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Development and Evaluation of a Citrus Sorting Machine with Rotary Semi-conical Disc

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Abstract: A citrus sorting apparatus based on principle of centrifugal force of a rotating disc with semi-conical surface was developed. The apparatus consisted of a 700 mm disc, 700×700×900 mm frame, one feeding tray and three receiving tray. Disc rotation at four levels (30, 35, 40, 45 rpm) was controlled by an inverter connected to a 0.5 hp electromotor. An adjustable step-height belt above disc peripheral allowed fruit desired size (59-72, 73-86 and 87-100 mm, mean diameter) to pass into the receiving tray. Experiments were carried out on orange samples (*Thompson variety*) to determine the optimum values of apparatus disc rpm, capacity, efficiency and mean error ratio. Results showed that at the disc rotary speed of 40 rpm, the optimum values of mean error ratio, efficiency and capacity were 11.1%, 94% and 1012 kg/h, respectively.
Key words: Sorting, rotary disc, citrusr, orange.

INTRODUCTION and LITERATURE REVIEW

Citrus production in Iran is increasing every year and according to the national reports, Iran produced about 4.4 million tones per year in 2006 (Ministry of agriculture, 2006). Most of this production is distributed in domestic market without any value-added operations such as sorting or packing. While there is a huge potential to manage this valuable horticultural crop for export purposes, it is essential to develop sorting and packing systems.

Customer preference internationally is for products that are sorted into sizes, either by size or dimensions or by weight, according to the shape and regularity of the product (Studman, 2001). Conformity of size is particularly desirable for packaging and display purposes. The aim of sizing is to produce a sample of uniform appearance which is acceptable for its intended use (McRae, et al., 1986).

Different mechanical and electronic sorting systems have been developed and are used in the world. These machines can be divided into several categories: (a) roller grader, (b) belt and border grader, (c) perforated conveyer grader, (d) weight grader and (e) machine vision (image analysis) grader (Jarimopas et al., 2007). Despite some advantages of electronic and computer graders, there are many disadvantages in these approaches, including high initial and operating costs and the need for specialist computer and electronic service personnel that is very important in developing countries. Therefore, still mechanical approaches are preferred and widely used in these countries.

The most widely used citrus sorting system in Iran is the parallel bar, or roller grader in which the gap between the rollers may be fixed or adjustable. In this system, griping or pressing the fruit between rollers causes damage and resulted in decreasing the fruit quality and value. An alternative for grading citrus with spherical shape (e.g., oranges and lemons) can be applying combined centrifugal and gravitational force. A rotating sloped-surface disc with a gap between rubbers belts above the disc periphery allow fruit to pass according to their dimensions. This idea resulted in development a rotary citrus grading machine.

Jarimopas et al (2007) used rotating disc sizing machine to sort mangosteens. They found that a rotating disc rolls fruit along the metering board, causing it to lie horizontally. The metering gap then measures the fruit height, which essentially is the diameter of the fruit body. In addition, disc rotation rolls the fruit into proper orientation for size measuring, and rolling action also reduces contact abrasion (Peleg, 1985). On the other hand, rotary system is more simple and economical than other mentioned systems. Therefore, many local vendors and producers are able to use this grading machine.

In this research, the objectives were (a) development a rotary citrus grading machine based on combined centrifugal and gravitational force, and (b) test and performance evaluation of this machine at four disc speed (rpm) to determine its efficiency, mean error ratio and capacity while grading oranges at three size range.

MATERIAL and METHOD

Machine development

The citrus grading machine developed in the Agricultural University of Sari in Iran, consisted of, (a) a 700 mm diameter rotary disc with semi-conical surface, (b) a step-height gage belt above the periphery of disc as sizing device, (c) one entrance tray and three receiving trays and, (d) a 0.5 hp electromotor connected to a controller. All these parts attached to a steel chassis with 700 mm wide, 700 mm long and 900mm height. Figure 1 shows schematic and components of this machine.

Machine operation

Disc rotation (rpm) was adjusted by changing the inverter frequency until the desired speed was attained. The fruit samples in clusters of 4-6 pieces at a time were continuously fed into the entrance tray. As the fruit rolled down and contacted with the disc surface, the centrifugal and gravitational force moved them toward the periphery of disc and gage belt. The fruit rolled along the gage belt due to the tangential force and according to their dimensions were graded and allowed to pass through gaps to the receiving trays.

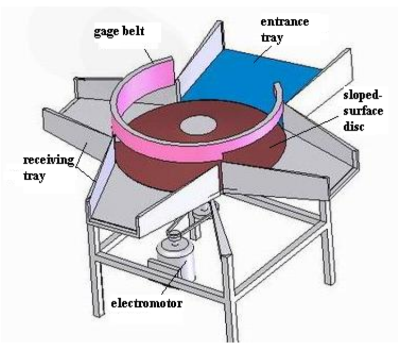

Figure 1. Schematic of sorting machine

Sample preparation and machine evaluation

Samples of the most commonly grown orange variety (Thompson), taken from the citrus orchards in the North of Iran, were used in the experiment. Ninety newly-harvested oranges were randomly selected and some of their physical characteristics were measured (Table 1). Based on the diameter range, oranges were graded and labeled into three categories (e.g., export, local market, or juicing). The maximum diameter in the plane perpendicular to calyx axis of each fruit was measured and the value of gage belt height for each category was derived from the measurements. The total weight of whole sample and each category were recorded. Samples were mixed in a single box and continuously fed into the entrance tray at a disc rotation of 30 rpm. The associated feeding time was measured from start to the end of operation. Thereafter, the correctly and incorrectly classified fruits were counted and weighed in each receiving tray, separately. This process was repeated two more time. Similar experiments at different speeds of 35, 40 and 45 rpm- three replication for each speed- were further conducted. The performance of the constructed machine (Figure 2) can be evaluated by determining the mean error ratio, grading efficiency and throughput capacity (Peleg, 1985):

