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Performance Evaluation of Engine Operated Potato Grader

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ድንችን በባህላዊ መንገድ በመጠን የመለየት ስራ ብዙ ሰዓትና የሰው ጉልበት የሚፈልግ በጣም አድካሚና አነስተኛ ውጤት የሚያስገኝ ስራ ነው። ስለሆነም ድንችን ወደ ተለያየ መጠን የሚለይ በሞተር ኃይል የሚሰራ ማሽን ፍተሻ እና የመገምገም ስራ ተሰርቷል። የመለያ ማሽኑ በተለያየ መጠን የሚለየውን ድንች ማስገቢያ፣መለያ ሲሊንደር፣ኃይል ማስተላለፊያ ዘንግና መቀበያ አሉት። ሙከራው በተለያየ ጡዘት (10፣15 እና 20 ጡዘት በደቂቃ)፣ ዘዌ (5፣10 እና 15 ዲግሪ) እና በተለያየ የድንች አጨማመር በደቂቃ (20፣ 30 እና 40ኪ.ግ) በስፕሊት ስፕሊት ፕሎት የሙከራ ዲዛይን (split split plot design)ተከናውኗል። የማሽኑን የድንች የመለየት አቅም፣ የመለየት ስርዓት ውጤታማነት፣የነዳጅ ፍጆታ እና መካኒካዊ ጉዳት ከግምት ውስጥ በማስገባት የመገምገም ስራ ተከናውኗል። የፍተሻ ውጤቶቹ እንደሚያሳዩት የማሽኑ የመለየት አቅም እና የነዳጅ ፍጆታው የመለያ ሲሊንደሩ ፍጥነት እና የሚለየው የድንች መጠን ሲጨምር አብሮ የሚጨምር ሲሆን የድንች ሜካኒካዊ ጉዳት እና የመለየት ስርዓት ውጤታማነት ደግሞ የዘዌ መጠን ሲጨምር እየቀነሰ ይሔዳል። ከፍተኛው የማሽኑ የመለየት ስርዓት ውጤታማነት የተገኘው ማሽኑ በ15 ጡዘት በደቂቃ እና በ5 ዲግሪ ዘዌ፤ 20 እና 30 ኪ.ግ. በደቂቃ ድንችን በተለያየ ጊዜ በመጨመር በሚለይበት ጊዜ 97.57 እና 97.67% በቅደም ተከተል ሆኖ ተመዝግቧል። ይህ የድንች መለያ ማሽን የኢኮኖሚ አዋጭነቱ ተጠንቶ በሀገር ውስጥ አምራቾች ተባዝቶ ለተጠቃሚዎች ቢቅርብ የድንች አምራቾችና በምርት እሴት ሰንሰለት ላይ የተሰማሩ ባለድርሻ አካላትን ውጤታማነትን ያሳድጋል።

ቁልፍ ቃላት፡ የአፈፃፀም ግምገማ፣ድንች፣መለያ

Abstract

Traditional methods of grading potato tubers require high labor-hour, cause fatigue to workers and has low output. Hence, engine driven machine capable of grading potato tubers into different size classes was evaluated. The grader prototype consisted of feeding table, grading cylinder and catchment tray. Grading capacity, grading system efficiency, mechanical damage and fuel consumption were used to determine the performance of the machine. Split-split-plot experimental design where grading cylinder speeds (10, 15, 20 rpm) were the main plots, angle of inclinations (5, 10, and 15°) as sub-plots and feeding rates (20, 30, 40 Kg.min^{-1})as sub-sub-plots with three replications were used. The results indicated that grading capacity and fuel consumption increased with increasing cylinder speed and feed rate while percentage mechanical damage and grading system efficiency decreased with increasing angle of inclination. The maximum grading system efficiency of 97.57% and 97.67 % was observed, when the machine was operated at speed of 15rpm, angle of inclination of 5° and feed rate of 20 and 30 kg.min^{-1}, respectively. From the performance indices, it can be concluded that the performance of the machine is very much acceptable with high prospect for extending the technology for small and medium scale farmers and potato whole sellers along the value chain..

