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A Astina Joice
Research Scholar, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore, Tamil Nadu, India

P Rajkumar
Professor and Head, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore, Tamil Nadu, India

R Arulmari
Assistant Professor, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore, Tamil Nadu, India

I Geethalakshmi S
Assistant Professor, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore, Tamil Nadu, India

Pazhanivelan
Professor and Head, Department of Remote Sensing and GIS, AC&RI, TNAU, Coimbatore, Tamil Nadu, India

Corresponding Author:
P Rajkumar
Professor and Head, Department of Food Process Engineering, AEC&RI, TNAU, Coimbatore, Tamil Nadu, India

Development and performance evaluation of size grader for Mosambi (*Citrus limetta*)

A Astina Joice, P Rajkumar, R Arulmari, I Geethalakshmi and S Pazhanivelan

Abstract
Fruit and vegetable quality is extremely important in today's agricultural industry because of the intense market. Grading of agricultural products, particularly fruits and vegetables, has become a need for trading. It is primarily done by hand, which necessitates a substantial amount of labour. Human operations may be difficult, inconsistency, inefficiency, and time consumption. Farmers are hoping for a suitable solution for the farm produce-grading machine to reduce manpower shortages, save time, and create graded items in a better quality with market acceptance. Taking this as an objective a size grader was developed for the Mosambi fruits. The components of the grader were fabricated after studying the engineering properties of the fruit. The developed grader's performance was evaluated. For optimising the grader conveying speed of 170,220 and 270 rpm were chosen. The angle of inclination between roller and the belt conveyor varied as 10,15 and 20˚. Maximum overall efficiency of the grader for Mosambi was recorded as 82% at 10˚, 270 rpm and the capacity of the grader was around 770 kg/h.

Keywords: Grading, Mosambi, conveyor speed, angle of inclination, capacity, overall efficiency

1. Introduction
Fruits and vegetables are important components of the human diet because they provide necessary vitamins, minerals, and fiber. India's varied temperature and physiography make it suitable for horticultural crops including fruits, vegetables, flowers, nuts, spices, and plantation crops [1]. It accounts for more than 90% of the country's overall horticultural production. India is currently the world's second-largest fruit and vegetable grower. According to the National Horticulture Board's Database, India produced 99.069 million metric ton of fruits and 191.769 million metric ton of vegetables in the year 2019-2020. Mosambi (sweet orange) is a widely grown fruit. It needs a dry, hot environment, as well as a loose, loamy, well-drained soil that is neither slimy nor sticky. After being transplanted in rows in the nursery, the seedlings are grown for about a year in the nursery beds and budded in the warm weather [2]. The seedlings are planted in their permanent locations when the buds have properly established themselves. Pits measuring 2' x 2' are dug 20' apart and filled with soil mixed with agricultural manure, bone meal, and other ingredients. For the first five years, the plants are generally manured every year. Following the harvest of these crops, the ground is ploughed, harrowed, and weeded appropriately. When trees are 5 to 7 years old, they begin to yield fruit. Mosambi fruit blooms in the month of January or February, and the fruits are available to harvest in the month of August or September. Each tree produces around 300 to 1,000 fruits each year on average [3].

Grading is the process of classifying or categorising fruits and vegetables into different classes based on their size, shape, colour, and volume in order to get a higher market price. Grading is one of the most essential post-harvest processes used in the management of fruits and vegetables because it removes unwanted or foreign materials from the harvested products and divides them into fractions. The benefits of grading include a higher market price for graded goods and the development of greater confidence between buyers and farmers [4]. It improves the marketing efficiency by allowing for the purchase and sale of goods without the need for personal selection. Grading can save money on marketing costs such as packaging and delivery. It promotes product consistency within a grade and acts as a pricing benchmark. Every fruit and vegetable producing country has its own criteria for various grades based on market demands [5]. Hence the objective of this research work is to determine the engineering properties for the mosambi fruit, to evaluate the overall efficiency and capacity of the grader.