$$E_{mr} = \frac{\sum N_{ij}}{\sum N_i} \tag{1}$$

$$R = \frac{\sum P_{gi} W_i G_i}{Q P_i} \tag{2}$$

$$Q = \frac{W_t}{t} \tag{3}$$

Which,

$$P_{gi} = \frac{N_{gi}}{N_{ti}} \tag{4}$$

$$W_i = \frac{K_i P_i}{\sum K_i P_i} \tag{5}$$

$$G_i = \frac{w_i}{t} \tag{6}$$

$$P_i = \frac{N_i}{\sum N_i} \tag{7}$$

$$N_{ti} = N_{gi} + N_{ij} \tag{8}$$

İn which;

E_m	mean error ratio
R	grading efficiency (%)
Q	throughput capacity (kg/h)
N_{ig}	number of size i dropping into receiving tray j

N_i number of fruit size i dropping to the sizing machine

$\sum N_i$ total number of fruit

P_{gi} fraction of fruit size i to total fruit dropping into receiving tray size i

N_{gi} number of size i dropping correctly into receiving tray size i

N_{ti} total number of fruit dropping into receiving tray size i

W_i weighted function

K_i relative value fraction of grade i

P_i fraction of size i to total fruit at the beginning of sizing

G_i outflow rate of fruit size i (kg/h)

w_i total weight of fruit in receiving tray size i

W_t total weight of fruit corresponding to $\sum N_i$

tgrading time

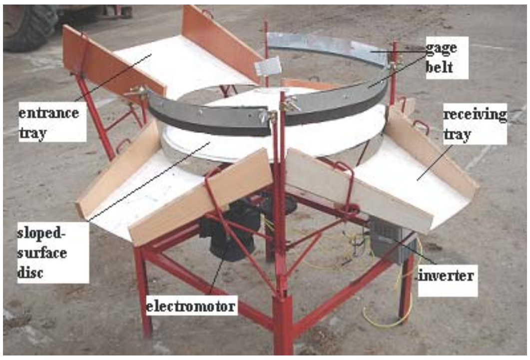

Figure 2. Constructed and evaluated citrus sorting machine

RESULTS and DISCUSSION

According to data from table 1, the value of gage belt height from the disc surface was derived from the maximum diameter of fruit for each category. Therefore, it was adjusted for category 3 at 72mm, category 2 at 86 mm and category 1 at 105mm. The machine test and performance evaluation data are given in table 2. As it is seen, changing the disc speed affected the mean error ratio. At the speed of 30 rpm, mean error ratio and capacity were the greatest and lowest, respectively. High mean error ratio may be due to the small centrifugal and gravitational force that causes the fruit rolls around itself and move to the next step and drop to the incorrect category. Increasing the disc speed from 30 to 40 rpm

Table 1. Some physical characteristics of oranges (Thompson variety) for three categories

Property	Category C (59-72) mm				CategoryB (73-86) mm				Category A (87-105) mm			
	Max	Min	Avg	SD	Max	Min	Avg	SD	Max	Min	Avg	SD
Average diameter	72	59	66.2	3.85	86	73	80.9	4.67	99.8	86.8	91.4	3.49
(mm)	194	101	151.3	26.1	328	190	263.1	44.8	493	299.3	253	47.5
Mass (g)	92.5	96.9	96.5	1.2	94.9	99	97.9	1.1	98	97	99	0.3
Sphericity (%)	200	100	165	32.2	430	211	292	59.8	600	300	392	55.2
Volume (cm^3)												

Data was derived from 30 orange samples for each category.

Table 2. Machine performance parameters for different disc speeds

Parameters	Disc speed (rpm)			
	30	35	40	45
Mean error ratio (%)	18	16.6	11.1	14.3
Throughput capacity(kg/h)	560	655	1012	1200
Efficiency (%)	91	92.4	94	82.8
Grading time(min)	2.42	2.07	1.37	1.13

Each data is the mean value of three replication

decreased the mean error ratio but at 45 rpm it again increased. This indicates that at disc high speed the fruits move very fast and have no time to move along gage belt. Therefore, disc speed must be adjusted in a specified range. Despite the maximum capacity was attained at 45 rpm, but at the speed of 40 rpm the mean error ratio was minimum (11.1%) and efficiency (94%) was the highest among all speeds. Therefore, it is suggested that the 40 rpm for disc speed is the most suitable for commercially scale design.

CONCLUSION

A citrus grading machine with rotary mechanism was developed. The machine is able to grade the citrus fruit in three category based on their mean diameter. Test and performance evaluation of the grading machine indicated that at the disc speed of 40 rpm the mean error ratio, efficiency and throughput capacity were 11.1%, 94% and 1012 kg/h, respectively. With respect to the cost of prototype construction (about 200US$) it is very economical for small and average citrus producers especially in developing countries.

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