Keywords: Performance evaluation, potato, grader

Introduction

Potato (*Solanum tuberosum*) is the world‘s top non-grain food commodity ranking first in volume produced among root and tuber crops grown in more than 125 countries. It is consumed almost daily by more than a billion people (Gebru *et al.*, 2017). In Ethiopia, potato plays an important role in improving food security and income of smallholder potato growers due to its high yield potential per hectare (Tewodrose, 2014; CSA, 2015). Potato is grown in four major areas in Ethiopia: the central, the eastern, the north western and the southern regions, that cover approximately 83% of the potato farmers (CSA, 2009). Around 1,288,146 households are dependent on potato production and about 67,361.87 ha of land is under potato production which has 31.13% area coverage among root crops (CSA, 2015). Potatoes can be used for a variety of purposes as a fresh vegetable for cooking at home, as raw material for processing into food products, food ingredients, starch and alcohol production, as feed for animals, and as seed tubers for growing in the next season.

Around the world, consumers demand is shifting from fresh tubers to processed products and ever greater quantities of potatoes are being processed to meet rising demand for convenience food and snacks (FAO, 2009). As a result, a group of unit operations like washing, drying, grading, waxing, packaging and pre-cooling are performed after harvesting and before they reach the ultimate consumers. In this group of unit operations, grading is one of the most important operations, which add value to the product, and gives higher economic gain to the producers (Mangaraj *et al.,* 2006).

Grading of vegetables is an important operation affecting quality, handling and storage of produce and plays a major role in the food processing industries. Grading is done to standardize a product, to facilitate marketing, for sales appeal, for ease in quantifying, for ease in price fixing of uniform sized lot and for compliance of international or national grading standards (Thirupathi, 2009).

Mahirang *et al* (2009) provided a basis on the classification of potato tubers as small, medium and large with minor diameters of 30-39 mm, 40-74 mm and 75 mm and above respectively. According to Swarnalakshmi and Kanchanadevi (2014) potato tubers with diameter, ≥60 mm was considered as big and small when the diameter is ≤50 mm. Large size potato tubers are used for processing, especially for making chips, and for baking. Medium and small size potato tubers are preferred for culinary use. Seed potato tubers should have diameters between 28 and 55 mm and are graded into two sizes of 28 to 40 mm and 40 to 55 mm (Roy et al., 2005). According to FAO (2009) tubers of uniform size, ranging from 25 to 50 mm can be used as planting material.

Different potato grading machines were developed around the world. Studies made by different researchers on the performance of potato tubers, fruits and vegetables grades indicate that, 10 to 20 rpm of grading speed, 6 to 39 kg.min^{-1} of feed rate and angle of inclination of 10 to 20^{0} were used (Omre and Saxena, 2003; Roy *et al.,* 2005; Valentin *et al*., 2017). Generally, grading is done on the basis of size, shape, weight, color etc. Different studies were carried out to determine the application of various types of grader used in the process of grading different types of vegetables and other agricultural products (Dattatraya *et al.*, 2013).

Traditionally Small and medium-scale farmers need to produce a high quality, standardized production in order to sell potato to processors, and join the regional and international markets as exporters. In this regard, evaluation of potato grading machine amenable to local conditions and low in cost of owning and operating, labor and time saving and safe to operate is the order of the day. Therefore, the objective of this research was to test and evaluate the performance of developed potato grading machine capable of grading potato tubers into different sizes.

Materials and Methods

Description of study area

Fabrication, testing and performance evaluation of the potato tubers grading prototype were conducted at Melkassa Agricultural Research Center (MARC); which is found in Oromia region, Ethiopia. It is located at an altitude of 1550 meters above sea level (masl) and lies between 8° 24' 0" to 8° 30' 12" N, 39° 21' 0" to 39° 35' 14" E latitude and longitude, respectively. Agro-ecologically, the area is characterized as arid and semi-arid. The average maximum and minimum temperatures are 28.40^{0}C and 14.00^{0}C, respectively.

