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Performance Evaluation of an Engine Driven Onion Grading Machine

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ABSTRACT

To replace the traditional way of onion grading mechanism practiced in the Ethiopia, the performance evaluation of an onion grading machine developed and fabricated at Asella Agricultural Engineering Research Center (AAERC) was undertaken. The experimental design used was factorial in a completely randomized design with two factors (three levels of speeds of grading unit (rpm) and three levels of feed rate (kg/min) with three replications). The main and interaction effects of machine operational parameters on grading capacity, grading efficiency, bulb damages, fuel, and energy consumption were studied. The optimum result was obtained when the machine operated at 55 rpm speed of the grading unit and a feeding rate of 15 kg/min. At these operational parameters, a grading capacity of 1488.43 kg/hr, maximum grading efficiency of 96.04%, bulb damage percentage of 1.20%, and fuel and energy consumption of 1.37(ml/kg) and 4.23 W-hr/kg, respectively were obtained. Statistical analysis of the data showed that the combination of grading unit speed and feed rate of the grader had a significant effect on grading machine capacity, efficiency, and percent of bulb damage at $p < 0.05$. The cost of the grader was estimated to be 20,880.99 ETB with a cost-benefit ratio of 1.00: 9.09. Generally, it can be concluded that this grading machine is simple in design, easy in operation, and found to be suitable for small and medium-scale farmers.

INTRODUCTION

Fruits and vegetables are among the different agricultural commodities that have recently attracted a lot of attention in international trade and have also been widely acknowledged as a vital part of a healthy diet in the health sector. More crucially, changes in spending and consumption patterns, as well as the removal of barriers, have helped most developing nations grow their share of the global fruit and vegetable trade (Deepak, 2001). Owing to their high profitability per unit area, ease of production, and the growth of small-scale irrigation zones, onions are steadily becoming more and more popular in Ethiopia (Nigussie *et al.*, 2015).

In onion production, postharvest losses are widespread due to the perishable nature of the onion and the lack of proper postharvest practices and processing technology, which is a major production restriction that reduces productivity. As an onion crop is a highly perishable vegetable, it starts to lose its quality right after being harvested and continued throughout the process until it is consumed. For this purpose elaborated and extensive postharvest handling practices like grading are vital.

Narvankar *et al.*, (2005) presented the grading of fruits and vegetables as one of the most important operations since it adds value to the product and gives a better economic return to the producer. Manual grading is an expensive and time-consuming process and even the operation is affected by the non-availability of labours during peak seasons. Also, Ranganna and Tiwari, (2002) explained that grading and standardization bring about an overall improvement not only in the marketing system but also in raising quality consciousness. It lowers handling losses

during transport and saves time and energy in various processing procedures. Grading also facilitates packing, marketing, and other post-harvest procedures.

Abd El-Tawwab *et al.* (2012) measured the performance of a multi-germ beet-seeds grading machine in terms of grading capacity, grading efficiency, and energy requirements. Umari (2011) designed and evaluated the performance of a mechanical olive-size grading system, with three different grading speeds (10, 16, and 23 rpm). The results showed that grading accuracy was relatively affected by grading speed and harvesting date. Also, Charles and Etiese (2020) developed and evaluated a manually operated single-cylinder type onion grading machine at cushioned and non-cushioned. The machine's grading efficiency and capacity were investigated for the machine's operational parameters with two levels of feed gate opening and four levels of crank revolutions.

In a developing country like Ethiopia, most fruit and vegetable growers grade their products by hand. Grading by hand is expensive and the operation is hampered by labour shortages during high seasons. Human operations can be inefficient, inconsistent, and time-consuming. Farmers are hoping for suitable agricultural product grading equipment to help ease labour shortages, save time, and improve the quality of graded products. To achieve this a low-cost and suitable an onion grading machine was designed, developed, and fabricated at Asella Agricultural Engineering Research Center(Wabi, and Adesoji, 2023). This type of grading machine lowers costs and labor requirements, enabling farmers to be more productive. In the future, research in this area will be crucial to the development of a new mechanism that

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will help farmers become competent of managing their own crops. Thus, it is vital to assess how well an engine-driven onion bulb size grading equipment performs. Additionally, this study plays a critical role in determining the machine's economic relevance and, consequently, in recommending the optimal performance operational parameters under various working conditions.

MATERIALS AND METHODS

Description of Experimental Site

To fulfill the objective, the performance evaluation of the onion grading machine prototype was conducted in the Asella Agricultural Engineering Research Center which is located in Oromia National Regional State, Ethiopia. It is located at 6° 59' to 8° 49' N latitudes and 38° 41' to 40° 44' E longitudes, having an elevation of 2430 meters above sea level.

Experimental Material

In Ethiopia, there are a lot of onion bulb varieties, but to investigate the machine performances, the onion bulb of Bombay red variety was procured directly from the farmer's field in Awash Melkasa area. The variety was selected based on their productivity, quality of the bulb, acceptance among the farmers, and distribution rate in Ethiopia.

Performance Evaluation of the Machine

Experimental Design

The experimental design for the performance test of the grading machine was done for three rotational speeds of the rotating grading unit (45, 55, and 65 rpm) and three feeding rates (15, 25, and 35 kg/min) of onion bulbs. These ranges were selected based on the size of the designed and fabricated grading machine against previously developed machines and variables repeatedly recommended for re-evaluation in different literature by different researchers. The experimental plan of full factorial design with two factors was used. The design had the form of 3 × 3 equal to 9 treatment combinations with three replications which resulted in a total test run of 27.