2. Materials and Methods

Mosambi were procured by considering proper physiological maturity, appearance, uniformity and healthy fruits at random from the farmer's market in Coimbatore. Engineering properties of fruit are essential to design and develop the equipment for sorting, grading, processing, transporting and packing.

2.1. Engineering properties

2.1.1 Physical properties

The physical properties such as size, arithmetic mean diameter (D_a), geometric mean diameter (D_g), shape, sphericity (Φ), surface area (S_a), mass (M), bulk density (ρ_b), true density (ρ_b), porosity, angle of repose, and coefficient of friction were estimated. For estimating these parameters standard methods were used, which are explained below [6].

2.1.1.1 Size

To determine the average size of Mozambi 50 fruits were selected, its axial dimensions along X, Y, Z axes were measured using a vernier caliper with a least count of ± 0.01 mm. The mean diameters such as arithmetic mean diameter (D_a) and geometric mean diameter (D_g) were calculated using the formula given below,

$$D_a = \frac{L+B+T}{L} \quad (1)$$

$$D_g = (LBT)^{1/3} \quad (2)$$

Where

L – Length, mm; B –Breadth, mm;
T –Thickness, mm
D_a – Arithmetic mean diameter, mm;
D_g – geometric mean diameter, mm;

2.1.1.2 Shape

The shape of a fruit is expressed in terms of sphericity. Sphericity refers to the ratio of the surface area of an equal-volume sphere to the actual surface area of a particle.
Random samples of mosambi were taken and its axial dimensions were calculated using vernier caliper having a least count of ± 0.01 mm. Sphericity of the fruit is calculated using the following formula,

$$\phi = \frac{(LBT)^{1/3}}{L} * 100 \quad (3)$$

Where

L – length, mm; B – Breadth, mm;
T – thickness, mm;
Φ – Sphericity.

2.1.1.3 Surface area (S_a)

The surface area of fruit is interrelated with a sphere of same geometric mean diameter. The surface area was calculated using the following formula,

$$S = \pi D_g^2 \quad (4)$$

Where

D_g – Geometric Mean Diameter of the fruit, mm.
S – Surface Area, mm^2.

2.1.1.4 Mass of the fruit (M)

To estimate the mass, sample fruits of Mosambi were selected randomly and weighed using electronic balance.

2.1.1.5 Density (ρ)

The density ρ is defined as the ratio of the mass (M) of the material to its volume (V).

Bulk density (ρ_b)

Bulk density is defined as the mass of the fruit to its total volume (including its pore space). Bulk density was determined by filling them in a 500 ml volumetric flask, gently tapped and weighed the content. Care was taken to avoid compaction of the fruits, during tapping in the container and filled to full volume. The measurement was replicated ten times and the mean was recorded. Bulk density was calculated as the ratio between mass and bulk volume of sample.

$$\rho_b = \frac{M}{V} \quad (5)$$

Where

M - Mass of the sample (kg);
V - Volume of the container (m^3);
ρ_b- Bulk density (kg/m^3);

True density (ρ_f)

True density was determined using water displacement method. It was calculated by filling a 1000 ml volumetric flask with 500 ml water. The fruits were dropped one by one till it get displaced. The rise in volume (V_1) of water was noted down. True density was calculated as the ratio between mass and difference in volume of water (V_1- V).

$$\rho_f = \frac{M}{V_d} \quad (6)$$

Where

ρ_f - True density (kg/m^3);
M - Mass of the sample (kg);
V_d -Difference in Volume of water (V_1- V) (m^3).

2.1.2 Frictional properties

Angle of repose, coefficient of friction and rolling resistance are essential frictional parameters to consider when designing an equipment for solid flow. It helps to identify the suitable material necessary to design the different parts for the equipment.