Source of experimental material

A total of 2430 kilograms of potato tubers (*Gudene* variety) were used during the entire test runs. *Gudene* variety was selected based on its availability in the market during performance evaluation. The samples were divided into 27 groups each containing small, medium and large tubers measured with digital caliper and labeled manually. Each group had the mass 20, 30 or 40 kg of potato tuber.

Description of the machine

The component parts of the grader prototype include feeding table, cylindrical grading unit, catchment tray, pulleys and belts, bearings, power source and mounting frame as shown in figure 1. The grading unit is a cylindrical type with 19 trapezoidal holes spaced at equal distance along the grading cylinder length with increasing slot sizes starting from the inlet. It has three compartments for small, medium and large sized tubers according to the size and shape of potato tubers. The grader has a prime mover and power transmission assembly vertically aligned with the shaft of the grading cylinder mounted on the frame.

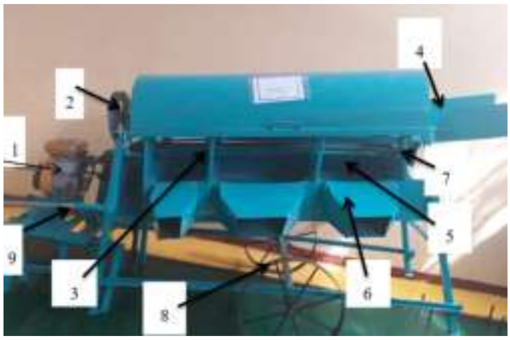

Figure 1. Prototype potato grading machine in operation

1: Prime mover, 2: Pulley, 3-Grading Cylinder, 4: Feeding Table, 5: Receiving Tray, 6: Outlet, 7: Frame, 8: Transportation wheel, 9: Handle

Beneath each grading unit, there is a tray covered with cushioning material to receive the tubers at each of the grade sections. The tray has 4 sections along the length of the grading unit to collect graded tubers as shown in Figure 2.

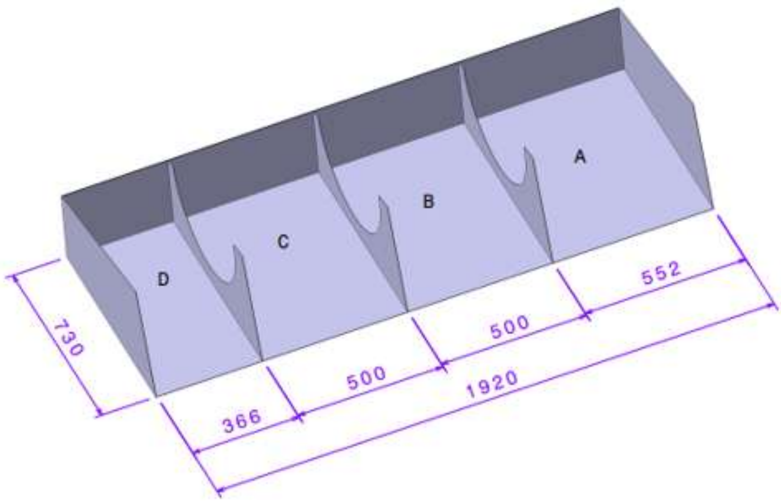

Figure 2. Partition tray covered with cushioning material to catch the tubers at each grading section A: section for small size potato tuber, B: section for medium size potato tuber, C: section for large size potato tuber, D: section for extra-large size potato tuber