Statistical Analysis of Data

The collected data were analyzed by Analysis of Variance (ANOVA) using statistical R-software (version 3.4.3, 2017). Where the effects of the treatment were found significant, the Least Significance Difference (LSD) test was performed to assess the difference among the treatments at a 5% level of significance.

Sample Preparation

To investigate the performance of the fabricated onion bulb grader, 675 kg of onion bulbs of the Bombay red variety were bought directly from the farmer's field in the Awash Melkasa area. The bulbs were manually cleaned to remove foreign materials, damaged bulbs, and immature onions bulbs. Before carrying out the test, the bulbs of

each sample were graded manually into three grades. Each bulb in the sample was given a number for identification of its classified grade to which it belonged. Twenty-seven (27) samples of onion bulbs of equal proportions of the graded sizes were weighed and obtained for the performance test analysis of the grader. The total weight of the whole sample and each category were recorded. Samples were continuously fed into the feed hopper. The associated feeding time was noted from the start to the end of the operation. Therefore, the correctly and incorrectly classified onion bulbs were counted and weighed in each receiving sack, separately.

Variables and Data Collection

Independent Variables

Two independent variables (machine parameters) were used during the evaluation. These were the speed of the grading unit (45, 55, and 65 rpm) and the feeding rates (15, 25, and 35 kg/min). The desired amount of onion bulbs was discharged into the feeding hopper with the feed gate closed and then the machine was calibrated at a specified rotational speed by adjusting the position of the fuel control throttle. The cylinder speed was measured using a tachometer that can measure angular speeds from 2 to 9999 rpm with an accuracy of 0.10 rpm. After calibration, the bulbs were discharged and rolled to the collecting sacks provided below the grading unit and onion bulbs in each sack were weighed and performance evaluation analysis was done accordingly.

Measurements and Calculations

A predetermined weight of onion bulbs was fed into the hopper and then rolled down into the grading unit at the selected grading unit speed. The performance of the onion grader was evaluated in terms of overall grading system efficiency, grading capacity, damaged bulbs (%), fuel consumption, Energy requirement, and Grading costs.

Grading Capacity

The grading capacity of the onion bulb grader was determined based on the amount of onion bulbs graded within a specific period of time and Eqn. (1), was used to estimate grader's capacities (Valentin *et al.*, 2016).

$$\text{Grading capacity (kg/hr)} = \frac{\text{weight collected at outlet (kg)}}{\text{(Total time taken for grading (hr))}} \quad (1)$$

Grading System Efficiency

The grading efficiency of the grader was estimated based on known feed composition. Under the known feed composition test, onion of different sizes was selected. Three collection units were collected the graded onion bulbs according to commercial grade as well as the size group decided as, small, medium, and large grade. Grading system efficiency was determined by taking the products of the efficiencies of grading small, medium, and large bulbs using Eqns. (2), (3), (4), and (5) (Valentin *et al.*, 2016).

$$GSE(\%) = (\eta_s \times \eta_M \times \eta_L) \times 100 \quad (2)$$

$$\eta_s = (\text{Weight of correctly graded smaller bulb}) / (\text{Total weight of small bulb in the sample}) \quad (3)$$

$$\eta_M = (\text{Weight of correctly graded medium bulb}) / (\text{Total weight of the medium bulb in the sample}) \quad (4)$$

$$\eta_L = (\text{Weight of correctly graded larger bulb}) / (\text{Total weight of large bulb in the sample}) \quad (5)$$

Where:

GSE = grading system efficiency (%),
 η_s = efficiency of grading smaller bulbs,
 η_M = efficiency of grading medium bulbs, and
 η_L = the efficiency of grading large bulbs.

Bulb Damage

Damage to onion bulbs with abrasion after the grading operation was considered. All physically damaged bulbs were visually observed, manually sorted, and weighed using a digital balance. Damage due to mechanical grading was determined as the ratio of the weight of the damaged onion bulbs to the weight of the sample using Equation (6) (Karthik *et al.*, 2018).

$$BD(\%) = (W_{d1} + W_{d2} + W_{d3}) / W_t \times 100 \quad (6)$$

Where:

BD = the bulb damage percentage, (%)
 W_{d1} = the weight of damaged bulbs collected at small size collection unit (kg),
 W_{d2} = the weight of damaged bulbs collected at medium size collection unit (kg),
 W_{d3} = the weight of damaged bulbs collected at large size collection unit (kg), and
 W_t = the total weight of the sample (kg).

Fuel Consumption

Fuel consumed while grading onion bulbs at a given rotational speed of the grading unit and feeding rate was measured using the refilling method. The fuel tank was filled before and after the test. The amount of refueling after the test was the fuel consumption for the performance evaluation. While filling up the tank, careful attention was paid to keeping the tank horizontal and not leaving space in the tank. The fuel consumption has a direct effect on the economics of the machine and gave an idea of the energy required by the grading machine during operation (Sirmour and Verma, 2018).

Energy Requirements

To estimate the engine power during the grading process, the decrease in fuel level was accurately measured immediately after each treatment. The following formula was used to estimate the corresponding used engine power (EP) according to Ali *et al.*, (2007).

$$EP = [F_c (1/3600) PE \times LCV \times 427 \times \eta_{thb} \times \eta_m \times 1/75 \times 1/1.36], kW \quad (7)$$

Where:

EP = engine power (kW),
 F_c = the fuel consumption (l/hr),
 PE = the density of fuel (kg/l, for Gas oil = 0.85), L.C.V.

