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ENGINEERING STUDIES ON CLEANING OF SOME HORTICULTURAL CROPS

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ABSTRACT

The main objective of the present work is to develop a low–cost mechanical washer and drying of a small-scale washing machine to reduce the labor and time requirements for these two processes. Mandarin fruits (variety of Ponkan) and potato tubers (Diamant variety) were used for the experimental work. Design considerations and operating constraints included: nozzle water pressures ranging from 0.3 to 0.4 MPa (3 to 4 bar), air speeds ranging from 2 to 4 m/s, operating speeds ranging from 0.45 to 0.85 m/s and different nozzle numbers ranging from 20 to 28.

Physical and mechanical properties of the studied fruits, cleaning efficiency, removed water efficiency, mechanical damage; operating cost and productivity were studied to evaluate the performance of the developed washing machine.

The obtained results indicated that the optimum performance of the developed washing machine was at operating speed of. 0.65 m/s, nozzles water pressure of 0.4 MPa (4 bar), number of nozzles 28 and drying air speed of 4 m/s .Cleaning efficiencies at these conditions were 98.33 and 94.40 %, removed water efficiency values (by sponge rollers and blower fan) were 96.23 and 97.87 %, mechanical damage percentages were 1.15 and 1.95 %, operating costs were 1.92 and 2.47 L.E/Mg, and machine productivity values were 4.75 and 2.44 Mg/h for mandarin fruits (variety of Ponkan) and potatoes (Diamant variety), respectively.

INTRODUCTION

Citrus are the major horticultural crops in Egypt. The cultivated area of citrus is 346.24 thousand feddans (145.42 housand hectare) in 2002.

The areas of orange, mandarin and lemon are about 210, 94 and 38 thousand feddans (88.2, 39.48 and 15.96 thousand hectare) respectively. Meanwhile cultivated area of vegetables in Egypt is 1.84 million fed. to produce 17.87 Tg/year. Potatoes are one of the major vegetable crops in Egypt, whose cultivated area is about 200000 fed. to produce about 2 Tg/year distributed on the summer, Nile and winter seasons. The amount of Egyptian potato exports was estimated from 250-300 Gg/year, it has arrived to 430 Gg from fresh potatoes exported to Europe and Arabic market, which gives export income 140 million U.S.$/year (The annual statistics book, 2005). Some of crops should be washed and cleaned after harvesting to remove undesirable materials such as leaves, soil, stems, twigs, chemical, and residues of pesticides to improve product as early as possible after harvesting. Washing is one of the most important steps of handling and increased life of product.. Kushman (1997) reported that sweet potatoes always have significant amounts of soil adhered to the surface when harvested from dry sandy soil and stored for many months. Pallet bins of sweet potatoes harvested after heavy rains have been known to contain more than 42.86 kg (100 pounds) of loose soil. Separating this soil from the roots and cleaning the surface is a major function of packing. Sweet potatoes are generally unloaded from the pallet bins by dumping them into a tank of water (dump tanks) either by a box rotation device on the lift truck or by the use of an automatic bin rotator, then enter a final wash, with high-pressure spray washers installed. Flat fan spray nozzles at the surface of the sweet potatoes direct water at as much as 250 psi as they tumble over rotating brushes. Petracek et al. (1998) studied the effect of high pressure washing (HPW) on the surface morphology and physiology of citrus fruits. Mature white (citrus paradisi cv. Marsh) and red (C. paradisi cv. Ruby Red) grapefruits, oranges (C.sinensis cv. Hamlin) and tangelos (C. reticulate x c. paradise orlando) were washed on a roller brush bed and under a water spraying system with variable water pressure. Washing white grapefruit and oranges for 10 s under conventional low water pressure (345 kPa at cone nozzle) had little effect on peel wax structure. Washing fruit for 10 s under high water pressure (1380 or 2760 kPa at veejet nozzle) removed most epicuticular wax platelets from the surface, and removed surface debris such as sand grains.. Moos et al. (2002) developed small-mechanical carrot washer. The carrot washer removed foreign material sufficiently to allow grading and sorting to proceed. The system can accommodate samples up to 16 kg. The water requirement per sample is approximately 11 to 15 l. An operator needs to be present only for sample loading and is free for other tasks during the wash cycle. Washing time was 5 to 7 min per sample, a reduction of over 50% from the 15 to 20 min per sample for manual washing system. Timeliness of sample processing and improved carrot quality was the primary benefits of the mechanical carrot washer compared with the manual washing system. The reduced time and labor requirements of the washing process allowed workers to simultaneously wash and grade carrots. Amin et al. (2003) developed a small-scale machine for washing fresh fruits and vegetables. The cleaning efficiency was above 97 %, the results also showed that, the soaking time and pressure of spray washer had a pronounced affect on the cleaning efficiency. Additionally, the method of water draining (using air and centrifugal device) was high affecting on drying vegetables and fruits after soaking stage. Thapet (2005) mentioned that increasing the nozzles water pressure from 2 to 3 bar, increasing the cylinder brushes rotating speed from 0.43 to 0.62 m/s (55 to 80 rpm.), and decreasing the distance between nozzles and fruits from 200 to 100 mm caused a corresponding increase in total efficiency of washing machine from 61.73 to 93.64 % for orange and from 69.47 to 96.67 % for potatoes, respectively.