Working Principle

Grading operation begins with a rotating motion of the grading unit through belt and pulley by the power obtained from the prime mover/engine. A speed reducer (with a ration of 1:50) was used to reduce the speed of the prime mover through belt and pulley. Potato tubers were fed into the inclined and rotating cylinder from feeding table and travel down along the length of the cylinder. Potato tubers at the lower portion of the cylinder were lifted upwards by the trapezoidal slot, from which they are again lifted along with it and slide down. The potato tubers gradually move towards the opposite end of the cylinder from the feeding table. The potato tubers have contact only with a portion of the cylinder inner surface with no relative velocity during their lift. Potato tubers based on their minor diameters were forced to pass through the slots during the rotation of the grading cylinder and collected on the catchment tray placed below the grading unit.

Experimental design

The experiment was laid in a split-split plot design (Gomez and Gomez, 1984) having grading cylinder speeds as main plots, the angle of inclination as sub-plots and feeding rates as sub-sub-plots with three replications as a block. The design was 3^3 factorial combinations with three replicates giving 81 total experimental units (3x3x3x3 = 81). The treatments were three levels of cylinder speeds (10, 15 and 20 rpm), three levels of angle of inclination (5, 10 and 15 degrees) and three levels of feeding rates (20, 30 and 40 $kg.min^{-1}$) (Omre and Saxena, 2003; Roy *et al.*, 2005; Valentin *et al*., 2017).

Testing and performance evaluation of potato grader

Before performance evaluation, potato tubers were graded and labeled into classes with specified ranges of measured minor diameter manually with digital caliper. During manual grading, it was observed that a single person performing at higher grading system efficiency and having a maximum grading capacity, the average throughput of labor was 37.25 $kg.hr^{-1}$. Small, medium and large tubers had minor diameters between 26 and 39mm, 40 and 57 mm and greater than 57 mm respectively. Tubers with initial damages such as scratches, abrasion, decay and greening were not included in the sample.

During the experiment, the engine was turned on and the selected cylinder speed was achieved by adjusting the position of fuel throttle control. The cylinder speed was measured using a non-contact tachometer that can measure angular speeds from 2 to 9999 rpm with accuracy of 0.10 rpm. When the cylinder speed was at the desired level, the machine is loaded with a selected feed rate. After the grading operation, tubers that dropped at respective collection tray were counted and recorded. The time, in seconds, it took to grade the samples was recorded. The performance of potato grader prototype; overall grading system efficiency, grading capacity, damaged tuber (%), power consumption, labour requirement and costs (fixed and variable) was evaluated.

Grading capacity

Grading capacity of potato grader prototype was determined on the basis of the amount of potato tubers graded within a specific period of time by Eqn. (1), (Cochran and Cox, 1975).

$$\text{Grading Capacity (kg. hr.}^{-1}\text{)} = \frac{\text{Weight of potato tuber collected at outlet (kg)}}{\text{Total time required for grading (hr.)}} \quad (1)$$

Grading system efficiency

Grading system efficiency was determined by taking the products of the efficiencies of grading small, medium and large tubers and Eqns. (2), (3), (4), and (5), (Valentin *et al.*, 2017).

$$\text{GSE (\%)} = \eta_s \times \eta_m \times \eta_L \times 100 \quad (2)$$

$$\eta_s = \frac{\text{Number of correctly graded small potato tuber}}{\text{Number of correctly graded small potato tuber}} \quad (3)$$

$$\eta_m = \frac{\text{Number of correctly graded medium potato tuber}}{\text{Number of correctly graded medium potato tuber}} \quad (4)$$

$$\eta_l = \frac{\text{Number of correctly graded large potato tuber}}{\text{Number of correctly graded large potato tuber}} \quad (5)$$

where:-

GSE = grading system efficiency (%),

η_s = efficiency of grading smaller tubers,

η_m = efficiency of grading medium tubers and

η_l = the efficiency of grading large tubers.