= the lower calorific value of fuel (11,000 k.cal/kg),
 η_{thb} = thermal efficiency of the engine (35 % for Diesel),
 427 = thermo-mechanical equivalent (Kg.m/k.cal), and
 η_m = mechanical efficiency of the engine (80 % for Diesel).
 Hence, the energy requirement was calculated as follows:-
 Energy requirements = (EP, (kW)) / (Feed rate (kg/hr)), W.
 hr/kg (8)

Cost Analysis of Onion Grading Machine

The initial cost of the onion grading machine was calculated by adding up the cost of individual components involved in the prototype fabrication at the dominant market price. These would be added to a percentage for prototype fabrication cost and marginal profit of the manufacturer. The cost of the onion bulb grader was divided into two heads known as a fixed cost and variable cost. Estimation of annual and hourly operational costs of the grader was based on the capital cost of the grader, interest on capital, cost of repairs and spare parts, labor cost, fuel cost, and depreciation. The operational cost of the components of the grader prototype was estimated in Ethiopian Birr (ETB) as follows;

Fixed Cost

Material cost + Labor cost + Machine cost (C) = 16,076.33 ETB

Salvage value cost (S) @ 10% of total cost of the machine = 1,607.63 ETB

Operational Cost

Annual use (U) (Expected operational hours) = 750 hrs
 Expected life years (L) = 8 years

Fixed Cost

Depreciation (D)
 $D = (C - S) / UL = (16,076.33 - 1,607.63) / (750 * 8) = 2.41$ ETB/hr
 Interest on capital investment @ 12% per annum on average price (I)
 $I = ((C + S) / 2U) \times 0.12 = (16,076.33 + 1,607.63) / (2 * 750) \times 0.12 = 1.41$ ETB/hr
 Repairs / maintenance cost @ 2% (R)
 $R = (C \times 2\%) / UL = (16,076.33 \times 0.02) / (750 * 8) = 0.054$ ETB/hr
 Total fixed cost (D + I + R) = 2.41 + 1.41 + 0.054 = 3.87 ETB/hr

Operational Cost / Variable Cost

Labor cost @ 100 ETB/ day (8 hours/day) per person (W) = 12.50 ETB/hr
 Total variable cost = Fuel cost + labor cost = 160.76 ETB/hr
 The total cost of operation (A) = Total fixed cost + Total variable cost
 = 3.87 + 160.76 = 164.63 ETB/hr
 When the grader was performing at high grading

efficiency and having a maximum grading capacity, the average throughput of the machine was 1488.43 kg/hr. Therefore, the grading cost is 0.11 ETB to grade one kg of onion (or 11.06 ETB/ per quintal of onion bulbs) by a developed onion grading machine.

Benefit from One kg Onion

Manual cost of grading = 1 ETB/kg
 Cost of grading by machine = 0.11 ETB/kg
 Cost Benefit Ratio = 1: 9.09
 Manual operational cost
 Labour cost @ 100 ETB/ day (8 hours) per person = 12.5 ETB/hr
 Maximum manual grading capacity of onion bulbs (2 labours) = 200 kg/day (8 hours). This result was estimated by considering the performance of manual grading performed before the grading operation to identify the size of onion bulbs into three size categories.
 Therefore manual grading capacity of a single person = 100 kg/day (8 hours) or 12.5 kg/hr
 Cost of manual grading per kg = 1 ETB/kg
 When man was performing at higher grading efficiency and having a maximum grading capacity, the average throughput of labor was 12.5 kg/hr. Grading of 1 kg of onion bulbs by manual grading process requires 1ETB/kg compared to 0.11 ETB/kg by designed and developed onion grader. Cost-Benefit Ratio = 1: 9.09

RESULTS AND DISCUSSION

Performance Evaluation of the Developed Onion Grader Prototype

The results of performance evaluation obtained from the experiments conducted in the research investigation was reported and discussed in this chapter. The main and combined effect of rotating cylinder speed and feed rate on onion grading machine performance was studied. The grading capacity (GC), grading system efficiency (GSE), bulb damage percentage (BD), fuel consumption (FC), and consumed energy (CE) were estimated and examined as a function of the grading cylinder's speed and feed rate.

Interaction Effects of Rotating Cylinder Speed and Feed Rate on Performance Parameters of Onion Grader

Grading Capacity

Figure 1 and Table 1 showed the relation between cylinder speed and grading capacity of onion bulbs at rotating cylinder speeds of 45 rpm, 55 rpm, and 65 rpm and feeding rates of 15, 25, and 35 kg/min. The maximum and minimum grading capacity was found to be 2429.93 and 1232.84 kg/hr at cylinder speeds of 65 and 45 rpm and feed rate of 35 and 15 kg/min respectively. As the feed rate increased from 15 to 35 kg/min, the grading capacity increased from 1232.84 to 1622.16 kg/hr at 45 rpm. Similarly, for the same range of feed rate, the grading capacity increased from 1488.43 to 2131.9 kg/

hr and 1872.78 to 2429.93 kg/hr at cylinder speeds of 55 rpm and 65 rpm respectively. The analysis of variance (ANOVA) revealed that the interaction of cylinder speed and feeding rate had a significant effect ($p < 0.05$) on grading capacity. The results showed that grading capacity gradually increased with increasing cylinder speed and feed rate and decreased with decreasing the speed and feed rate which is similar to the report of Abd and Magda (2011). The results of this study were greater than the findings of other workers including Abd and Magda (2011), Charles and Etiese (2020), and Gunathilake *et al.* (2016). This may be attributed to the increase in onion bulb speed which resulted in reducing the time of grading and consequently increasing the grading capacity. In other words, increasing the rotating cylinder speed and onion bulb feed rate increases the throughput of onion bulbs from the grading unit openings which in turn, increases the machine grading capacity. For this reason, a greater amount of onion bulb was graded with less time hence the capacity was increased. For grading operation, it is therefore important to select a suitable combination based on use and grading efficiency requirements.