Washing fruits is necessary to remove soil and other foreign material before sorting, grading, and weighing. The primary motivations for development of a mechanical fruits washer for small samples are improved fruits quality, time and labor savings, and improved speed and efficiency of sample handling. This article presents the need and design constraints for a small–scale mechanical fruits washer, the methods and materials used to construct the washer, the results obtained, suggestions for improvement, and safety considerations.

The aim of the present work is to develop a low–cost mechanical washer and drying of a small-scale washing machine to reduce the labor and time requirements for some horticulture crops.

MATERIALS AND METHODS

A) Materials:

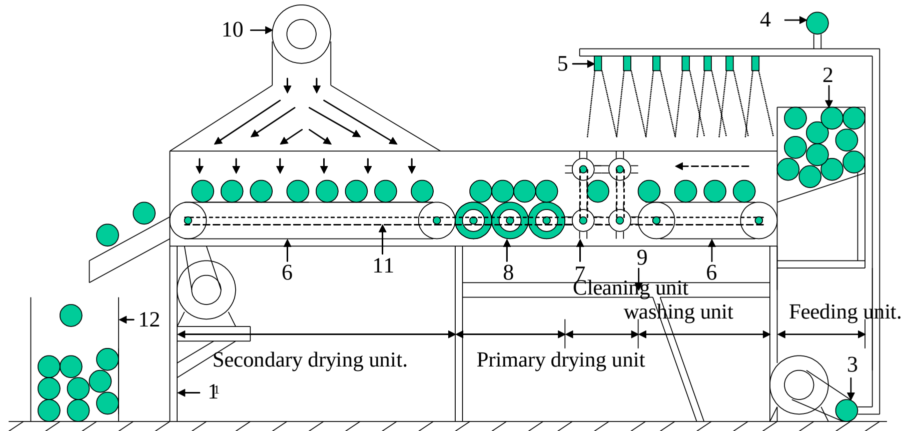
In the present investigation, a small handling machine was developed it was constructed and tested at a private workshop in Government of Kalubia, Egypt. The main components of the washing system are a frame, feeding unit, washing unit, cleaning unit, primary drying unit, secondary drying unit, collecting unit and water basin (Fig.1).

Fruits used in this investigation:

Spherical ripe fresh mandarin fruits (variety of Ponkan) and oblate vegetables like potatoes tuber (variety of Diamant) were used for the experimental work. The fruits were collected from private farm in Kaluibia Governorate and the measurements were taken in the same day.

Washing machine specifications and description:

The machine was **frame** made of angle steel sections 5x5x0.5 cm, with 300 cm length, 80 cm width and 80 cm height, feeding box made of galvanized steel sheet of 2 mm thickness, with 50, 70 and 45 cm length, width and height, respectively. It was constructed in such a way to give suitable slope of 0.348 rad (20 degree) for the materials to slide smoothly to washing unit. The slope angle was determined according to the higher determined friction angle of the studied crops. The capacity of feeding box was about 60-70 kg of mandarin and 40 - 50 of potato tubers. Washing unit 20-28 nozzles (5-7 nozzles x 4 lines), conveyor belt of 75 cm length and 70 cm width, the distance between fruits surface and nozzles is 10 cm (according to Thapet, 2005). A hydraulic pump was used for water pumping up to 0.40 MPa (4 bars) through electrical motor of 0.225 kW (0.3 hp). The pump was connected to the nozzles through high-pressure tube of 6 mm bar. The conveyor belt was driven by sprockets and chain attached with an electrical motor, cleaning unit 2 pairs of soft hairbrushes with 4 cm spacing. All brushes have 15 cm diameter and 70 cm width. Each brush was suspended on the frame by two bearings. It was driven by sprocket and chain attached with an electrical motor, as one sprocket is fixed on each drum, primary drying unit 3 sponge rolls with 70 cm width and 15 cm diameter. Each roll is suspended on the frame by two bearings. It is driven by sprockets and chain attached with an electrical motor, as one sprocket is fixed on each drum, secondary drying unit consists of conveyor belt with 100 cm length and 70 cm width and blower fan with 0.225 kW (0.3 hp) power and 1500 rpm. Height pyramidal sidewall was fixed 40 cm above the belt, water collecting basin made of galvanized steel sheet of 2 mm thickness was used for the washing process. The basin was located under the washing, cleaning and primary drying units to collect the water from them and power transmission an electrical motor with power of 1.5 kW (2 hp) was used to operate the washing machine. Sprockets and chains were used to transmit the available power from the motor driven shaft to each cylinder used in washing, cleaning, primary and second drying units.



