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DEVELOPMENT OF DRY-SCALE CLEANER CUM GRADER FOR STORED ONION BULBS (*ALLIUM CEPA L.*)

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Abstract

Uncleaned and ungraded onions stored in sacks command low prices, a significant share of farmers' income. Manual cleaning and grading of stored onions are labor intensive, tedious, and provide inconsistent results. This study sought to develop a dry-scale cleaner cum grader for stored onion bulbs to simplify operations, reduce labor costs, minimize operation losses, and generate more income for the onion farmers. The design of the machine parts was computed based on the onions' average physical (shape, size, surface area, density, colour, and weight) and mechanical (hardness, compressive strength, impact, and shear resistance) properties. The study used locally available materials to fabricate the machine and conducted a preliminary performance test to ensure functionality and optimum machine speed settings. Based on the results, machine cleaning and grading speed of 71 rpm and 17 rpm can remove dry scales and grade them according to standard sizes at a rate of 493 kg/hr at 73 % efficiency. The machine reduced manual labor utilization from 3 man-day/100kg to 0.08 man-machine-day/100kg. Mechanical damage (2%), including slight bruises in the bulbs, and the noise level (82 dB) were lower than the maximum threshold of 3% and 92 db. The machine costs ₱125,000 with an operating cost of ₱40/100kg and power consumption of 14.41W-hr. It can break even after cleaning and grading 33,263 kg of stored onion bulbs at a custom rate of ₱1/kg per year. The study successfully developed the onion cleaning cum grading machine suggesting group ownership for utilization.

Key words: *cleaning, grading, machine, stored onion bulbs, performance*

INTRODUCTION

Onion (*Allium cepa* L.), locally known as "sibuyas" in the Philippines, is a beneficial and widespread vegetable crop grown primarily for its pungent bulbs and flavorful leaves. It is among the 15 most commonly grown vegetables worldwide [11]. Primarily, its application is to spice up meat, salads, and vegetable dishes and address various health concerns such as poor appetite, atherosclerosis prevention, and the treatment of cough, obesity, insomnia, hemorrhoids, and constipation.

In the Philippines, onion was among the top five vegetables and the most significant contributor to domestic vegetable earnings of Php5.5 B in 2017. There are two major types of onion locally grown, "Red Creole" and "Yellow Granex." It has a total production of 184.43 thousand metric tons, which was higher by 50.4% than its total production in 2016. Its increase is due to the expansion in area by 5,271.07 hectares from 2016 to 2017. Central Luzon leads among the onion-producing areas, followed by Ilocos and MIMAROPA region [18]. Onion farming has been one of the major sources of livelihood and income among Filipino farmers, especially in Luzon. However, due to the lack of local supply, farmers have difficulty competing with imported onions [5]. It resulted in fluctuation in the supply and its prices in the market. In addition, onion is only a one-season crop and must be available year-round [8]. As a conventional practice, farmers and traders stored their harvest to prolong its shelf-life.

Curing is significant if onions are to be stored [4]. It involves some polymerization of substance present in the scales to allow natural dormancy to develop, resulting in the development of the darker color, dry shrunken neck, and dry outer scales of the onion skin [7]. Before farmers sell onions in the market, excess scales due to curing are removed or cleaned to increase their marketability. This process is tedious in which farmers manually clean the onion bulbs individually.

Grading especially based on size and quality, is another tedious job. It is an essential primary processing operation to market fruits and vegetables successfully. However, farmers in Nueva Ecija sell their produce by sacks and are not graded due to the timeliness and inconsistency of the operation [6]. This practice takes away a significant share of their income.

Hence, there is a need to develop an onion cleaner with a size grader that can simplify and hasten the onion postharvest operation. Cleaning and grading onion bulbs mechanically can also help improve the quality, add value, and reduce the operation cost, thus, generating better livelihood opportunities for onion farmers.

MATERIALS AND METHODS

This section involves the machine components' conceptualization, analysis, and calculations. The mechanical and physical properties of onion bulbs from literature, standards, and specifications were used to serve as bases in choosing the materials and their sizes. Computer-Aided Design (CAD) software provided an output for technical drawing and 3D simulation of the designed frame.

