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RESEARCH ARTICLE

Development and Evaluation of an Onion Bulb Size Grading Machine: A Promising Solution to Enhance Efficiency and Reduce Costs for Local Onion Farmers

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ABSTRACT

Grading is vital in food processing, ensuring adherence to commercial standards and facilitating marketing. Unfortunately, the Philippine Onion industry lacks a suitable onion grader for field-level operations. Consequently, farmers still resort to manual grading, leading to labor scarcity during peak seasons, increased time and financial costs, and physical strain on the workers. Thus, the study aimed to develop a suitable onion (Allium cepa L.) bulb-size grading machine for farm-level operations. The device comprised six significant parts: input chute, cylindrical grader, discharge unit for onion bulbs, frame assembly, cover of the grading machine, and power transmission assembly. To evaluate the grader's performance, tests assessed grading efficiency, grading capacity, and energy demand at different shaft speeds (10 rpm, 20 rpm, 30 rpm). The experimental layout followed a Completely Randomized Design (CRD) and was analyzed using the Analysis of Variance test. The mean comparison was carried out using the Least Significant Difference (LSD) method, with a significance level set at 5%. The results revealed that the most effective shaft speed was 10rpm, yielding an impressive 95.45% grading efficiency and a notable grading capacity of 583.23 kg/hr. The cost analysis indicated that the grader could generate an additional income of at least 82,301.52 Php/year for onion farmers, with a payback period of 0.32 years and a remarkable rate of return of 204.85%. These findings highlight the grader's cost efficiency, making it a valuable device for onion farmers.

KEYWORDS:
Cost efficiency, Grading, Onion industry, Size Grading Machine, Grader Performance

1 | INTRODUCTION

Onion (Allium cepa L., from Latin cepa meaning "onion") is a highly popular and widely cultivated vegetable crop globally. Its distinctive flavor makes the onion bulb the third most crucial horticultural spice, commanding significant commercial value [1]. It is a staple ingredient in Philippine cuisine, consuming around 17,000 metric tons of onions per month [2]. In 2022, the total onion harvest in the country reached 283,172 metric tons, and the retail prices of onions surged to Php720 per kilo due to a shortage in supply [3]. The Department of Agriculture reported that in 2022 alone, thirty-five percent of onion production, amounting to 100,000 metric tons, was lost after harvest due to the lack of facilities [4]. In the Philippines, Central Luzon is the leading onion producer, contributing 63.7% of the total production volume, followed by the Ilocos Region with 17.7%, and the MIMAROPA (Mindoro Oriental Occidental, Marinduque, Romblon, and Palawan region) with 14.7% contribution to the national produce. Mindoro Island, part of MIMAROPA, emerges as the primary onion producer in the area, exporting to neighboring provinces and regions like Iloilo, Negros Occidental, and the National Capital Region.

Onion farming significantly contributes to the livelihoods of many families on the island. Filipinos have a monthly per capita onion consumption of 17,000 metric tons. With a total production volume of 283,172 metric tons, it should theoretically meet the national demand and generate a surplus. However, annual losses amounting to 100,000 metric tons, resulting from inadequate postharvest facilities and machinery, lead to a scarcity in supply, driving up the price per kilogram of onions and necessitating imports from other countries. Based on benchmarking, the Onion industry lacks a suitable onion grader that farmers can utilize. Grading is crucial in food processing, ensuring conformity to commercial standards and facilitating marketing. The Philippine National Standards specify three marketable sizes for red onions: small (1.5 - 3.0 cm), medium (3.1 – 5.0 cm), and large (>5.1 cm) [5]. Currently, onion farmers manually grade their products using a slanted table made from bamboo slats and wood planks.

This time-consuming and laborious process often leads to inefficient grading, mainly when unskilled workers rely on subjective judgment. Skilled workers can manually grade up to 78 kg/hr, but labor scarcity during peak seasons results in expensive costs. Farmers must hire additional workers during harvesting seasons to keep up with market demand and fetch higher prices. While onion graders are available online, they are designed for large-scale operations, making them unaffordable and impractical for small-scale farmers. Moreover, smaller grader machines imported from abroad are costly to repair and maintain due to the lack of spare parts. The situation calls for a suitable, affordable, and farm-friendly onion grader that can meet the needs of farmers efficiently. Hence, the main objective of this study was to develop an onion (Allium cepa L.) bulb-size grading machine. Specifically, the study aimed to design the machine using locally available materials and fabricate it using local manufacturing technology. The machine's performance was evaluated based on its grading capacity and efficiency. Additionally, the energy consumption of the onion bulb size grading machine was calculated, and a simple cost analysis of using the device was conducted.