Grading damage

The percentage of damaged tubers was taken by considering the total number of tubers with abrasion after the operation against the total number of tubers in the sample as indicated in Eqn. (6).

$$\text{Damaged tuber(\%)} = \frac{\text{Total number of tuber with abrasion}}{\text{Total number of tuber in the sample}} 100 \quad (6)$$

Fuel consumption

Fuel consumed while grading potato tuber at a given feeding rate, grading cylinder speed and angle of inclination was measured using measuring cylinder by using filling and re-filling method.

Results and Discussions

Grading capacity

The ANOVA analysis indicated that the grading capacity of the grader prototype was significantly ($P<0.05$) affected by speed of cylinder, angle of inclination and feed rate. The combined effect of cylinder speed and angle of inclination, speed of cylinder and feed rate, and angle of inclination and feeding rate were also significant at the same level. The maximum grading capacity of 2,769.91 $Kg.hr^{-1}$ was recorded when the grading cylinder speed was 20 rpm, the angle of inclination was 15° and the feed rate was 40 $kg.min^{-1}$ (Table 1). In general, the grading capacity increased with increasing cylinder speed, angle of inclination and feed rate (see the regression equation given below).

$$Y = 230.27 + 60.13\omega + 32.12\alpha + 22.13f; \quad R^2 = 0.96$$

Where:

Y = Grading capacity, $kg.hr^{-1}$
ω = cylinder speed, rpm
α = cylinder inclination, degrees
f = feed rate, $kg.hr^{-1}$

Table 1. Interaction effect of cylinder speed, inclination angle and feed rate on grading capacity

Grading Cylinder		Feeding Rate($Kg.min^{-1}$)			
Speed (rpm)	Inclination angle(°)	20	30	40	Grand Mean
10	5	$1430.97^{s}\pm33.27$	$1661.80^{q}\pm25.57$	$1822.98^{no}\pm23.08$	
	10	$1543.02^{r}\pm19.23$	$1862.07^{mno}\pm0.00$	$2128.18^{ij}\pm18.24$	
	15	$1714.93^{pq}\pm40.84$	$1928.98^{lm}\pm34.45$	$2150.53^{hi}\pm64.22$	
15	5	$1800.75^{op}\pm45.03$	$2000.46^{kl}\pm37.05$	$2227.64^{gh}\pm53.02$	
	10	$1895.61^{mn}\pm49.91$	$2160.58^{hi}\pm43.22$	$2361.09^{ef}\pm38.71$	
	15	$2058.26^{jk}\pm58.33$	$2298.57^{fg}\pm48.92$	$2469.69^{cd}\pm64.17$	
20	5	$1946.89^{lm}\pm52.64$	$2219.39^{gh}\pm26.51$	$2428.99^{de}\pm86.55$	
	10	$2118.87^{ij}\pm62.35$	$2512.53^{cd}\pm58.44$	$2618.76^{b}\pm47.62$	
	15	$2484.73^{cd}\pm85.73$	$2555.39^{bc}\pm128.44$	$2769.91^{a}\pm53.28$	2117.47
Grading speed × Angle of inclination × Feed rate					
SED				30.16	
LSD				86.09	
CV (%)				2.1	

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability; SE = standard errors of differences of means; LSD = least significance difference, and CV = coefficient of variation.

Grading system efficiency

The analysis of the grading efficiency of the grader prototype shown in Table 2 revealed that; feeding, angle of inclination and cylinder speeds had significant ($p<0.05$) effect on percent grading efficiency. The interaction of cylinder speed, angle of inclination and feed rate were significant at 5% level. The interaction of cylinder speed and inclination angle, angle of inclination and feeding rate was significant at the same level. The interaction of cylinder speed and feeding rate was not significant. As can be seen from Table 2, the maximum grading system efficiency of 97.58% and 97.67% was observed at cylinder speed of 15 rpm, inclination angle of 5° and feeding rate of 20 and 30 $kg.min^{-1}$, respectively. Cylinder speed and feed rate appear to have the least effect on system grading efficiency as can be seen from the coefficients in regression equation given below.

$$G_e = 113.15 + 0.49\,\omega + 1.32\,\alpha + 0.23\,f; \quad R^2 = 0.76$$

Table 2. Interaction effect of cylinder speed, inclination angle and feed rate on grading system efficiency (Ge) (%).