Design considerations

The onion dry-scale cleaning cum grading machine was designed based on the following considerations: (a) should be electric motor-driven and made from locally available materials; (b) the hopper should have a maximum loading capacity of 25kg; (c) should be able to clean the onion bulb by removing and separating only the cracked and partially sloughed dry scales from the onion bulb and maintaining a least one layer of intact dry scale; (d) the machine should grade red onion bulbs into small (15 to 30 mm), medium (31 to 50 mm), and large (51 to 80 mm); (e) the machine should obtain a minimum machine capacity and efficiency of 300kg/hr and 70%, respectively; (f) the machine should only exhibit a maximum mechanical damage (e.g., scratched, sliced, or bruised) of 3%; (g) the machine should not produce noise of more than 92db; (h) can be lifted and moved by a maximum of three (3) physically fit laborers; (i) the machine can be operated by a maximum of three (3) laborers (e.g., one person assigned for loading and the others for bagging); and, (j) the break-even weight of the machine should be less than the capacity per year of the storage facility to ensure ownership.

Design of machine's major parts and principle of operation

The conceptualized machine comprised five (5) major components: hopper, cleaning unit, grading unit, frame, and transmission assembly. It has an overall dimension of 1.78m x 0.8m x 1.25m (L x W x H) (Fig. 1).

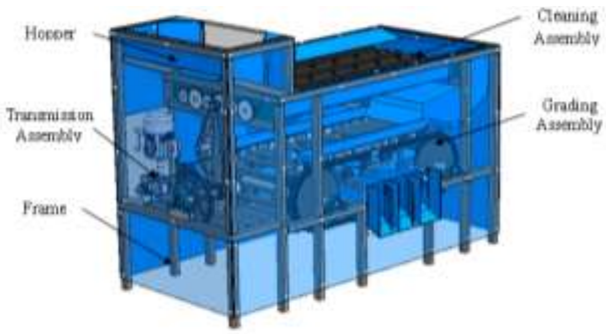

Fig. 1. Conceptualized design of the machine
Source: Own conception.

The onion cleaning cum grading machine was designed to be operated by three persons. The operator would first turn on the electric motor's push button switch to operate the machine. The electric motor's power requirement was calculated based on the weight, diameter and speed for cleaning and grading as in the equation below [12]:

$$P = F \times D/2 \times 2\pi N/60 \qquad (1)$$

where:
P = power, W
F = weight, N
D = diameter, m
N = speed, rpm

The loading of the uncleaned and ungraded onion bulbs take place in the hopper positioned at the upper part of the cleaning unit. It also holds and regulates the feeding to the cleaning assembly (Fig. 2). The cross-sectional shape of the hopper was rectangular. It was made from 1.5mm galvanized iron sheet metal. It was attached to the frame using rivets. The side slope was based on the angle of repose of the unclean onion bulb. The total holding capacity of the hopper was computed using:

$H_C = \gamma_O \times V_H$..(2)

where:
H_C = holding capacity of the hopper, kg
γ_O = bulk density of onion bulb (kg/m^3)
V_H = volume of the hopper, m^3

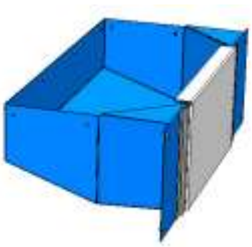

Fig. 2. Conceptualized hopper of the machine
Source: Original.

The cleaning assembly was composed of six (6) rollers. Three (3) were coated with rubber and were screwed with V-belts. They were arranged alternately with the other three (3) plain rollers made from Polyvinyl Chloride (PVC) pipes. Each end was attached to a fabricated housing for bearings with a center-to-center distance of 85 mm. The conveying capacity (kg/hr) was determined using the following formula: [1]

$$C_C = \frac{\pi}{4}(D^2 - d^2) \times p \times (N \times \epsilon_v \times 3600/60) \times \rho_b$$
....(3)

where:
D = screw diameter, m
d = plane rubber diameter, m
p = pitch of the screw, m
ϵ_v = volumetric efficiency, decimal
A belt and pulley were used to transmit the power from the source to the middle right shaft of the cleaning assembly.
To meet the intended peripheral speed of the rotating components, the pulley diameter was calculated using [20].