2 | METHODS

2.1 | Conceptualization of the study

To understand the existing challenges in onion farming, interviews were conducted with onion farmers. The interviews revealed that onions are manually graded using an improvised table, typically requiring four to six people for operation. Achieving size uniformity manually is challenging, affecting the product's attractiveness and processing quality. Therefore, the study prioritized the development of an onion-size grading machine to address these issues and improve the efficiency of onion grading. Figure 1 shows the study's conceptual framework, following the input-process-outcome method. It was primarily based on the study's general objective: to develop an Onion Bulb size grading machine.

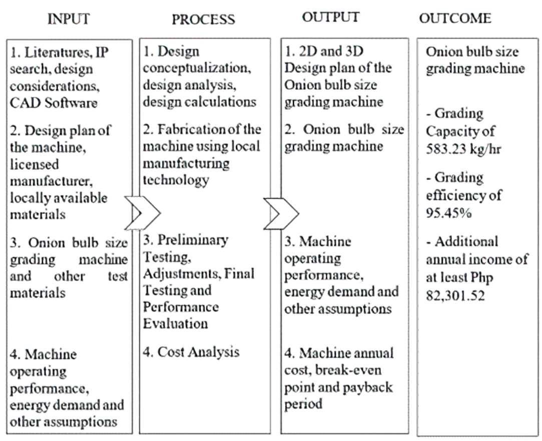


FIGURE 1 Conceptual Framework of the study

2.2 | Design Concept of the Machine

The onion bulb-size grading machine [6] was conceptualized based on interviews with local onion farmers in Mindoro Island and was designed using Computer-Aided Design (CAD). Figure 2 illustrates the conceptualized design, highlighting its major components, such as the input chute, cylindrical grader, discharge unit for onion bulbs, frame assembly, cover of the grading machine, and power transmission assembly. The machine's fabrication utilized locally available materials and local manufacturing technology—the design prioritized ease of operation, operator safety, and comfort to ensure a user-friendly experience.

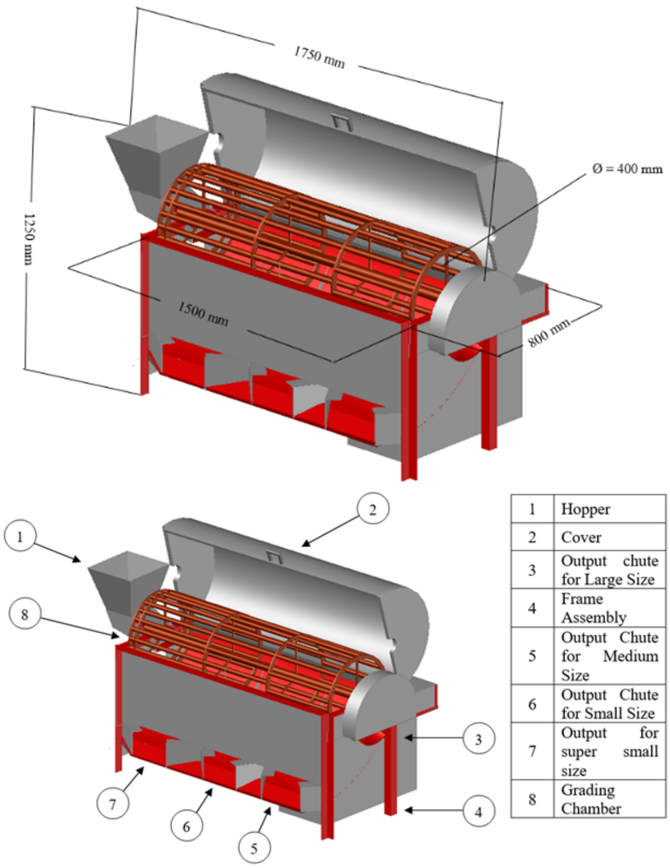


FIGURE 2 Perspective view of the onion bulb-size grading machine

2.3 | Design of Major Components

2.3.1 | Hopper

The hopper/input chute in Figure 3 is where the onion bulbs were fed into the machine. It had a trapezoidal shape with gradually sloping sides, enabling the onion bulbs to slide down easily. The inclination angle of the input chute was set at 6 degrees. A galvanized iron sheet with a gauge of 16 was used to construct the input chute.