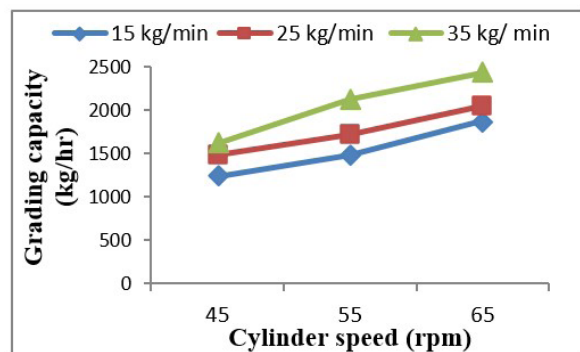


Figure 1: Combined effect of cylinder speed and onion bulbs feed rate on grading capacity

Grading System Efficiency

The result of cylinder speed and feed rate on grading efficiency was given in Figure 2 and Table 1. It is evident from the table that the best combination to achieve the highest grading system efficiency of 96.04% was operating the machine at 55 rpm with 15 kg/min of feed rate. The minimum grading efficiency of 87.32% was obtained at a cylinder speed of 65 rpm and a feed rate of 35 kg/min. As the feed rate increased from 15 to 35 kg/min, the grading efficiency increased from 91.89% to 94.01% at a 45 rpm rotating cylinder. A maximum grading capacity of 96.04% was observed at 55 rpm grading unit speed and 15 kg/min feed rate and gradually decreased with increasing the speed and feed rate of onion bulbs. This decrease in grading efficiency by increasing rotating cylinder speed and feed rate may be due to the increase in the speed and quantity of material displacement, which, in turn, shortened the time of grading, and also, makes difficult the penetration of onion bulbs through their size

openings. For this reason, some of the small-size bulbs moved into the region of openings for medium and large size classification and some of the medium size moved into the large-size opening which decreased the grading system efficiency. Similar trends of decrease in efficiency as cylinder speed increases were reported in different speeds of onion bulb grader by Abd and Magda (2011), Gunathilake *et al.* (2016), and Charles and Etiese (2020). However, the efficiency of the grading machine found in this study was higher and this may be due to the improved part arrangements and size of the machine. The analysis of variance (ANOVA) revealed that the combination of grading unit speed and feeding rate had a significant effect ($p < 0.05$) on grading efficiency.

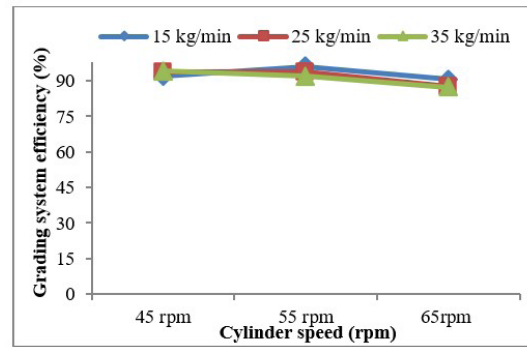


Figure 2: Combined effect of cylinder speed and onion bulb feed rate on grading system efficiency

Table 1: Interaction effect of the cylinder speed and feed rate on the performance of an onion grading machine

Speed (rpm)	Feed Rate (kg/min)	GC (kg/hr)	GSE (%)	BD (%)	FC (ml/kg)	CE (W.hr/kg)
45	15	1232.84±42.55 ^f	91.89±1.44 ^c	0.34±0.07 ^s	1.18±0.03 ^f	3.73±0.15 ^c
	25	1488.97±28.24 ^c	93.76±1.27 ^b	0.84±0.09 ^f	1.43±0.06 ^{dc}	4.20±0.26 ^d
	35	1622.16±50.91 ^d	94.01±1.38 ^b	1.33±0.02 ^e	1.66±0.03 ^e	4.73±0.06 ^e
55	15	1488.43±40.58 ^c	96.04±0.01 ^a	1.20±0.18 ^c	1.37±0.10 ^e	4.23±0.15 ^d
	25	1619.38±69.35 ^d	93.87±1.35 ^b	1.65±0.05 ^d	1.62±0.03 ^e	5.00±0.10 ^e
	35	2131.91±66.32 ^b	91.86±0.54 ^c	1.88±0.10 ^c	1.80±0.02 ^{ab}	5.53±.15 ^a ^b
65	15	1872.78±58.46 ^c	90.63±0.53 ^c	2.04±0.10 ^{bc}	1.47±0.02 ^d	4.73±0.25 ^c
	25	2051.37±42.17 ^b	87.50±0.90 ^d	2.13±0.12 ^{ab}	1.76±0.03 ^b	5.37±0.12 ^b
	35	2429.93±55.45 ^a	87.32±1.25 ^d	2.25±0.07 ^a	1.86±0.02 ^a	5.77±0.21 ^a
CV (%)		2.94	1.17	6.57	2.85	3.62
LSD(0.05)		89.18	1.84	0.17	0.08	0.29
SEM		30.00	0.62	0.06	0.03	0.10

Values are mean ± SD, and Mean values followed by the same letter in a column are not significantly different at 5% level of significance, Where; GC=Grading capacity (kg/hr), GSE=Grading system efficiency (%), BD=Bulb damage (%), FC= Fuel consumption (ml/kg), CE=Consumed energy (W.hr/kg), CV=Coefficient of variation (%), LSD=List significance difference, SEM= Standard errors of means

Bulb Damage

Figure 3 and Table 1 showed that at 45 rpm rotational speed of grading unit cylinders and 15 kg/min feed rate of onion bulbs, the lowest percentage of bulb damage (0.34%) was observed. At 35 kg/min and 65 rpm rotational speed of the grading machine, the highest percent of bulb damage (2.25%) was found. Table 1 showed that as the feeding rates increased from 15 to 35 kg/h and the rotating speed of the rotating cylinders increased from 45 to 65 rpm under study conditions, the bulb damage percentage of onion bulbs increased. The result indicated that increasing the grading unit rotating speed from 45 to 65 rpm caused a gradual increase in the total bulb damage from 0.34 to 1.33; from 1.20 to 1.88 and from 2.04 to 2.25% at feeding rates of 15, 25, and 35 kg/min, respectively.