$n_S D_S = n_L D_L$..(4)

where:
n_S = speed of small pulley, rpm
D_S = diameter of small pulley, inch
n_L = speed of large pulley, rpm
D_L = diameter of large pulley, inch
The length of belt and the speed ratio of the drive were calculated using:

$L = 2c + \pi/2\,(D_2 + D_1) + (D_2 - D_1)^2/4C$......
....(5)

where:
L = length of the belt, inch
C = distance between centre of pulleys, inch
Speed ratio= n_S/n_L
Spur gear transmission was used to incorporate counter rotations of the roller. The desired center distance given the module and speed ratio was computed using:

$C = M\,(t_1 + t_2)/2$..(6)

where:

C = centre distance, mm
M = module
t_1 = teeth of the driver gear
t_2 = teeth of the driven gear
The bulbs were cleaned by the counter-revolution of the plain and screwed rollers, and the slough-off dry scales were separated and fell straight to the scale outlet. The cleaning operation also permits manual inspection and selection of rotten onions. On the other hand, the cleaned bulb traveled straight to roller length with the help of the screwed rollers (Fig. 3).
The bulbs were pushed to the end and entered the grading assembly.

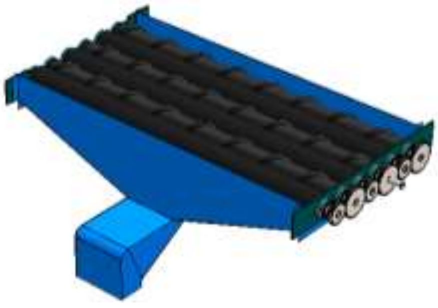

Fig. 3. Cleaning assembly of the machine
Source: Original.

The grading assembly comprised forty (40) rollers connected at a high-pitched continuous chain link (Fig. 4). The length of the chain was computed using:

$$L_P = 2(C/P) + (N+n)/2 + (N\text{-}n/2\pi)^2 \times (P/C) \quad (7)$$

where:
L_P = length of chain, pitches, mm
N = number of teeth of teeth of the large sprocket
n = number of teeth of the small sprocket
C = centre to centre distance, mm
P = pitch of the chain, mm
To suit the length of the chain, the centre distance for a given length was determined by using:

$$C = \frac{P}{8} = \left[2L_P - N - n + \sqrt{(2L_P - N - n)^2 - 0.810(N-n)^2}\right] \quad (8)$$

where:
C = center to center distance, mm
P = pitch of the chain, mm
Twenty (20) roller shafts, arranged alternately, were attached and rotated along with the chains. The other twenty were provided with slot mechanisms to permit a downward movement. The formula for the law of cosine and trigonometric functions was used to calculate the height of the downward movement. Both ends of the roller shafts were incorporated with small-sized wheels.
Large-sized sprockets were utilized to drive the grading rollers with a shaft driven by a belt and pulley. All shaft diameter was selected on the basis of strength and subjected to fluctuating combined twisting and bending moments and computed using equivalent twisting moment [12]. The material for shafting was AISI 1020 -Cold rolled steel [17]. Sizes were computed using the following formulas:

$$T_e = \sqrt{(K_M M)^2 + (K_T T)^2} \quad (9)$$
$$T_e = \pi/16\ \tau d^3 \quad (10)$$

where:
T_e = equivalent twisting moment, N-mm
M = maximum bending moment, N-mm
T = maximum twisting moment, N-mm
K_M = combined shock and fatigue factor for bending
K_T = combine shock and fatigue factor for torsion
τ = maximum permissible shear stress, MPa
d = diameter of the shaft, mm

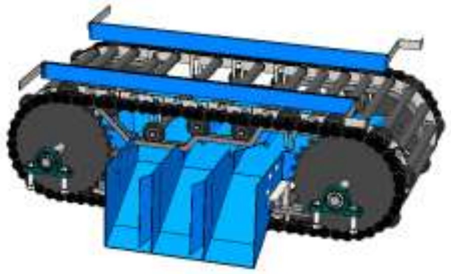

Fig. 4. Machine's grading assembly design
Source: Original.