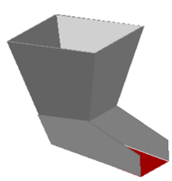


FIGURE 3 Perspective view of Input chute

The dimension of the input chute was calculated with the use of the following formulas:

$$SubscriptSA_t = \frac{1}{2}(a+b)\ x\ h \qquad (1)$$

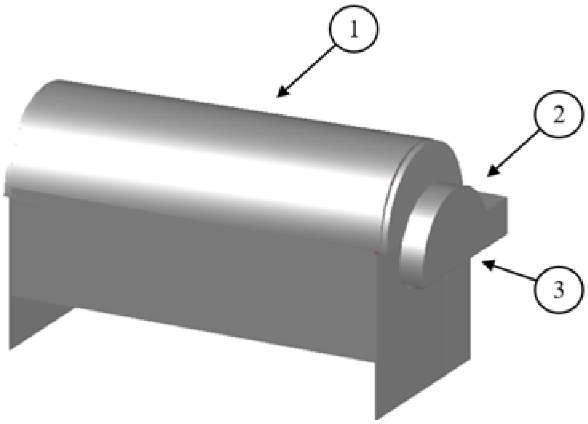
where the SA_t is the surface area of the trapezium (cm^2); a = base width (cm); b = length of the hopper (cm); h = height of hopper (cm), and

$$V = SA_t\ x\ t \qquad (2)$$

where V = volume of the trapezium (cm^3); SA_t = surface are of the trapezium (cm^2); t = thickness of the trapezium (cm).

2.3.2 | Cover of the machine

Figure 4 displays the cover of the onion bulb-size grading machine. It was designed to provide safety to the operator and prevent the scattering of onion bulbs during the grading process. Additionally, moving parts like belts, pulleys, and prime mover were also covered for added protection. The covers were not fixed to the machine, allowing for easy adjustments and modifications to the internal components. A galvanized iron sheet with a gauge of 16 was utilized to construct the covers.



1	Cover of the cylindrical grader
2	Cover of the Prime mover and transmission assembly
3	Cover for the belt and pulleys

FIGURE 4 Perspective view of the machine cover

2.3.3 | Power Transmission Assembly

The onion bulb-size grading machine was powered by a single-phase electric motor with specifications of 1 hp, 220 volts, and a speed of 1720 rpm. A series of V-shaped belts and pulleys were employed to transfer power from the prime mover to the cylindrical grader. Figure 5 illustrates the design of the power transmission assembly.

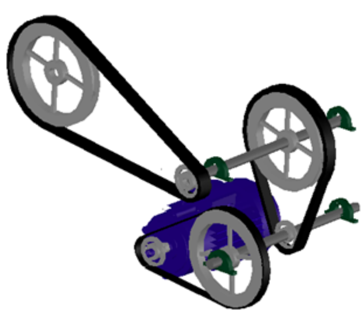


FIGURE 5 Power transmission assembly

The design of the power transmission was calculated with the use of the following formulas [7],[8],[9]:

$$CapN_1D_1 = N_2D_2 \qquad (3)$$

where N_1 is the diameter of the driver ($motor$); $N_2 = diameter$ of the driven shaft ($machine$); D_1 is the speed of the driver ($motor$) (rpm); $D_2 = speed$ of the driven shaft ($machine$) (rpm).

$$L = 2C + /2(D_L + D_S) + \frac{(D_L + D_s)^2}{4C} \qquad (4)$$

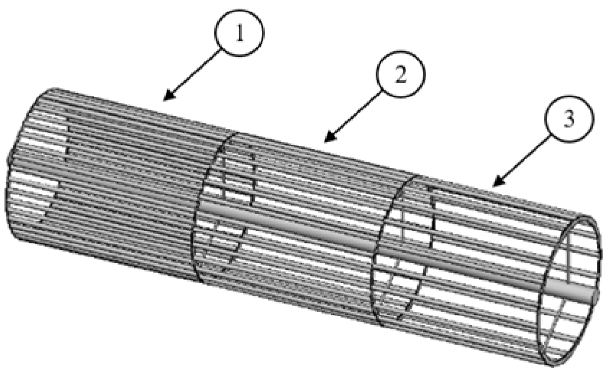
where L is the length of the belt (mm); $C = distance$ between centers of pulleys (mm); $D_L = pitch$ of the large pulley (mm); $D_S = pitchdiameter$ of the small pulley (mm).