The analysis of variance (ANOVA) revealed that the interaction of cylinder speed and feeding rate had a significant effect ($p < 0.05$) on bulb damage. The overall bulb damage percentages increased gradually from 0.34

to 2.25% when the feeding rate was increased to 35 kg/min at grading cylinder rotation speed varies between 45 and 65 rpm. A rise in cylinder speed and feed rate results in an increase in onion bulb rolling action, which results in an increased impact on onion bulbs. Furthermore, bulbs may not be able to resist the force. As a result, the injuries and abrasions happened when bulbs collided during the grading process. All of the results observed were found

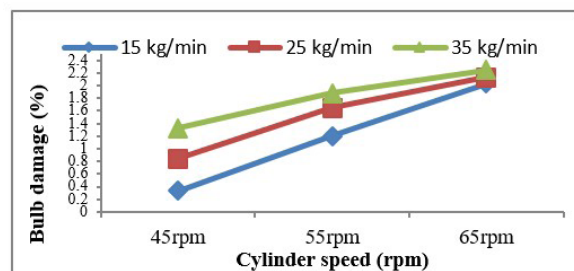


Figure 3: Combined effect of cylinder speed and onion bulbs feed rate on bulb damage

in the range of allowable mechanical damage of onion bulbs during the grading process (4.66%) as reported by Abd and Magda (2011).

Fuel and Energy Consumption

The fuel and energy requirements were a measure for all parameters affecting the grading operation. Results obtained in Figure 4 and Table 1 indicated that the fuel consumption and consumed energy data of the onion grading machine for the interaction of the different combinations of feed rates and cylinder speeds varied between 1.18 to 1.86 ml/kg and 3.73 to 5.77(W.hr/kg)

respectively. By maintaining the speed constant if the bulb feed rate increased the fuel and energy consumed also increased. The same trend was reported by Dereje, (2019).

The required fuel and energy were the least when the lowest cylinder speed of 45 rpm and lowest feed rate of 15 kg/min combined and increased with the combination of an increase in cylinder speed and feed rate. However, the analysis of variance in fuel consumption and consumed energy revealed that the combination of cylinder speed and feed rate had no significant ($P > 0.05$) effects on fuel consumption and energy consumed.

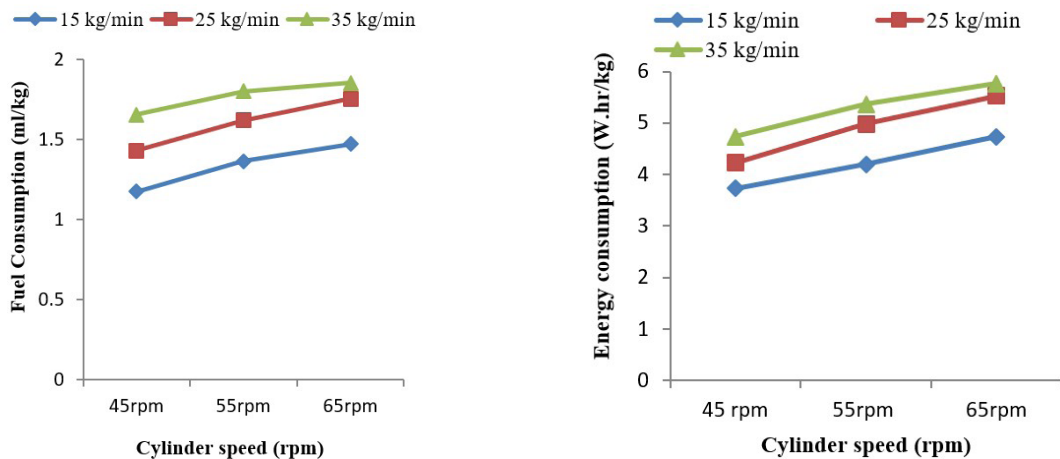


Figure 4: Combined effect of cylinder speed and feed rate on fuel and energy consumption

Main Effect of Rotating Cylinder Speeds and Feed Rates on the Performance of the Onion Grading Machine

Effect of Cylinder Speed and Onion Feed Rate on Grading Capacity

Concerning the effect of rotating cylinder speed and feed rate on the grading capacity, the mean grading capacity and analysis of variance are presented in Table 2, Figure 5. The statistical analysis, ANOVA revealed that the speed of the cylinder and feed rate had a significant difference ($P < 0.05$) in the grading capacity of the machine.

Results obtained showed that the capacity of the grader using a speed of 55 and 65 rpm is significantly higher than

using a speed of 45 rpm. Increasing cylinder speed from 35 to 65 rpm under a constant feed rate increases machine grading capacity from 1447.99 to 2118.03 kg/hr. High speed (65 rpm) encourages more rapidity to the onion bulbs causing them to travel along the grading unit at a faster rate. Conversely, the lowest speed (45 rpm) relatively resulted to slow material flow through the grading unit resulting in a long time of grading that caused lower capacity. Table 2 and Figure 5 show that increasing the feed rate increased the grading capacity of the grading machine under all experimental conditions. Increasing the feed rate from 15 to 35 kg/min under constant drum speed results increasing of grading capacity from 1531.35 to 2061.33 kg/hr.

