DEVELOPMENT AND EVALUATION OF PUMMELO (*Citrus grandis L.*) FRUIT SORTER

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ABSTRACT

Pummelo is popular in the market worldwide; however, sorting is necessary to meet the market's demands. This study was conducted to design, fabricate, and evaluate the performance of a Pummelo sorting machine. Three conveyor belt speeds, each replicated three times, were used in the actual field test, resulting in a total of nine experiments. Complete Randomized Design (CRD) in one-way ANOVA was used to differentiate significant differences among treatment means. Belt speeds for treatment tests were 7-8, 11-12, and 27-28 meters per minute. Further tests of significant differences among means of treatment were done using Duncan's Multiple Range Test at a 5% level of significance. Results showed that the sorter's highest sorting capacity was achieved at 507 pieces per hour, using a conveyor belt speed of 27-28 meters per minute. The highest mean sorting efficiency was recorded at 96.97% at a conveyor belt speed of 11-12 m/min. The lowest mechanical damage, with a mean of 0.48%, occurred at a conveyor belt speed of 7-8 m/min. The manual sorting had an average capacity of 477 pieces per hour and a mean efficiency of 72.78%. A pummelo sorter operating at a conveyor belt speed of 27-28 meters per minute, with a sorting capacity of 507 fruits per hour, had a total estimated sorting output of 973,440 fruits

per year. It had an operating cost of Php0.088 per piece with a custom rate of Php0.118 per fruit. The sorter had to sort 384,536 pieces of Pummelo to attain the break-even cost of operation. It had an estimated net income of Php29,467.45 per year and a payback period of 1.4 years.

INTRODUCTION

The Philippines produced an average of 36,686 metric tons of Pummelo, spread across five major producing areas: Davao City, Isabela, Cagayan, Nueva Vizcaya, and Davao Oriental. The Philippines exported pummelo from 1999 to 2001, but due to increasing domestic consumer demand, the country began importing pummelo from other countries (Lustria et al., 2009).

Davao City, as the number one producer of Pummelo, was able to produce 12,672 metric tons of Pummelo in 2009, which was 34% of the total production. It is followed by Isabela, which produced only 6,917 metric tons, representing 18% of the total. The volume showed and proved that Pummelo is a signature fruit and landmark of Davao City.

Pummelo plays an essential role in the market; however, sorting is necessary to meet customers' quality standards and enhance its market value. Sorting is one of the critical operations that determines the acceptance of fruit by consumers in national and even international markets (Mangraj et al., 2009). Fruits undergo postharvest preparation, especially sorting, before being transported from the field to the market.

Manual sorting and grading of fruit are globally adopted practices for fruits, including the Pummelo. However, these operations require qualified staff to consider certain factors through physical parameters by visual inspection (Omre & Saxena, 2003). Size and weight are the prevalent features to classify a particular fruit. Manual weighing is time-consuming, inconsistent, and less efficient. Moreover, prices become expensive due to a labor shortage during peak seasons, which significantly affects operations (Londhe et al., 2013). Hiring inexperienced sorters affects the quality of work in terms of efficient classification, which needs extra checking of their sorted fruits, mentoring of newly hired workers, and additional cost of supervision.

Research has found that farmers are already educating their children to improve their standard of living and transition away from farm work. Currently, the labor shortage has become a significant issue in the farming industry. The situation is supported by the decrease in the labor force in 2004 (Briones, 2009). As of today, the majority of small Pummelo traders and farmers in Davao rely on manual sorting, and they have experienced the aforementioned problems. Based on the situation, it reveals a need for the development of an automated grading and sorting machine to address the shortage of farm laborers. To sustain the quality of agricultural produce, an affordable and portable fruit sorting machine must be designed and developed.

Objectives of the Study

The general objective of the study was to design, fabricate, and evaluate the performance of Pummelo, a fruit sorter. The specific objectives of the study were the following:

1. To design an automated Pummelo sorter.
2. To fabricate the Pummelo sorter;
3. To evaluate the performance of the Pummelo sorter in terms of sorting capacity, sorting efficiency, mechanical damage, and power requirement;
4. to compare the performance of the fabricated sorter machine to the manual sorting; and,
5. To calculate the cost of operation.