$$C = \frac{b \pm \sqrt{(b^2 - 32(D_L - D_S)^2}}{16} \qquad (5)$$

where C is the center distance; $D_L = pitchdiameter$ of the large pulley (mm); $D_S = pitchdiameter$ of the small pulley (mm); $b = 4L_s - 6.28(D_L - D_S)$; $L_S = standardbeltlength.$

2.3.4 | Cylindrical Grader of the machine

The cylindrical grader consisted of three grading sections, each measuring 500 mm in length. Each team had three distinct spaces to accommodate the desired output sizes. The first section, intended for super small products, featured slatted openings of 15mm. The second section, for small-sized output, had 30 mm slatted spaces, while the third section, producing medium-sized work, utilized 50 mm slatted openings made of round bars with an 8mm diameter. The entire cylindrical grader was inclined at an angle of 3 degrees.



1	Super Small grading section
2	Small grading section
3	Medium grading section

FIGURE 6 Perspective view of cylindrical grader

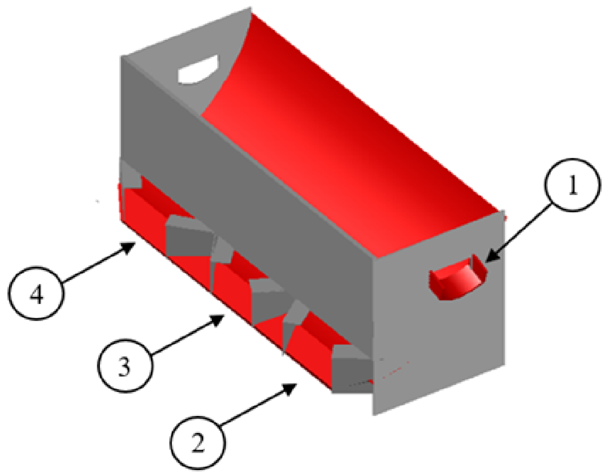
The volume of the cylindrical grader was calculated using the equation 6.

$$V = \Pi r^2 \ x \ L \qquad (6)$$

Where V is the volume of the cylindrical grader (cm^3); r = radius of the cylindrical grader (cm);
L = length of the cylindrical grader (cm).

2.3.5 | Discharge unit

The discharge unit depicted in Figure 7 consisted of four individual parts, each tailored for the discharge of specific sizes of onion bulbs. The first discharge unit catered to super small size onion bulbs, the second unit for small size bulbs, the third unit for medium size bulbs, and the fourth unit for large size bulbs. All discharge units were constructed using galvanized iron sheet of gauge 16.



1	Output chute for large size Onion
2	Output chute for medium size Onion
3	Output chute for small size Onion
4	Output chute for super small size Onion

FIGURE 7 Perspective view of output chute

2.3.6 | Frame assembly

The frame assembly of the onion bulb size grading machine, as illustrated in Figure 8, was constructed using mild steel angle bars and mild steel flat bars with a width of 50 mm and a thickness of 4mm. The soft steel angle bars were skillfully welded together, with flat bars as supplementary support for the machine.

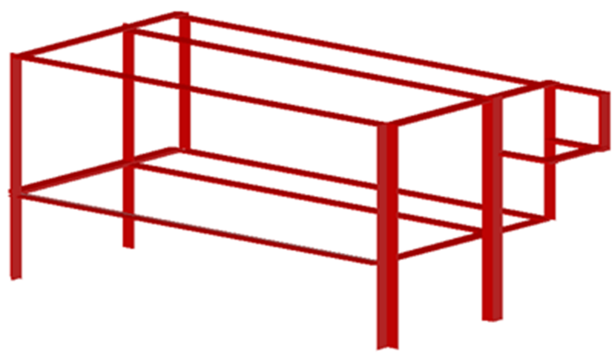


FIGURE 8 Perspective view of the frame assembly

For the calculation of allowable stress, use equation 7.