Roller shafts was designed to follow a downward path to allow expansion of the gaps between rollers. The height of the downward movement of the roller corresponded to the hypotenuse gaps between the rollers following the onion grades. The grading length was divided into three sections of onion grades (small: 15 to 30mm; medium: 31 to 50mm, and large: 51 to 80mm) and was provided with a separate outlet. The belt and pulley were used to transmit the power from the driver to the grading assembly, and the bevel gear was used to change the power source's rotation orientation. The pitch angle of the driver bevel gear (γ) was computed using:

$$\gamma = \tan^{-1}(t_1/t_2) \quad (11)$$

The frame is the primary holder of the entire load during the working condition. It was made of a 40 mm square tube. It was designed to withstand the stresses and working loads during the operation.

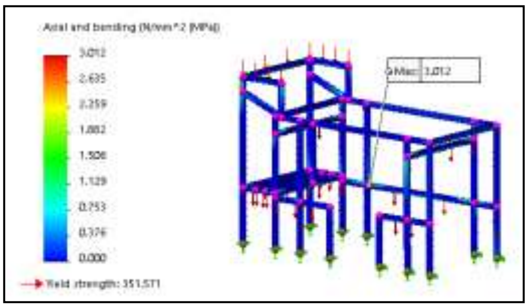

Fig. 5. Results of the frame equivalent stress analysis
Source: Original.

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The stress analysis on the machine's frame, in Fig. 5, reveals a maximum stress of 3.01MPa upon applying the forces. This result is lesser than the yield strength of the material, which is 351.57MPa. This result clarifies that the frame can withstand all the loads applied during the operation. On the other hand, the simulation analysis for resultant displacement in Fig. 6 shows a maximum value of 0.035mm. This result proves that applying the forces can cause negligible change or deformation in the frame's shape.

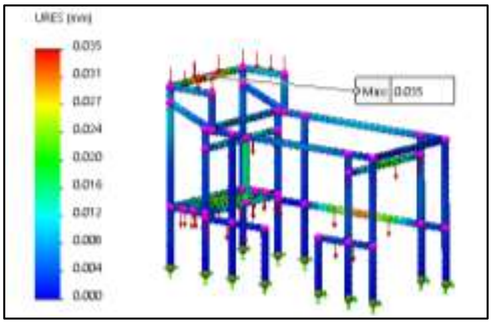

Fig. 6. Results of the resultant displacement analysis
Source: Original.

Fabrication

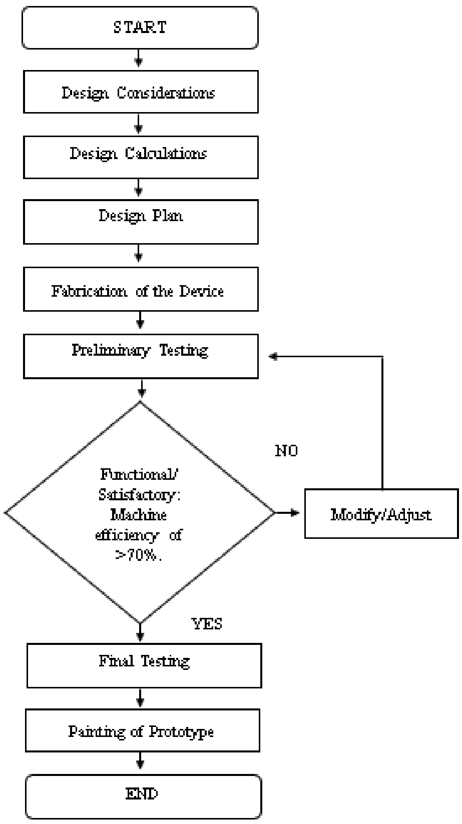

Fig. 7. Flow chart of activities for the development process
Source: Original.

The machine was fabricated from April to August 2020 at San Rafael Village, Navotas City, Philippines at the midst of the COVID19 pandemic. The process flow chart in Fig. 7 presents the different processes done during machine fabrication. The machine undergoes preliminary testing and modifications or adjustments on different components until machine efficiency reaches ≥70%. Finally, the machine was tested to evaluate its performance.