METHOD

The study follows the input-output design. The following criteria were considered in the design of the Pummelo fruit sorter.

Properties of crops that are relevant to the design, development, and performance evaluation include variety, size of the fruits, bulk density, and weight class standard for sorting purposes.

1. Input capacity of 500 to 700 fruits per hour, which can accommodate 450 to 650kg of fruits per hour.
2. Standard dimensions from PAES 2008, such as pulleys and belts, including chain sprockets
3. Simplicity of the design for ease of operation and maintenance.
4. Use of locally available material so that it can easily be constructed in the shop.
5. Use of some standard parts readily available at the local market.
6. Safety of operating the machine.

The Pummelo sorter is composed of six main parts: (1) feeding hopper, (2) conveyor belt system, (3) load cell, (4) selector arm, (5) fruit container, and (6) main frame. Figure 1 was operated using an algorithm for a sorting mechanism in four weight classifications. The procedures were as follows:

1. Start the machine.
2. Initialize it through the universal asynchronous receiver-transmitter (UART) and analog-to-digital converter (ADC);
3. Clear output open collector (OC) and the Voltage controls the system on a chip (SOC);
4. Check the Pummelo fruits at the load cell;
5. Initialize the overlapped execution circuits (OEC);
6. Determine the weight calculation (ADC conversion), storing it as a variable 'w' for weight;
7. Wait for the end of conversion (EOC) Selection to be disabled;
8. Rotate the motor at the conveyor for the corresponding weight of

Pummelo;

9. The following weight range is decided:
    a. 801g up
    b. 800-601
    c. 401-600
    d. <400

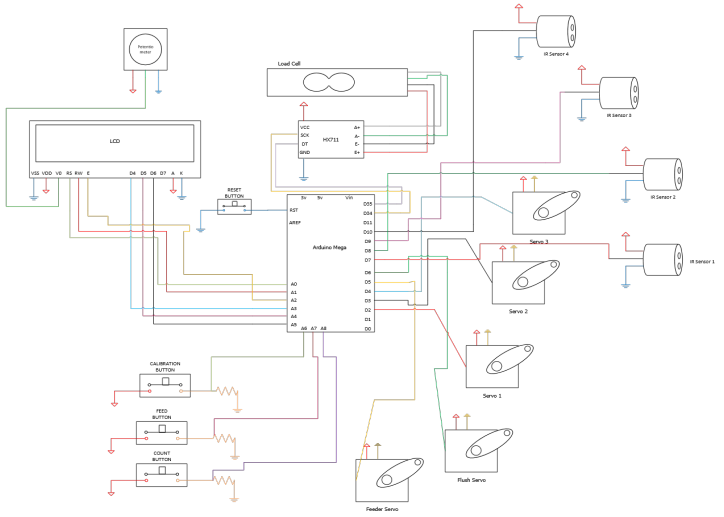
Decide the weight range based on:
If the calculated weight is w>b, then arm one sorts the Pummelo fruit;
If the calculated weight is c<w<a, then arm two sorts the Pummelo fruit;
If the calculated weight is d<w<b, then arm three sorts the Pummelo fruit;

1. If the calculated weight is w<c, then sort to the fourth basket;
    a. This process is repeatedly performed in all the above steps until all pummelo fruits are sorted; and,
    b. This is the end of the sorting process.

Testing of the machine was conducted after its completion to verify that the various parts were functioning correctly. The chain, sprocket, and belt tension were checked, as well as the calibration of the RPM of the rotating parts and the electronic system. The RPM, power requirement, and consumption, as well as belt slippage and other necessary data, were gathered while the machine was at no load. The belt speed with the corresponding pulley was 7-8,11-12, 27-28 m/min, served as treatment.

Figure 1

Electronic and Arduino system



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For final testing, the study arranged and analyzed statically using the single factor experiments in Completely Randomized Design (CRD) to determine the effect of the different levels of belt speed at (8-9, 11-12, 2728m/min) on the efficiency, capacity, and mechanical damage on the fruit being tested.