$$\sigma_{Allow} = \frac{YS}{FOS} \qquad (7)$$

Where σ_{Allow} is the Allowable Stress, MPa; YS = Yield Strength or Ultimate strength, MPa; FOS = Factor of Safety. Following the calculation of the allowable stress, the section modulus is determined using the formula:

$$Z = \frac{M_{max}}{\sigma_{Allow}} \qquad (8)$$

Where Z is the Section modulus of angle bar, mm^3; M_{max} = Maximum bending moment, $N.mm$; σ_{Allow} = ultimate strength of the material, MPa.
To solve for both the outer side and inner side of the angle bar, the following formula was employed:

$$Y = \frac{1}{Z} \qquad (9)$$

where Y is the distance from Neutral Axis, *mm*; I = Moment of Inertia, $N.mm$; Z = Section modulus of angle bar.
The thickness of the angle bar was calculated using equation 10.

$$t = \frac{a - a_1}{2} \qquad (10)$$

where t is the thickness of angle bar, *mm*; a = Outer side of angle bar, *mm*; a_1 = Inner side of angle bar, *mm*.

2.4 | Performance Parameters

The following formulas were utilized for the purpose of this study [10]:
For the input capacity of the device, the formula used,

$$C_i = \frac{W_i}{T} \qquad (11)$$

where C_i is the Input Capacity, Kg/hr; W_i = Weight of Input Materials, Kg; T = Operating Time, hr.
The Efficiency of the machine was computed using the formula:

$$E_s = \frac{W_s}{W_i}\, x\ 100 \qquad (12)$$

where E_s is the grading Efficiency, Kg; W_s = Weight of Shredded Materials, Kg; W_i = Weight of Input Material, Kg.
For the electrical energy demand of the device, the working formula used:

$$E_d = \frac{Pi\ x\ T}{W_i} \qquad (13)$$

where E_d is the Energy Demand, $kW - hr/kg$; P_i = Power Input, Kw; T = operating Time, *hr*; W_i = Weight of Input Material, Kg.

3 | RESULTS AND DISCUSSION

3.1 | Description of the machine

The onion bulb-size grading machine starts by connecting a switch to a 1-hp electric motor to power up the device. Ungraded onions are continuously fed into the input chute (hopper). Once inside the device, the onions are immediately subjected to the rotating cylindrical grader, divided into three sections for different size grades. Onions smaller than 15 mm are classified as super small, those between 15 mm and 30 mm as small, 31 mm to 50 mm as medium, and onions larger than 50 mm as large. Each size grade falls into its designated discharge unit, guiding the onions to their container bins below.

FIGURE 9 Perspective view of the fabricated onion bulb size grading machine

1 = super small (<15 mm Ø); 2 = small (15mm to 30 mm Ø); 3 = medium (31mm to 50mm Ø); 4 = large (>50mm Ø)

FIGURE 10 Output of graded onion bulb

Figures 9 and 10 display the perspective of the fabricated onion bulb size grading machine and the graded onion bulbs after the operation. Meanwhile, Table 1 provides the detailed specifications of the onion bulb size grading machine. The machine effectively sorts and separates onions into distinct size categories, streamlining the grading process and ensuring uniformity in product sizes.

TABLE 1 Specification of the onion bulb size grading machine.

Item	**Specification**
Main Structure	
Overall dimensions, mm	
Length	1750
Width	800
Height	1250
Hopper	
Power Transmission Assembly	

V-Pulley	50.8 mm Ø
V-Pulley	304.8 mm Ø
V-Pulley	254 mm Ø
V-Pulley	101.6 mm Ø
V-Pulley	177.8 mm Ø
Prime Mover	
Electric motor	1-hp, 220 volts,1720 rpm, single phase
Cylindrical Grader	
Slatted rods	8 mm diameter
Shaft	25.4 mm diameter
Discharge unit	1.6 mm thickness
Machine cover	1.6 mm thickness
Frame assembly	50.8 x 50.8 x 4.7 mm thickness
Machine Performance	
Grading Efficiency	95.45%
Grading Capacity	583.23 kg/hr
Number of Operators	1 Person

3.2 | Fabrication of the machine

A design was initially conceptualized and drawn using Computer-Aided Design (CAD). However, certain materials were found to be unavailable during the fabrication process, leading to necessary modifications and adjustments in the fabrication shop. These modifications were essential to achieve the desired grading efficiency of 94% and grading capacity of 250 kg/h, as initially planned during the machine's design phase. Locally available materials and local manufacturing technology were utilized to complete the onion bulb-size grading machine fabrication.