Table 2: Main effect of rotating cylinder speed and feed rate on the performance of an onion grading machine

Cylinder speed (rpm)	GC (kg/hr)	GSE (%)	BD (%)	FC (ml/kg)	CE (W.hr/kg)
45	1447.99±175.11 ^c	93.22±1.55 ^a	0.84±0.43 ^c	1.42±0.21 ^c	4.22±0.46 ^c
55	1746.57±299.08 ^b	93.92±1.95 ^a	1.58±0.32 ^b	1.60±0.20 ^b	4.92±0.58 ^b
65	2118.03±250.53 ^a	88.48±1.80 ^b	2.14±0.13 ^a	1.70±0.17 ^a	5.29±0.48 ^a
Feed rate (kg/min)					
15	1531.35±282.02 ^c	92.85±2.57 ^a	1.19±0.74 ^c	1.34±0.14 ^c	4.23±0.46 ^b
25	1719.90±258.53 ^b	91.71±3.32 ^b	1.54±0.57 ^b	1.60±0.14 ^b	4.85±0.54 ^a
35	2061.33±357.29 ^a	91.06±3.11 ^b	1.82±0.40 ^a	1.77±0.10 ^a	5.34±0.49 ^a
CV (%)	2.94	1.17	6.57	2.85	3.62
LSD (5%)	51.49	1.06	0.10	0.04	0.17

SEM	30.00	0.62	0.06	0.01	0.06
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Where, GC = Grading capacity, GSE = Grading system efficiency, BD= Bulb damage, FC= fuel consumption, CE = consumed Energy, CV = coefficient of variation, LSD = least significance difference, SEM = standard error of the mean, values are mean \pm SD and Mean values followed by the same letter in a column are not significantly different at 5% level of significance

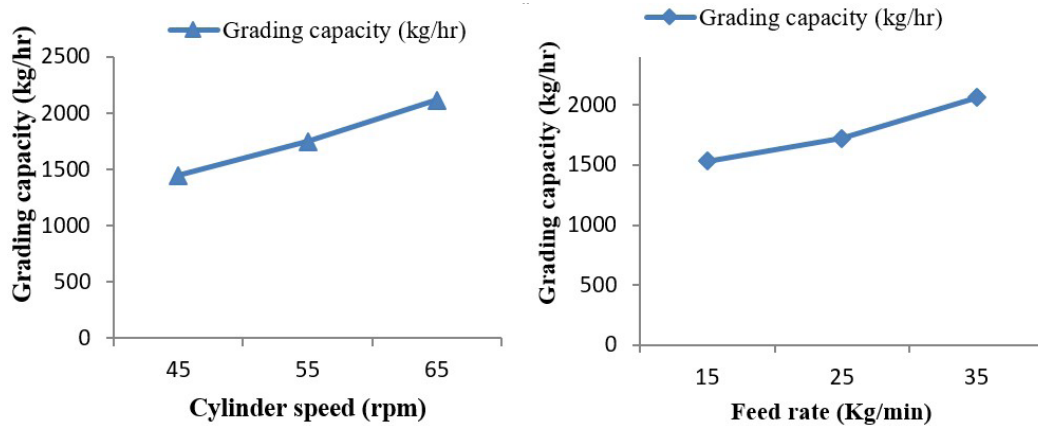


Figure 5: The main effect of cylinder speed and onion bulb feed rate on grading capacity

Effect of Cylinder Speed and Feed Rate on Grading System Efficiency

Referring to the effect of cylinder speed on the machine grading system efficiency results in Table 2 above and Figure 6 revealed that the grading machine had the highest grading system efficiency of 93.92% when the machine operated at a cylinder speed of 55 rpm. The very fast speed of the grading unit was observed to cause the onion bulbs a fast movement through the grading unit. This movement caused some bulbs to move from one region to another to the extent that small-sized bulbs even move to the region of the opening for medium and large-sized sorting. This escaping movement of onion bulbs during extreme rotation significantly affected the grading system efficiency of the machine. On the other hand, the slower speed of the grading unit was observed to cause the bulbs to move slowly through the grading unit hence the bulbs got enough time for grading accurately. For this reason, grading system efficiency was high with a lower

rotating speed than the higher speed of the grading unit. Analysis of variance on the influence of cylinder speed on grading system efficiency showed a significant effect ($p < 0.05$) on the system grading efficiency. From Table 2 and Figure 6, it was observed that the grading system efficiency decreased to some extent when the amount of feed rate increased. The decrease in the percentage of grading system efficiency by increasing the onion bulb feed rate is attributed to the excessive onion bulbs in the grading unit. Consequently, onion bulbs leave the device without appropriate grading tends to decrease the amount of properly graded bulbs and decrease machine efficiency. Also, it may be due to the movement of onion bulbs in mass with an increase of mixing between different categories of onion bulbs which in turn decreases the efficiency of the system by some level. However, Analysis of variance revealed that feeding rates had no significant effect ($p > 0.05$) on the percentage of grading efficiency.