There were three treatments, each replicated three times, resulting in a total of nine experimental units. Each experimental unit was tested using 121 fruits or 97 kg of Pummelo fruits of the Magallanes variety. A total of 873 kilograms of Pummelo was used, with an average of 873 kg. Significant differences among treatment means were determined using one-way ANOVA. Duncan's Multiple Range Test was used to determine which of the means significantly differ from each other. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS).

Manual sorting activities were observed in a Pummelo packing house located in Davao. Data were gathered using a survey questionnaire. The sorting capacity of the Pummelo worker was based on the fruits sorted in a one-day operation under normal conditions. The results were analyzed using a two-sample t-test.

The cost of operation was analyzed using the Pummelo sorter. The fixed cost, variable cost, interest on investment, and breakeven point analysis were also determined.

RESULTS AND DISCUSSION

The designed Pummelo fruit sorter in Figure 2 had the following significant components: a hopper, a conveyor belt system or power transmission assembly, an electronic assembly (which includes a load cell, microcontroller, servo motors, and sensors), a mainframe, and a fruit container. The Pummelo sorter dimensions were presented in the Table.

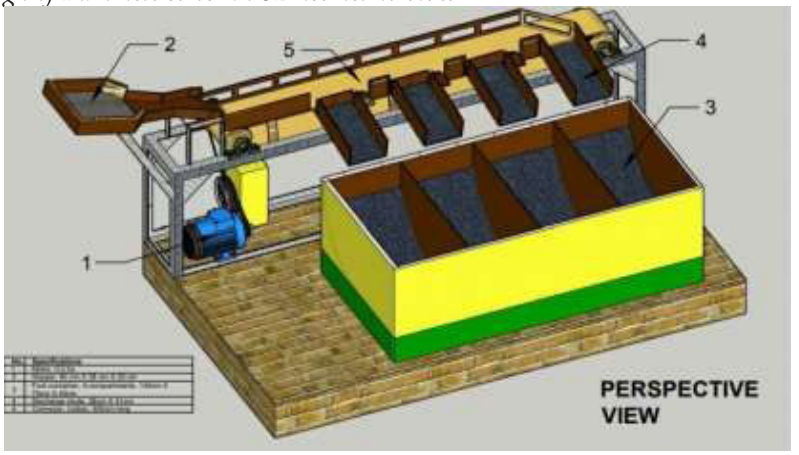
Table 1. *Specification of Pummelo (Citrus grandis L.) sorter*

Item	Specification
Capacity, pcs. /hr.	507
Sorting Efficiency,	95.87
Mechanical Damage,	0.79
Main Structure	
Weight, kg	250
Overall Dimensions	
Length, mm	3400
Width, mm	1500
Height, mm	1200
Discharge Chute	
Length, mm	280
Width, mm	410
Height, mm	150
Fruit Container	
Length, mm	1430
Width, mm	700
Height, mm	450
Hopper	
Length, mm	600
Width, mm	380
Height, mm	200
Feeding Mechanism	Manual Feeding, Batch Type
Prime Mover	220 V, 746 W single phase, capacitor type electric motor coupled with 1:40 Motor Reducer
Transmission System	Sprocket Chain Drive and Pulley Belt Combination
Gear Sprocket 1	11teeth
Gear Sprocket 2	28 teeth
Sprocket chain number	60mm
Pulley 1	127mm Single sheave pulley
Pulley 2	152.4mm,101.6mm,50.8mm
Belt type	V-belt, A-36, A-85, A-80
Conveyor Type	Flat Belt 120 mm x 4000 mm

Arduino &Electronic System	Arduino Mega, Load Cell, amplifier, Servo Motors, Light Sensors, and LCD

Figure 2

Design of Pummelo sorter in 3D isometric view



Performance Evaluation of the Device

The Pummelo sorter was evaluated based on its overall performance in terms of sorting capacity, efficiency, and mechanical damage, as affected by different conveyor belt speeds. Three conveyor belt speeds were tested at 7-8, 11-12, and 27-28 meters per minute.