Performance evaluation

The machine was tested to determine its performance based on the parameters such as capacity, efficiency, mechanically damaged bulbs, noise level, and power consumption. Machine performance was evaluated based on three levels of speed combination as treatment in the cleaning and grading assembly and was replicated three (3) times. The performance evaluation was set up according to the Completely Randomized Design (CRD). Samples used were uncleaned and ungraded onion bulbs with visible loose dry scales due to curing and storing. The sample for each replication comprised ten kilograms (10kg) and was randomly assigned among treatments considering that no rotten bulbs were included. Raw data were collected during each trial, such as initial weight, operating time, impurities left and removed, weight in each outlet chute, correct and correctly graded weight, the weight of mechanical damage, power consumption, and noise emitted. Lastly, statistical tests using the Analysis of Variance (ANOVA) and Post-Hoc test using Tukey's Honestly Significant Difference (HSD) were used to indicate statistical significance among treatments and to determine which speed combination is the best.

Capacity**:** It is the weight of the cleaned and graded onion bulbs received at the outlet per unit time of executing each operation. It is expressed in kilograms per hour (kg/hr). The capacity was calculated using the following formula [16]:

$$\text{Capacity} = \frac{\text{initial weight (kg)}}{\text{total duration of test (sec)}} \quad .....(12)$$

Efficiency**:** Machine efficiency is the product between cleaning and grading efficiencies [13]. Cleaning efficiency is the ratio of the weight of the impurities left in the bulb (e.g., dry scales, roots, etc.) during cleaning to the sum of the weight of the scales left and the weight of scales removed by the machine expressed in Percent (%). The weight of impurities removed by the machine is the difference between the initial and the weight after cleaning the test material. It was calculated using the following formula [3]:

$$\text{Cleaning Efficiency} = \frac{\text{weight of impurities left in the bulb}}{\text{weight removed+weight left}} \times 100$$
....(13)

Grading efficiency, on the other hand, refers to the ratio of the weight of a product of a particular grade to the total weight of the graded material expressed in percent. During the test, a one-kilogram sample was collected randomly on each chute, and each size was evaluated using a veneer caliper. Grading efficiency was calculated using the following formula:

$$\text{Grading efficiency} = (\text{eff}_s \text{ x eff}_m \text{x eff}_l) \text{ x } 100$$
....(14)

$$\text{eff}_n = \frac{\text{weight of correctly grade bulb (kg)}}{\text{total weight of sample (kg)}}$$
.... (15)

where: eff_n = eff_s or eff_m or eff_l
eff_s = efficiency for small grade, decimal
eff_m= efficiency for medium grade, decimal
eff_l= efficiency for large grade, decimal

Percent mechanical damage **:** It is the ratio of the damaged material to the total material after the operation expressed in percent [16]. Mechanically damaged onion bulb refers to the scratched, sliced, or bruised bulbs after the operation. Acceptable maximum mechanical damage is 3.5% [15]. It was calculated using:

$$\%\text{ mechanical damage} = \frac{\text{weight of damage bulbs}}{\text{weight of the sample}} \times 100$$
....(16)

Power consumption**:** It is the amount of power that the electric motor consumes during every test trial, expressed in watts-hour (W-hr). It was determined using a digital power meter.

Noise level**:** The noise emitted by the machine was measured using a digital noise level meter at the location of the feeder, and bagger express in decibels. The noise was taken approximately 50 mm away from the ear level of the operators [16]. Acceptable maximum noise level of a machine is of 92db [15].

Cost analysis**:** The economic performance of the machine was calculated based on annual cost, fixed costs, variable costs, unit cost of operation, break-even cost, and payback period. Fixed costs include depreciation, interest on investment, property tax, insurance, and shelter/housing. Variable costs are the cost of labor, repair, and maintenance per hundred (100) hours of use. On the other hand, the break-even and payback period determines when the total benefit compensates for the total costs.

RESULTS AND DISCUSSIONS

Machine Description

The machine comprised five major components: a hopper, cleaning unit, grading unit, frame, and transmission assembly powered by a 0.5hp electric motor. The loading of the uncleaned and ungraded onion bulbs takes place in the hopper. The cleaning unit, composed of six rollers, removes excess dry scales and remains one to two dry scales. Each roller rotates in the opposite direction using spur gears. After cleaning, onions are conveyed to the roller-type grading assembly for size grading.