1- Frame. 2- Feeding box. 3- Pressure pump. 4- Pressure gauge.
5- Nozzles. 6- Conveyor belt. 7- Brush rolls. 8- Sponge rolls.
9- Water draining basin. 10- Blower fan. 11- Chain. 12- Collecting box.
Fruits movement direction. Airflow direction.

Fig. 1: Sketch of washing and drying machine.

B) Methods:

The studied variables:

The following variables were tested to show their effect on washing efficiency, surface water removing efficiency, mechanical damage and productivity.

1- Nozzle water pressure: Three different nozzle water-pressures were used: 0. 30, 0.35 and 0.40 MPa (3, 3.5 and 4 bar).
2- Air speed: Three different air-speeds were used: 2, 3 and 4 m/s. (fan speed of 600, 650 and 700 rpm).
3- Operating speed: Three different operating-speeds were used: 0.45, 0.65 and 0.85 m/s (50, 75 and 100 rpm).
4- Number of nozzle: Three different nozzle-numbers were used: 20, 24 and 28.

Physical properties of the fruits:

A random sample of one hundred fruits was taken from mandarin fruits (variety of Ponkan) and potatoes (Diamant variety) to measure their physical properties.

Some Physical properties of mandarin fruits:

The shape of Ponkan mandarin fruits was studied in terms of fruit height (H) and fruit diameter (D) in mm. The digital caliper was used to measure different principal dimensions of fruit.

The following equations were used to calculate sphericity, according to Mohsenin, (1986).

$$\text{Sphericity ratio} = H / D \qquad \text{----------------------(1)}$$

Some Physical properties of potatoes tuber:

Dimensions like length (L), Width (W), and thickness (T) mm, mass of potatoes tubers g, , sphericity (S) %., for potatoeses tubers are reported according to El-Raie et al. (1996) as follows:-

$S = 100*(L\ W\ T)^{1/3} / L$, % ------------------------- (2)

Mechanical properties of the fruits:

Friction-angle measurement:

The fruits of mandarine and potato tubers were placed as a group bounded together on a horizontal surface then the angle of inclination is gradually increased until the fruits begin sliding without rolling. For each fruits group of an average sample (10), the friction angles were determined.

Coefficient of friction:

From friction angle, the coefficient of friction of the sample was estimated according the following equation:

$\mu = \tan\theta$ -------------------------(3)

Where: μ = Coefficient of friction and θ = Friction angle, deg.

Machine performance:

Machine productivity: Was calculated by using the following formula:

$P = 3600\ M / t$ -------------------------(4)

Where: P = Productivity, Mg/h. M = Mass of sample, Mg and
T = Time in seconds.

Washing efficiency: The washing efficiency (M_E) of potatoes tuber and Mandarin fruits was calculated according to Amin et al (2003) as follows:

$M_E = [(M_1 - M_2) / M_1] \times 100$, % -------------------------(5)

Where: M_1 = Mass of sample before washing, g and
M_2 = Mass of sample after washing and drying, g .

Mechanical damage: Percentage of mechanical damage was calculated by using the following formula:

$D_f = (N_d / N_t) \times 100$, -------------------------(6)

Where: N_d = Number of damaged fruits and
N_t = Total number of fruits.