Cylinder Speed(rpm)	Inclination angle(°)	Feeding Rate($Kg.min^{-1}$) 20	30	40	Grand Mean
10	5	89.99[cde]±2.19	94.17[ab]±2.26	91.33[bcd]±0.71	
	10	88.58[cdef]±0.82	88.41[cdef]±0.68	86.66[efgh]±0.06	
	15	84.28[ghi]±1.26	83.28[hij]±2.52	76.83[m]±1.68	
15	5	97.58[a]±0.43	97.67[a]±1.02	87.67[defg]±1.09	
	10	91.88[bc]±5.29	89.12[cdef]±0.20	88.38[def]±4.59	
	15	82.27[ij]±0.68	77.94[lm]±3.13	78.91[klm]±0.75	
20	5	94.54[ab]±0.38	90.01[cde]±4.35	85.24[fghi]±3.28	
	10	81.82[ijkl]±1.58	82.45[ijk]±0.37	79.58[jklm]±3.78	
	15	76.78[m]±0.93	78.22[lm]±0.52	71.24[n]±1.49	85.73

Grading speed × Angle of inclination × Feed rate	
SED	1.353
LSD	3.857
CV (%)	2.4

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability; SE = standard errors of differences of means; LSD = least significance difference, and CV = coefficient of variation.

Mechanical damage

Mean percent mechanical damage of potato tubers at various cylinder speeds, inclination angles and feed rates is given in Table 3. The analysis of variance, on percent damaged tubers, indicated that feeding rate, inclination angle and cylinder speed and their combination had highly significant ($P < 0.05$) effects on the level of tuber damage. The least percent tuber mechanical damage of 1.56% was observed at cylinder speed of 20 rpm, inclination angle of 15° and feed rate of 20 $kg.min^{-1}$. Maximum percent tuber mechanical damage of 5.31% was occurred when cylinder speed was 20 rpm, inclination angle 5° and feed rate of 40 $kg.min^{-1}$. Based on the regression equation given below, tuber mechanical damage decreased with increasing inclination angle at all levels of feed rate and cylinder speeds.

$$MD = 2.73 + 0.06\,\omega - 0.82\,\alpha + 0.05\,f; \quad R^2 = 0.82$$

Table 3. Interaction effect of cylinder speed, inclination angle and feed rate on mechanical damage (%)

Cylinder Speed (rpm)	Inclination angle (°)	Feeding Rate(Kg.min^{-1}) 20	30	40	Grand Mean
	5	3.05^{gh}±0.30	3.27^{efg}±0.14	3.87^{c}±0.22	
10	10	2.35^{jk}±0.15	2.72^{hi}±0.21	3.50^{def}±0.29	
	15	1.76^{m}±0.05	2.14^{kl}±0.11	2.87^{h}±0.23	
	5	3.22^{fg}±0.20	3.56^{cde}±0.26	4.71^{b}±0.50	
15	10	2.86^{h}±0.18	3.02^{gh}±0.11	3.47^{ef}±0.04	
	15	2.26^{jk}±0.12	2.25^{jk}±0.15	2.76^{hi}±0.09	
	5	4.65^{b}±0.18	4.72^{b}±0.28	5.31^{a}±0.16	
20	10	2.87^{h}±0.32	3.26^{efg}±0.14	3.82^{cd}±0.05	
	15	1.56^{m}	1.84^{lm}±0.08	2.51^{ij}±0.19	3.12
Grading speed × Angle of inclination × Feed rate					
SED					0.12
LSD					0.33
CV (%)					6.9

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability; SE = standard errors of differences of means; LSD = least significance difference, and CV = coefficient of variation.