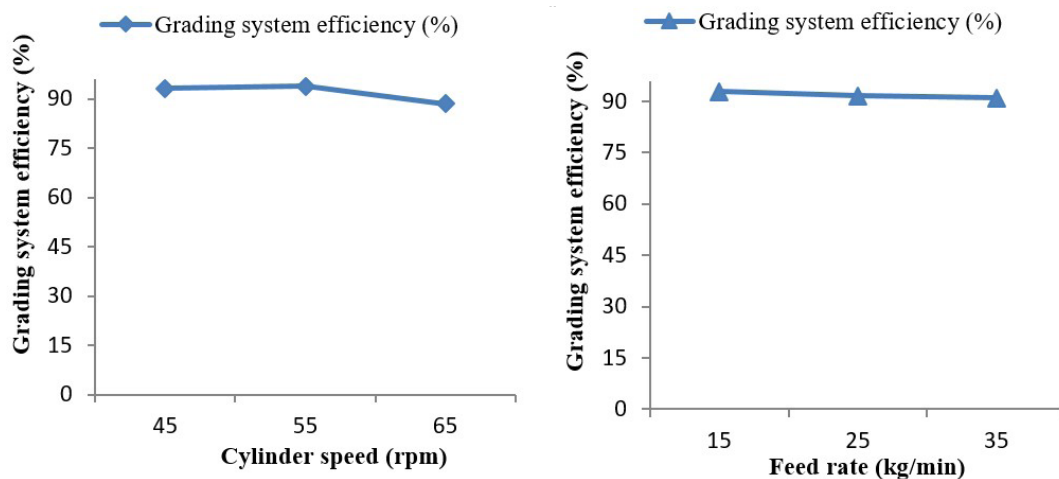


Figure 6: Main effect of cylinder speed and feed rate on grading system efficiency

Effect of Cylinder Speed and Onion Feed Rate on Bulb Damage

Data showing the effects of the onion bulb feed rate and cylinder speed of the onion grader are presented in Table 2 and Figure 7. It was observed that the damage percentage of onions increased when the rotational speed of the grading unit increased. Minimum damaged bulbs were found to be 0.84% at a speed of 45 rpm while the highest was 2.14% at 65 rpm. This increase may have happened due to the increase in the rolling action of onion bulbs, which is always associated with the increase in the physical contact between onion bulbs and results

in abrasion of the bulb cover. Abrasion and scratching of onion bulbs resulted not only due to the high speed of the grading unit but also due to the large quantity of onion added.

This means that the feed rate increased from 15 to 35 kg/min, the percentage of damage also increased from 1.19 to 1.82% and this abrasion or injury is due to the increment of collision formed between onion bulbs. The analysis of variance, on the percentage of damaged bulbs, showed that rotating grading unit speed and feeding rate had a significant effect ($P < 0.05$) on the percentage of onion bulb damage.

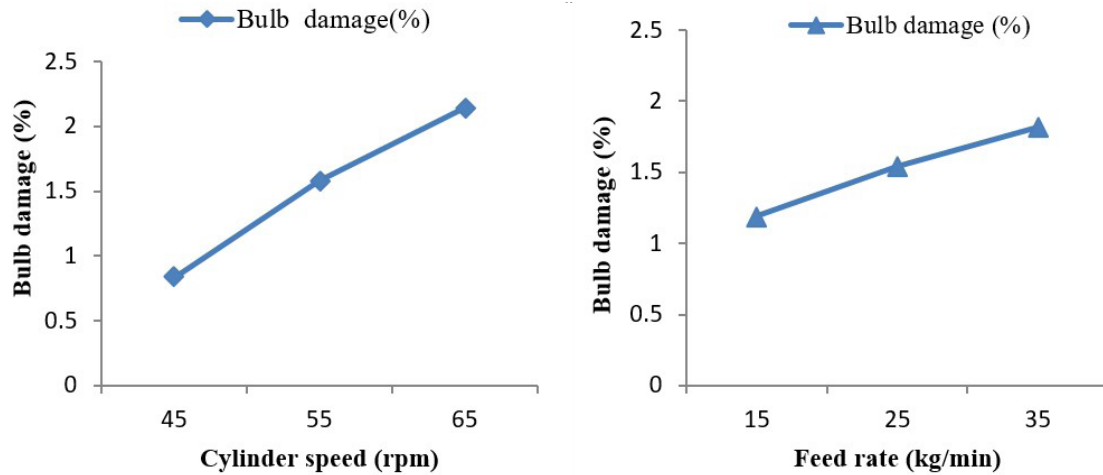


Figure 7: Main effect of cylinder speed and feed rate on bulb damage

Effect of Cylinder Speed and Feed Rate on Fuel and Energy Consumption

The effect of grading unit or cylinder speed on the fuel and energy consumption was shown in Table 2 and Figures 8 and 9. The results show that increasing cylinder speed increased the fuel and energy requirements under all experimental conditions. Increasing cylinder speed from 45 to 65 rpm under constant onion bulb feed rate increased the fuel and energy consumed from 1.42 to 1.70 ml/kg and 4.22 to 5.29 W.hr/kg, respectively under the same previous conditions. The increase in the fuel and

energy requirements by increasing cylinder speed is attributed to the high separating forces applied during grading operation, which tend to consume more fuel and increase energy requirements.

