three values are less than the obtained LSD $_{(0.05)}$ equals 4.53. Therefore, all of the above treatment combinations are not significantly different. The means of the grading system efficiency was put in the descending order when the inclination is combined with the lowest speed of the conveyer as shown in table 12 below.

Table 12 shows the results of the treatment combination of the speed (rpm) the angles of inclination of grading unit

Treatment combination	Angles of Inclination (degrees)		
	A_1	A_3	A_2
S_2 Speed (m/min)	84.8^a	84.2^a	75.8^b

The means difference values between S_2 (A_1, A_3), S_2 (A_1, A_2) and S_2 (A_3, A_2) are 0.6, 9 and 8.4respectively. The value of the LSD $_{(0.05)}$ obtained is 4.53. Therefore, the S_2 (A_1, A_3), S_2 (A_1, A_2) treatment combinations are not significantly different. Whereas, treatment combination between S_2A_1 and S_2A_2 are significantly different. In the same way the treatment combinations S_2 (A_3, A_2), is significantly different.

Table 13. Shows the results of the treatment combination of the speed (rpm) the angles of inclination of grading unit

Treatment combination	Angles of Inclination (degrees)		
	A_2	A_1	A_3
S_3 Speed (m/min)	90.6^a	87.1^a	77.4^b

The means difference values between S_3 (A_2, A_1), S_3 (A_1, A_3) and S_3 (A_1, A_3) are 3.5, 13.2 and 9.7, respectively. The treatment combination between S_3 (A_2, A_1) is not significantly. The means value differences between S_3 (A_2, A_3) and S_3 (A_1, A_3) are 13.2 and 9.7, respectively. Therefore, these treatment combinations are significantly different. Comparison among mean values of the grading system efficiency and capacity as influenced by the speed of the take-in conveyor. The GSE of the grader showed that 20 and 25m/min are significant from (15m/min). Lowest speed, 15m/min graded the tubers at a lower rate causing accumulation in the grading unit. While fastest speed 25m/min caused aggressive re-orientation of the tubers affecting the efficiency. Due to high velocity of tubers in the grading unit, some tubers were observed jumping and/or flying over longer distances of the round bars. As the speed increases the GSE tends to be decreased. Meanwhile, analysis of variance on the influence of machine parameters to grading system efficiency showed significant effect.

The capacity of the grader using speed of 20 and 25min is significantly higher than using a speed of 15m/min. Highest speed (25m/min) 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 diverging round bars or expanding pitch. This explains why efficiency is lower at high speed. Conversely, lowest speed (15m/min) resulted to slow material flow in the grading unit resulting to longer time of operation which caused lower capacity. No damaged tubers were found at all speeds.

Table 14: Shows the influence of conveying speed grading efficiency and capacity

Machine parameter	Speed (m/min)		
	S_1	S_2	S_3
Grading System Efficiency (GSE), %	75.17^a	81.6^b	85.03^b
Capacity, kg/hr	974.53^a	872.17^a	1082.63^b

The capacity of the grader at S_1 was significantly higher than at S_2 and S_3 to longer time of operation that caused lower capacity. The slow movement of tubers along the gaps of the caused accumulation of tubers which formed multi-layering. In this situation, some tubers were carried over by the layer to the region of next classification without gradually passing the gaps of the spiral. This explains why efficiency was lower at extremely high and low speeds.

Table 15. Comparison among mean values of the grading system efficiency, capacity, as influenced by the inclination of the grading unit.

Machine parameters	Inclination (degrees)		
	A_1	A_2	A_3
Grading System Efficiency (GSE), %	82.33	84	75.47
Capacity, kg/hr	858.20	1024.83	1046.30

Break even analysis and Economics of the potato grader

The total cost of the potato grader was Birr 40,000.00 with an estimated life span of 5 years. It had an annual fixed cost of Birr 8,000.00 and variable operating cost of Birr 15.00/hr. Assumptions include: interest, 10%, tax, insurance and shelter, 3%, repair and maintenance, 15%, operation per day, 8hr, annual use, 2500 hrs and custom rate Birr 0.5/kg. The grader had a break-even point of 50 ton/year. 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 (Stanton and Wintson, 1977).

Conclusion and Recommendations

The optimum operating parameters for the machine was established at a speed of 20m/min and inclination of 23 degrees with an efficiency of 90.6 %. The capacity of 1146.0 kg/hr and no damaged tubers were observed. A mechanical potato grader, powered by diesel engine, was designed, fabricated and evaluated. The device operates with the principle of expanding pitch as grading unit. The grading unit was formed by shaping round bars in pitch pattern with increasing spaces thereby promoting size differentiation of potato tubers being conveyed along the length, on the rods. The grader was made to vary the speed of the conveyor by varying the speed of the engine accelerator, degree of inclination of the grading unit. The speed imparts velocity on the tubers causing them to move along the gaps of the grading unit round bars. Inclination of the grading unit facilitates the flow of tubers on the grading unit. The performance of the fabricated grader was evaluated on one variety of potato tubers. Grading system efficiency and capacity were observed. The optimum operating parameters for the machine was established at a speed of 25m/min, inclination of 23 degrees and giving a system efficiency of 90.6%, capacity of 1146.0 kg/hr, no damaged tubers of the potato was observed. The initial cost of the grader was 40, 000.00 and was expected to last for 5 years.

The designed, fabricated and evaluated potato grader is recommended to be used by the local farmers at Harari, Dire Dawa 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 modification and improvement taking note, however, on the following recommendations based on the observations were noted during the evaluation: 1). Consider the use of longer length for the expanding pitch and incorporating oscillation/vibration and spirally rotating mechanisms to increase the capacity and grading efficiencies; 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.

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