2.1.2.1 Angle of repose

The angle of repose was calculated using the filling method. In this method, a 15 x 15 x 20 cm dimension box with an open top and slidable front plate was filled with fruits, the plate was gradually removed, and the height to which the resulting pile surface made with the horizontal surface on which it rested was measured, and angle of repose was calculated as:

$$\theta = \tan^{-1}\left(\frac{h}{x}\right) \quad (7)$$

Where

h = height of the inclined plane (cm),
x = horizontal surface (cm).

2.1.2.2 Coefficient of friction
The frictional forces operating between surfaces of contact and samples at rest with regard to each other is defined as the coefficient of friction. A frictionless pulley mounted on a frame, a bottomless cylindrical holder (94 mm diameter and 98 mm height), a loading pan, and test surfaces were utilised to determine the coefficient of friction. The bottomless holder on the test surface was filled with known-weight of fruits, and weights were added to the loading pan until the container started to slide.
Plywood, galvanised iron, mild steel, stainless steel, and aluminium were used as test surfaces for the experiment. The experiment was repeated three times, with the average value being calculated and recorded as the average friction coefficient. The normal force (N) and lateral force (F) are represented by the weight of the fruits and the weights placed to the pan, respectively. The static friction coefficient was determined as follows:

$$\mu = \frac{F}{N} \tag{8}$$

Where
µ - Coefficient of Friction;
F – Lateral Force (N);
N – Normal Force (N).

2.2 Components of the size grader
Size Grader for mosambi fruit was developed with working principle of gravitational and tangential forces.

2.2.1 Main Frame
Main frame is the basic structure on which whole grading assembly was mounted. All the frames were made of MS square pipe The whole conveyor system was assembled in main frame. The height of the belt conveyor from the ground level was fixed as 590 mm for easy feeding of fruits. Main frame supports fruit dropping assembly.

2.2.2 Feeding unit
Feed hopper was provided above the main assembly to facilitate feeding of fruits in the cup. It was made up of MS sheet. To allow single fruit in the grading belt the feeding unit was extended for 600 mm length at the slope of 10°.

2.2.3 Side Rollers
The flat plate of 2 mm thick, 450 mm length and 105 mm width was fixed with a square rod of 10 mm thick. Same way another flat plate was constructed and both the plates were attached to shaft. The bearing was able to move the shaft back and forth.

2.2.4 Sizing Board
The grading section consists of five sizing board each made of rubber fixed to the metering aperture. Three screws attached with this sizing board is used for adjusting the gap between belt and sizing board. The screw length was provided with provision of 10 mm marks throughout the length for measurement.

2.2.5 Bearing
6000 ZE bearings with 8 mm were used. It has an inner and outer diameter of 10 mm and 26 mm respectively.

2.2.6 Step Metering Aperture
Connecting rods were connected on both sides of the cylindrical rubber board. Helical compression spring of pitch 5.5 mm was fixed in the connecting rod with the main frame which helps to adjust the metering aperture. The step metering gap is characterized by increasing aperture to maximum diameter of the fruits. The chain drive was used for power transmission from the motor step metering aperture. The rubber roller acts as a drive pulley which enables to rotate.

2.2.7 Belt Conveyor
The belt width of 100 mm with the length of 4620 mm and thickness 3 mm was used to convey each fruit in to the grading aperture. The belt was mounted on a tapered stainless steel fixed on the main frame. The belt was made up of PVC rug belt material. The inclination of the tapered belt conveyor can be adjustable from 0^{0} to 25^{0}. This inclination changes can be measured using protractor which was fixed to it. Fruits graded are brought into contact with belt and a grading board through gravitational and tangential force.

2.2.8 Belt Guide Plates
The belt has to be moved throughout e length of the conveyor without any change in the alignment. Moreover, to avoid any jump, guide plates were given at the bottom of the tight side of belt. The guide plate was made of steel rods.

2.2.9 Central Rotor Shaft
The base plates were attached on the top and bottom of the main frame to fix the bearing with the center rotor hollow shaft. It was made of MS with the pipe inner diameter of 40 mm and outer diameter 50 mm. It was fixed at the top and bottom of the main frame with the help of bearing.