3.3 | Machine Performance Evaluation

The machine underwent evaluation based on its capacity, efficiency, and energy demand, which were influenced by varying shaft speeds (10 rpm, 20 rpm, and 30 rpm). The results were then analyzed using the Statistical Tool for Agricultural Research (STAR).

3.3.1 | Grading capacity

Table 2 displays the grading capacity results, indicating that the highest capacity of 1,272.74 kg/hr was achieved at the fastest shaft speed of 30 rpm. The mean value at 20 rpm was 998.44 kg/hr, while the slowest shaft speed recorded the lowest capacity of 583.23 $kg/_{hr}$.

The analysis of variance demonstrated that shaft speed significantly impacted the grading capacity at a 5% level of significance. Moreover, the mean grading capacities at various shaft speeds differed significantly, as evident from the comparison among treatment means in Table 2. However, no significant differences were observed between the 20 and 30 rpm conditions.

The findings revealed that higher grading capacity was associated with higher shaft speeds. Faster rpm resulted in an increased feeding rate, leading to higher grading capacity with the 3-degree grading slope. The decision to use a 3-degree grading slope was based on pre-evaluation during pre-testing. While a higher degree of grading slope led to higher capacity, it also caused issues, such as ungraded materials where smaller-sized onion bulbs were collected in the medium and large grading containers.

TABLE 2 Mean grading capacity at various main shaft speeds, kg/hr

Treatment RPM	Means
10	583.23 b
20	998.44 a
30	1,272.74 a

*Means with the same letter are not significantly different.

3.3.2 | Grading Efficiency

Table 3 presents the grading efficiency results, showing decreased efficiency with increased shaft speed. At 10 rpm, the grading efficiency was 95.45%, which decreased to 91.11% and 87.01% at 20 rpm and 30 rpm, respectively.

The analysis of variance confirmed that shaft speed significantly affected the grading efficiency. A comparison among means in Table 3 revealed that the grading efficiency at the lowest shaft speed of 10 rpm was significantly higher than the two higher speeds, and the efficiency at 20 rpm was also significantly higher than at 30 rpm.

Despite the higher grading output capacity at higher rpm, it was observed that this led to a higher amount of breakage or damage to onion bulbs. The grading chamber caused breakage or damage as the fast revolution of the chamber and its impact on the frame led to onions being stuck in the slatted round bars. This damage made the onions unsuitable for the market, resulting in losses. Additionally, the higher capacity and rpm did not allow enough time for the grading chamber sections to efficiently grade onions according to their desired sizes. This led to different-sized onion bulbs being collected in the grading containers. In contrast, at 10 rpm, there was no recorded breakage or damage, unlike at 20 rpm and 30 rpm, which significantly affected their efficiency performance.

TABLE 3 Mean grading efficiency at various main shaft speeds, kg/hr

Treatment RPM	Means
10	95.45 a
20	91.11 b
30	87.01 c

*Means with the same letter are not significantly different.

3.3.3 | Energy Demand

Table 4 displays the average energy demand at different main shaft speeds. Interestingly, the lowest revolutions per minute (RPM) corresponded to the highest energy consumption of 0.9167 kW-hr/kg.

TABLE 4 Mean energy demand at various main shaft speeds, kW-hr/kg

Treatment RPM	Means
10	95.45
20	91.11
30	87.01

However, the analysis of variance presented in Table 5 indicated no significant differences among the treatments regarding energy demand.

TABLE 5 Analysis of variance on energy demand as affected by shaft speed

Source	DF	Sum of Square	Mean of Square	F value	Pr (>F)
Treatment	2	0.0030	0.0015	2.46	0.1656
Error	6	0.0036	0.0006		
Total	8	0.0066			

* The null hypothesis (H_O) is accepted since 0.166 > 0.05 (p-value > α), which means there is no difference in the means independently.
* The null hypothesis (H_O) is accepted since 5.143 > 2.463, ($FT > FC$), which means there is no difference in the means independently.