Results obtained in Table 2 and Figure 9 show that increasing the material feed rate increased the amount of fuel and energy requirements under all experimental conditions. Increasing the material feed rate from 15 to 35 kg/min under constant rotating cylinder speed increased the fuel and energy requirements from 1.34 to 1.77 ml/kg and from 4.23 to 5.34 W.hr/kg respectively. The

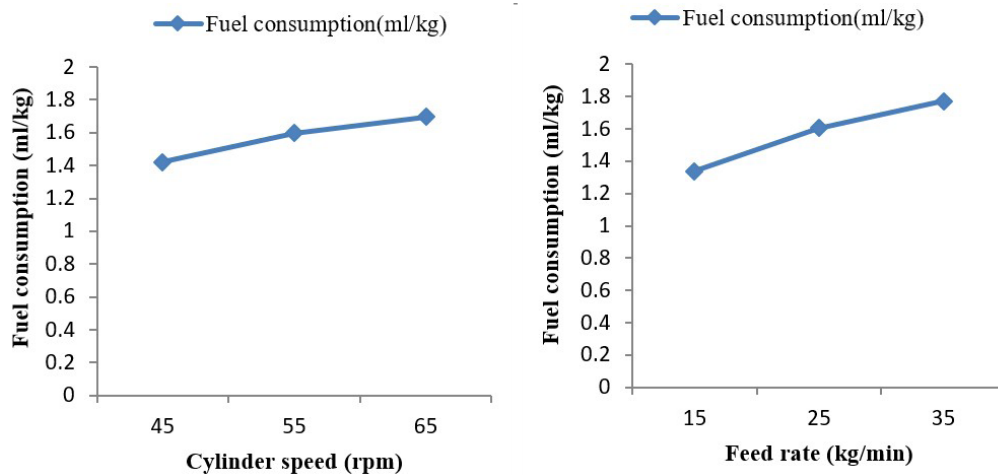


Figure 8: Main effect of cylinder speed and feed rate on fuel consumption

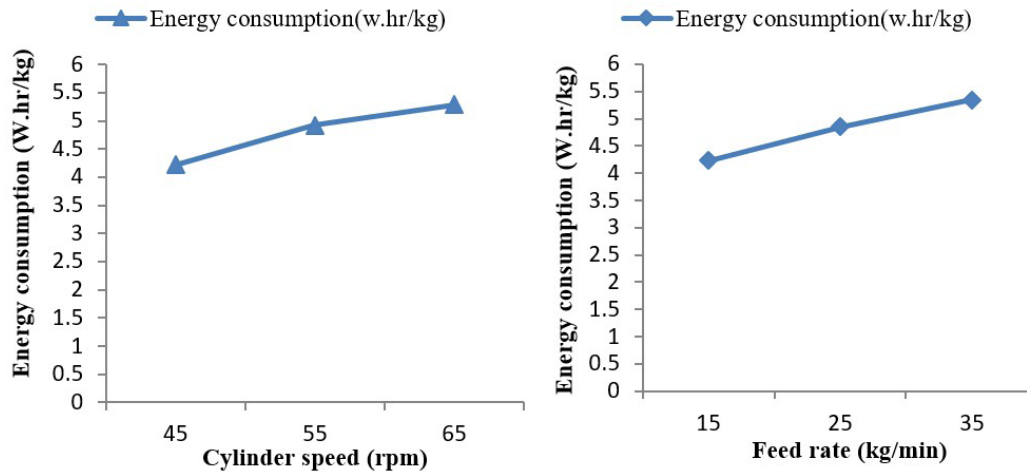


Figure 9: Main effect of cylinder speed and feed rate on energy consumption

increase in the amount of fuel and energy requirements by increasing feed rate is attributed to the excessive onion bulb materials in the grading unit, which increases the load on the grading cylinder caused more fuel consumed. The analysis of the variance of the amount of fuel and energy showed that cylinder speed and feeding rate had a significant effect ($P < 0.05$) on the fuel and energy requirement.

Grading Cost Evaluation

The cost analysis of grading using the developed and evaluated grading machine was determined by considering the fixed and variable costs. The details are presented above. The cost of grading onion by using the developed machine was determined to be 11.06 ETB/ per quintals of onion bulbs and the cost-benefit ratio was calculated to be 1.00: 9.09. The cost of the developed onion bulb grading machine prototype is quite low. It is easy to construct with locally available material at low cost and the operation is simple demanding practically little skill. Hence, the grading machine can be recommended for grading onion bulbs in the case of small and medium-scale farmers.

Conclusion and Recommendation

Based on the machine's operational parameters, the performance parameters namely, grading capacity, grading system efficiency, percentage of bulb damage, fuel, and energy consumption were determined and the results were analyzed statistically. The effect of operational parameters on machine performance parameters shows that the maximum grading capacity of 2429.93 kg/hr was obtained when the grading cylinder speed was 65 rpm and the feed rate was 35 kg/min. The maximum grading system efficiency of 96.04% was obtained when the grading unit was operated at speed of 55 rpm and a feed rate of 15 kg/min. It was observed that the lowest percentage of bulb damage (0.34%) was obtained at 45 rpm rotational speed of the grading unit and 15 kg/min feed rate of onion bulbs while the highest percent of

bulb damage (2.25 %) was observed at 35 kg/min and 65 rpm rotational speed of the grading unit. The maximum fuel and energy requirement was found to be 1.86 ml/kg and 5.77 W.hr/kg respectively when the machine was operated at a maximum grading unit speed of 65 rpm and feeding rate of 35 kg/min. When the onion grading machine operates at its maximum grading efficiency, the grading capacity, bulb damage, fuel, and energy consumption were obtained as 1488.43 kg/hr, 1.20%, 1.37 ml/kg, and 4.23 W.hr/kg respectively. Generally, the obtained results can be summarized as follows:

- ☑ Grading unit cylinder speed and feed rate affected the performance of the machine.
 - ☑ Machine grading capacity, percentage of bulb damage, fuel, and energy requirement increased with increasing cylinder speed and onion bulb feed rate.
 - ☑ Grading system efficiency decreased with increasing cylinder speed but was not affected by feed rate when the rotating cylinder speed is constant.
 - ☑ The evaluated grading machine was found to be promising and efficient in the onion grading process.
- In future study, it is recommended to investigate the grading machine to grade other crops such as potatoes, tomatoes, and apples based on their physical and mechanical properties.

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