2.2.10 Length of the Conveying section
The total length of the conveying section was calculated based on the feeding section, grading section and length of rollers.

$$L_C = L_F + L_G + L_R + \text{Allowance}$$

Where
L=length of the conveying section,
F= feeding section,
G=grading section,
R=length of rollers.
In the grading section 5 number of outlets were given in order to separate the fruits into 5 different grades.

2.2.11 Collecting Trays
Totally five collecting trays were fixed. The thickness of the trays were 10 mm made from MS sheet.

2.2.12 Motor: 1 hp three phase AC induction motor was used for driving the pulley so that the belt moves throughout the conveyor. The power required for grading process was found to be 746 watts.

2.3. Machine efficiency
The efficiency of the machine determines the effectiveness of the machine in transforming the power input to the device to power output. It determines how much energy is lost to friction and heat during its operation.

Overall Efficiency = $\frac{T_S - T_M}{T_S} \times 100$

T_S = Total no. of fruits used for grading
T_m = Total no. of misclassified fruits.

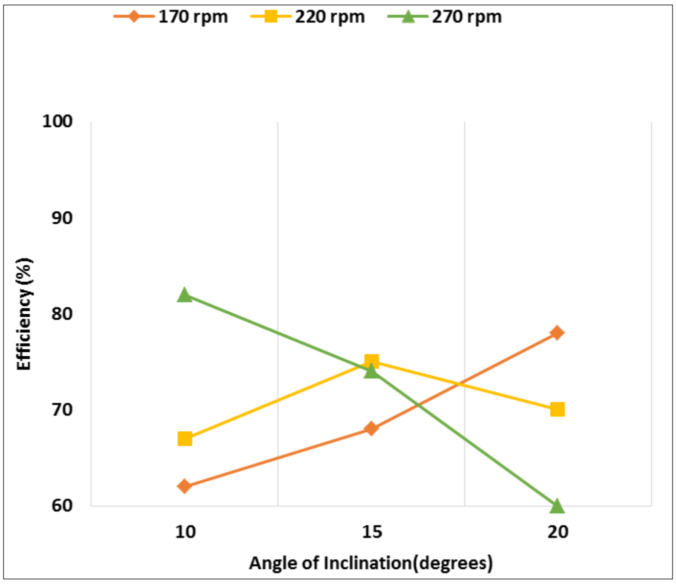
2.4. Capacity
It is a maximum measure that the machine can produce by performing it intended action. Capacity of the machine is ratio of the weight of the sample(kg) to the time taken for grading(hr).

Capacity = $\frac{\text{Weight of the sample(kg)}}{\text{Time taken for grading(hr)}}$

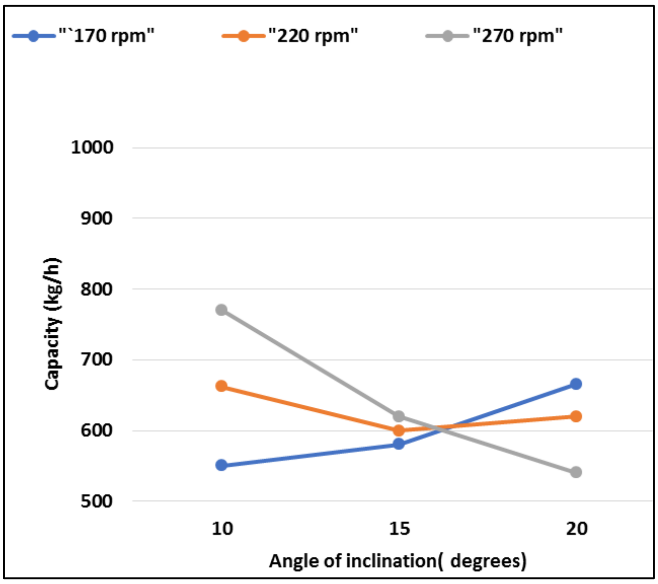
3. Results and Discussion
3.1 Physical properties
The properties of mosambi were calculated using the taken 50 samples. The average of the length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, mass and surface area of mosambi were 67.3 (±2.7) mm, 61.98 (±4.1) mm, 69.86 (±2.3) mm, 66.38 (±3.9) mm, 66.29 (±2.2) mm, 0.97 (±0.5), 168 (±9.3) g and 0.014 m^2 respectively. The high sphericity value is indicative of the tendency of the shape towards a sphere. The values of physical dimensions of the mosambi obtained in this research were quite close to that reported [7]. The bulk density and true density of the mosambi were found to be 515.9 (±11.8) kg/m^3 and 908.9 (±10.9) kg/m^3 respectively. The data obtained in this study was quite close to the results obtained by [8].