3.4 | Cost Analysis

The grading cost of the machine was determined based on the assumption that all Onion materials are already collected and placed in one location. The total cost of the Red Onion grading machine amounted to Php 29,249.00. Operating the machine incurs an annual expense of Php 40,176.78. The machine must grade 17,499.17 kg/yr of Onion bulbs to reach the breakeven point. The custom rate used is Php 0.5/kg, resulting in an annual net income of Php 82,301.52 for the machine owner. The rate of return is 204.85%, and the payback period is 0.32 years, equivalent to the first harvesting season. Table 6 displays the calculations for the annual fixed breakeven point;

TABLE 6 Cost Analysis of using the machine

Particulars		
Annual Fixed Cost	6,654.15	Php/yr
Depreciation	5,264.82	Php/yr
Interest on Investment	804.35	Php/yr
Tax and Insurance	584.98	Php/yr
Variable Cost	69.84	Php/hr
Operator's Wage	27,000.00	Php/yr
Repair and Maintenance	1,462.45	Php/yr
Power Cost	5,060.18	Php/yr
Breakeven Point	17499.17	Kg/yr
Net Income	82,301.52	Php/yr
Rate of Return	204.85	%
Payback Period	0.32	yr

While Figure 11 illustrates the cost curve associated with using the machine.

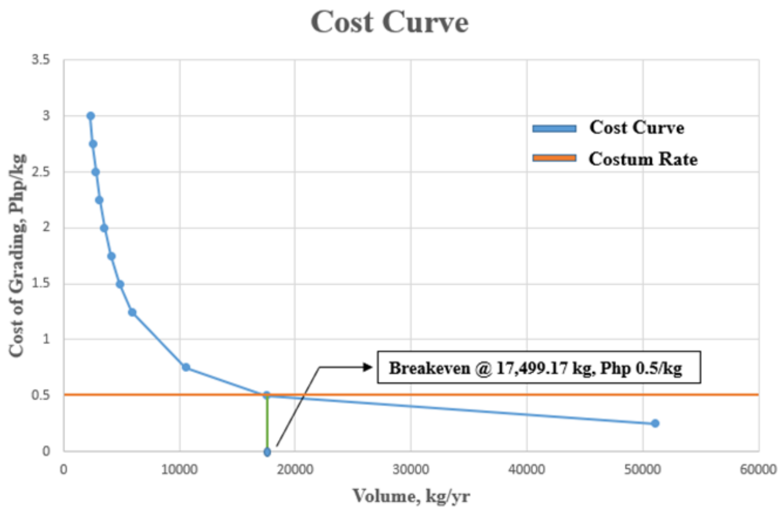


FIGURE 11 The cost curve of using the machine

4 | CONCLUSIONS AND RECOMMENDATIONS

The developed red onion grading machine's concept and mechanism proved highly effective in reducing labor, time, and grading expenses for onion bulbs while generating additional income for farmers and processors. The machine's fabrication can be achieved using locally available materials and manufacturing technologies, making it easily accessible for implementation. The machine performed excellently, meeting or surpassing the specified grading capacity and efficiency parameters. It was observed that as the shaft speed increases, the grading capacity also increases, but a decrease in efficiency accompanies this. To enhance efficiency, it is recommended to increase the length of the grading section, allowing more time for grading and minimizing the collection of different-sized onion bulbs in larger grading containers, which affected the efficiency at 10 rpm by 4.55%. Additionally, incorporating wheels in the machine would aid in its transportation.

Despite higher rpm resulting in increased energy demand, the analysis of variance showed no significant difference among the three treatment results. The machine's power consumption was economical, with an annual power cost of Php 5,060.184, considering 60 days of operation per year and 8 hours per day. The financial analysis affirmed the machine's viability, potentially enabling local onion farmers and processors to reduce labor costs and increase profits by Php 82,301.52 annually. The fabrication cost of the machine was Php 29,249.00, and the projected annual operating cost amounted to Php 40,176.78. The computed breakeven weight was 17,499.17 kg, and the payback period was estimated to be 20 working days or after the first harvesting season.

5 | ACKNOWLEDGEMENT

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