Photo 1. Dry-scale cleaner cum grader for stored onions
Source: Original.

Performance of the Machine

Statistically, the machine performance was affected significantly by speed in terms of cleaning capacity, grading capacity, overall capacity, and power consumption at a 1% confidence level. Results show that in terms of cleaning capacity, grading capacity, and overall capacity, speed in T3 was significantly higher among T1 and T2. In contrast, T1 and T2 were not significantly different. On the other hand, power consumption reveals that T3 was significantly lower than T1 and T2. The mean power consumption when using a speed combination of T1 and T2 was not significantly different. This provides sufficient evidence that speed variation has a significant effect on the performance of the machine. This further means that there is a significant increase in the machine's cleaning capacity, grading capacity, and overall capacity if the speed is increased [9, 2, 19], and power consumption if otherwise. Similarly, the means of the percent mechanical damage as influenced by different speed variations showed a significant difference at a 5% confidence level. Results show that the speed combination of T1 was significantly lower than T3. On the other hand, the means between T1 and T2 and between T2 and T3 were not significantly different. These results provide sufficient evidence that the increase in speed is directly proportional to mechanically damaged bulbs [10, 14].

Furthermore, regarding cleaning efficiency, grading efficiency, overall efficiency, and noise level, no significant difference was observed in the speed variations in the machine's performance. These results clarify that speed variation does not significantly affect the performance of the machine in terms of efficiency and noise level [9,10].

Overall test results revealed that satisfactory machine performance was expected when the speed combination was 71rpm and 17rpm (Table 1). It is based on the machine considerations and the Philippine Agricultural Engineering Standard (PAES).

Table 1. Machine performance as influenced by different speed variations

Machine Parameters	T1, rpm 53 & 13	T2, rpm 61 & 15	T3, rpm 71 &17
Cleaning capacity, kg/hr	427.52 b	458.83 b	535.28 a
Grading capacity, kg/hr	458.86 b	489.16 b	556.53 a
Overall capacity, kg/hr	401.72 b	430.08 b	493.30 a
Cleaning efficiency, %	80.84	87.16	88.50
Grading efficiency, %	87.46	85.79	82.20
Overall efficiency, %	70.70	74.77	72.75
Mechanical damage, %	1.23 b	1.60 ab	2.09 a
Noise level, dB	78.87	80.96	82.51
Power consumption, W-hr	17.17 a	16.2 a	14.41 b

Means with the same letter are not significantly different
Source: Original.

The total cost of fabricating the machine was ₱125, 000.00. The machine's unit cost was ₱196.22/hr or ₱40/100kg (Fig. 8).

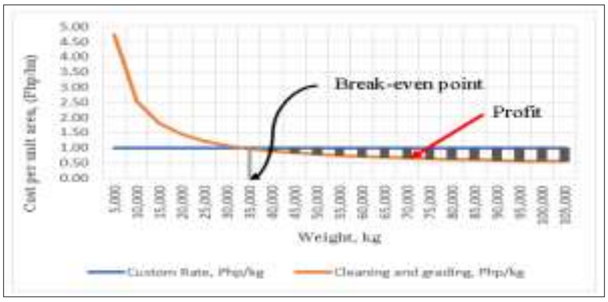

Fig. 8. Cost curve of using the machine
Source: Original.

As shown in Fig. 8, the machine needs to clean and grade 33,263kg to break even all the costs in 1 year at a custom rate of ₱1/kg to consider ownership; otherwise, it is expensive to use. Furthermore, using the machine requires 3 persons as operators, which lessens the utilization of manual labor from 3 man-day/100kg to 0.08 man-machine-day/100kg.

CONCLUSIONS

The results of the study led to the following conclusions:

- A dry-scale cleaner cum grader for stored red onion bulbs was successfully developed based on the considerations and was fabricated using locally available materials;
- The machine showed satisfactory performance in cleaning capacity, grading capacity, overall capacity, cleaning efficiency, grading efficiency, overall efficiency, percent mechanical damage, power consumption, and noise level when set up to 71rpm in cleaning and 17rpm in grading; and,
- The machine should be owned by a group of farmers or farmer's cooperatives. Although individual ownership may also be considered, it should be subjected to custom service.

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