Sorting Capacity

Table 2 presents the sorting capacity, efficiency, and mechanical damage at conveyor belt speeds of 8-9, 11-12, and 27-28 meters per minute. It has a highest mean of 507 pieces of pummel fruits per hour at a speed of 27-28 meters per minute, followed by 396 pieces at 11-12 meters per minute, while the lowest mean was 371 pieces at a speed of 8-9 meters per minute. The sorter, operating at speeds of 7-8, 11-12, and 27-28 meters per minute, revealed that as belt speed increases, performance capacity also increases.

Sorting Efficiency

Sorting efficiency was 96.97% at belt conveyor speed of 11- 12 meters per minute, followed by 96.69% at 7-8 meters per minute and 95.87% at conveyor belt speed of 27-28 meters per minute. Data showed that the sorting efficiency ranged from 1.65%. Results revealed that increasing the belt speed has a positive effect on the machine's performance.

Table 2. *Performance of Pummelo Sorter as affected by different belt speeds*

Conveyor Belt Speed, m/min	Sorting capacity, Pummelo/hr.	Sorting Efficiency, %	Mechanical damage, %
7-8	370.85[a]	96.69[a]	0.48[a]
11-12	396.08[a]	96.97[a]	0.65[a]
27-28	506.87[b]	95.87[a]	0.79[a]

Means not sharing the same letter, in row or column, differ significantly by DMRT at the 5% level of significance .

Mechanical Damage

Table 2 shows the results of mechanical damage to fruits at three conveyor belt speeds: 7-8, 11-12, and 27-28 meters per minute. The highest mean was 0.79% at a conveyor belt speed of 27-28 meters per minute, followed by 0.65% at conveyor belt speed 11-12 meters per minute, while the lowest mean of 0.48% was obtained at conveyor belt speed of 7-8 meters per minute. Data revealed that 0.92 %. The pummelo sorter showed less mechanical damage to the fruits during the testing operation.

Comparison of Manual Sorting Versus Machine Sorting

Table 3 revealed that manual sorting has a mean capacity of 477 pieces of fruit per hour. The results showed that the Pummelo Sorter has a lead difference in terms of capacity, efficiency, and cost per day: 30 pieces. /hr. 23.09% efficient and PHP 150 /day, respectively.

Table 3. *Comparison of the Pummelo sorter manual sorting*

Types of Sorting	Efficiency, %	Labor cost/day	Capacity, pcs/hr.
Pummelo sorter	507	95.87	300
Manual sorting	477	72.78	450

Operating Cost of Pummelo Sorter

The machine has a total fixed cost of PHP 11,536.07 per year. These costs entailed a depreciation of Php7,449.30 and Php2,845.22 for the interest on the investment. The taxes, insurance, and shelter costs are Php1,241.55. Variable costs accumulated during operation included repair and maintenance (R&M), energy costs, engine costs, and labor costs, totaling Php38.47 per hour. Over the course of one year of operation, this would amount to Php73,862.40. The total operating cost of using the machine is Php 85,398.47 per year. It has an operating cost of PHP 0.088 per piece, with a custom rate of PHP 0.118 per piece. Thus, the machine has an estimated gross income of Php114,865.92 per year and a net income of Php29,467.45 per year, with a payback period of 1.4 years.

CONCLUSION

The designed Pummelo sorter is timely in addressing the needs of Pummelo growers and traders. Additionally, the fabricated Pummelo sorter is functional, with a performance capacity and efficiency. It can sort a maximum of 4056 fruits per day and is 95.87% efficient. Moreover, there is a significant difference in the machine's performance in terms of sorting capacity at three different conveyor belt speeds. However, no significant difference in sorting efficiency and mechanical damage is noted at the three conveyor speeds. It is also found that there was no significant difference in terms of capacity between the Pummelo sorter and manual sorting. However, there is a substantial difference in terms of sorting efficiency. It has a lead difference capacity and efficiency of 30 pieces per hour and 23.09 %, respectively. Thus, the Pummelo sorter is better than manual sorting. The cost of fabricating the machine is Php41,385.00.00. The projected annual net income of the machine is PHP 29,467.45 per year. The designed Pummelo sorter has a payback period of 1.4 years.

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