Fuel consumption

The mean fuel consumption, in (ml.kg^{-1}), of the potato tubers grader prototype operated at different cylinder speeds, inclination angle and feed rates is given in Table 4. The analysis of variance on fuel consumption revealed that cylinder speed and feed rate had highly significant ($P< 0.05$) effects on fuel consumption. Fuel consumption of the grading machine increased with increasing cylinder speeds and feed rates. Fuel consumption increases with increasing cylinder speed and feed rate though it appears to decrease with increasing inclination angle (see the equation below).

$$FC = 1.99 + 0.19\,\omega - 0.004\,\alpha + 0.073\,f; \quad R^2 = 0.94$$

Table 4. Interaction effect of cylinder speed, inclination angle and feed rate on fuel consumption (FC, ml.kg^{-1})

Cylinder Speed (rpm)	Inclination angle(°)	Feeding Rate(Kg.min^{-1}) 20	30	40	Grand Mean
	5	1.54^{lm}±0.04	1.97^{j}±0.04	2.27^{i}±0.02	
10	10	1.27^{no}±0.10	1.67^{kl}±0.04	2.05^{j}±0.04	
	15	1.12^{o}±0.09	1.46^{lmn}±0.13	1.84^{jk}±1.75	
	5	1.89^{j}±0.05	2.84^{f}±0.26	3.69^{c}±0.22	
15	10	1.65^{klm}±0.09	2.59^{gh}±0.16	3.38^{d}±0.15	
	15	1.45^{mn}±0.09	2.36^{i}±0.17	3.13^{e}±0.13	
	5	2.75^{fg}±0.18	3.84^{c}±0.26	4.69^{a}±0.22	
20	10	2.72^{fg}±0.05	3.65^{c}±0.21	4.58^{a}±0.15	
	15	2.45^{hi}±0.09	3.36^{d}±0.17	4.31^{b}±0.20	2.61
Grading speed × Angle of inclination × Feed rate					
SED					0.07
LSD					0.21
CV (%)					4.7

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability; SE = standard errors of differences of means; LSD = least significance difference, and CV = coefficient of variation.

In general, from tests carried out, the maximum grading system efficiency of 97.58 and 97.67% was recorded when the grading unit was operated at speed of 15 rpm, inclination angle of 5° and feed rate of 20 and 30 $kg.min^{-1}$, respectively. At this optimum condition, the grading capacity, mechanical damage and fuel consumption were obtained as 2000.46 $kg.hr^{-1}$, 3.56% and 2.84 $ml.kg^{-1}$, respectively.

Percent tubers mechanical damage decreased with increasing cylinder inclination angle at all levels of feed rates and cylinder speeds indicating that 15° inclination angle to be an optimum one. Furthermore, it was noted that the 20 rpm cylinder speed resulted in the highest tuber mechanical damage.

Fuel consumption in $ml.kg^{-1}$ of the potato tubers grader prototype when operated at different cylinder speeds, inclination angles and feed rates revealed that cylinder speed, inclination angle and feed rate had highly significant ($P<0.05$) effects on the mean fuel consumption. Fuel consumption of the grading machine increased with increasing cylinder speed and feed rate indicating that energy cost would increase with increasing rate of work though it appears to decrease with increasing cylinder inclination angle.

Conclusion and Recommendation

The developed potato tubers grader prototype for different varieties of potato tubers evaluated for *Gudene* variety was found to be efficient at cylinder speed of 15 rpm when the cylinder inclination angle is 5° and the feed rate is 30$kg.min^{-1}$. It is recommended that the prototype should be further evaluated by using different available potato varieties in the country and demonstrated to users along the potato value chain. Systematic, coordinated and relentless efforts should also be made by the research and local private manufactures to make the machine affordable, so as to be jointly owned and make it economical and to fabricate locally and promote market quality potato tubers, in order to get a premium price.

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