3.2. Frictional properties
The frictional properties of mosambi fruits such as angle of repose and coefficient of friction and rolling resistance were important parameters for designing material for conveyers and hoppers.
The coefficient of friction shows the friction forces between the mosambi and the surface of contact which was measured to be 0.22,0.18,0.21,0.23,0.21 for Plywood, Galvanised Iron, Mild steel, Stainless steel and Aluminium respectively. Fruits on the mild steel require less frictional force than the other materials.
Angle of repose of mosambi fruit is 55˚(±1.85) shows strong flow ability of material as angle of repose of fruits is impacted by shape, and size of the fruits [9]. As a result, mild steel may be utilised to construct conveyors, hoppers, and other mosambi fruit equipment.

3.3 Performance evaluation of the size grader
The equipment is developed especially for grading spherical fruits. Mosambi fruits were taken for grading. Different trials were conducted by varying the conveyor speed and angle of inclination. Belt speed of 170,220,270 rpm and angle of inclination of 10,15,20˚ were taken as independent variable after studying the engineering properties of the fruits. Time taken for grading the fruit is noted in seconds. The efficiency of the machine is calculated accordingly during various trials. The following graphs represent the changes in the value of machine efficiency and capacity by varying angle of inclination and conveyor speed.



Graph 1: Angle of inclination vs Efficiency,



Graph 2: Angle of inclination vs Capacity

The efficiency of machine largely depends on varying angle and speed. At 170 rpm with the increase in angle of inclination the efficiency starts to increase. But when the speed increased to 270 rpm the machine efficiency decreases with the increase in angle of inclination. Hence the machine reaches its maximum efficiency of 82% for grading mosambi fruits at 10˚angle of inclination with 270 rpm.
The capacity of the grader depends on conveyor speed and angle of inclination [11]. At 5˚angle of inclination, with the speed 270 rpm no movement were observed as the fruits were static on the belt. Hence 10˚ angle was considered to be the minimum angle of inclination for mosambi fruits. The speed less than 170 rpm is not efficient because the rolling effect of fruit is reduced it results in improper grading. At 170 rpm the capacity was raised from 529 to 666 kg/h by varying the angle of inclination as 10, 15 and 20˚. At 220 rpm the capacity for 10˚ was found to be 610 kg/h and it decreased with the increase in angle of inclination because the fruits are not free falling from the belt to the step metering aperture when the angle increases. For the conveyor speed of 270 rpm the capacity was increased up to 770 kg/h at 10˚ and decreased gradually with increase in angle of inclination up to 540 kg/h.
Therefore, the effective angle of inclination and conveyor speed for grading mosambi are 10° and 270 rpm which gives the capacity of 770 kg/h and machine efficiency up to 82% respectively.

4. Conclusion
Fruit grading is a crucial procedure that has an impact on product quality, management, and storage. The grader was created with farmers' needs, locally accessible resources, and ease of operation in mind. The grader's performance was assessed in terms of grading efficiency and capacity. The grader's efficiency and capacity for mosambi fruits were 82% and 770 kg/h respectively.

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