Estimating the costs of using the machine: The operation cost of washing machine was calculated according to the following equation given by Awady, 1978 (updating 1998) modified for electrical motor drive:

C=P/h(1/a+I/2+t+r)+(w.e)+m/144------------------------- (7)

Where: C = hourly cost, P = price of machine, h = yearly working-hours, a = life expected of machine, I = interest rate/year, t = taxes and overhead ratio, w = power of motor in kW,e= hourly cost/kW.h, and m/144 = monthly wage ratio.

Notice that all units have to be consistent to result in " C = LE/h".

Operating cost(LE/Mg)=machine cost(LE/h)/machine productivity (Mg/h)--(8)

RESULTS AND DISCUSSION

1) Physical properties of fruits:

Physical properties of mandarin fruits (variety of Ponkan).

Table 1 shows dimensions, sphericity, mass, volume, bulk and real density, and projected area of Ponkan mandarin fruits. These data were measured for 100 fruit sample, according to the standards set in (Mohsenin, 1986).

Table 1: Physical properties of Ponkan mandarin fruits.

Physical properties	Max.	Min.	Average
Diameter, mm	85.89	55.71	72.15
Height, mm	77.54	44.51	61.10
Sphericity	0.89	0.78	0.81

Dimensions of fruit:

Table 1 shows that the fruit diameter (D) and height (H) ranges of sample were 55.71-85.89 mm (average 72.15 mm) and 44.51-77.54 mm (average 61.10 mm) respectively.

Fig. 1 indicates the percentage of frequency is 50 % at mean fruits height of about 60 mm and mean fruits diameter of about 75 mm with the percentage of frequency 40 % for Ponkan mandarin fruits.

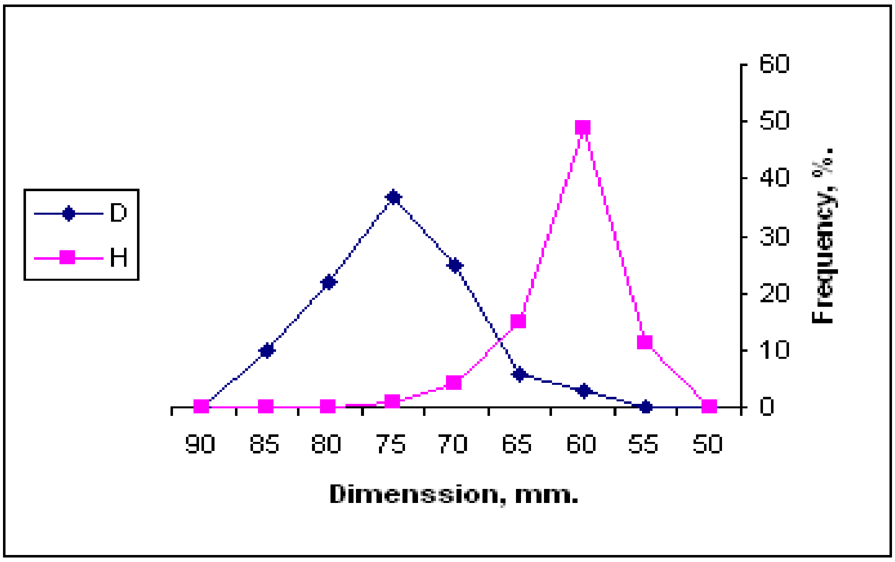


Fig. 1: Frequency curves distribution of mandarin fruits (variety of Ponkan).

Sphericiety:

If sphericiety is less than 0.9, the fruit belongs to oblate group, if it is greater than 1.1 it belongs to oblong group, the remaining fruits with intermediate index values are considered to be round (Buyanov and Voronyuk, 1985). Table 1 indicates that the fruit sphericity ranged between 0.78 and 0.89 % (average 0.81 %) of mandarin fruits (variety of Ponkan). This mean that the studied fruits were an oblate shape.

Physical properties of Diamant potatoes tubers:

Table 2 shows dimensions and sphericity of potato tubers. These data were measured for 100 fruit sample, according to the standards set in (El-Raie 1996).

Table 2: Physical properties of Diamant potatoes tubers variety.

Physical properties	Max.	Min.	Average
Length, mm	130	36.1	82.81
Width, mm	74.34	30.27	51.75
Thickness, mm	65.19	25.44	44.35
Sphericity, %	89.21	55.12	74.02

Dimensions of fruit:

Fig.2 indicates that the percentage of frequency is 51 % at mean length of about 80 mm, mean width of about 60 mm with the percentage of frequency of 45 % and for mean thickness of about 40 mm with percentage of frequency 50 % for potato tubers.

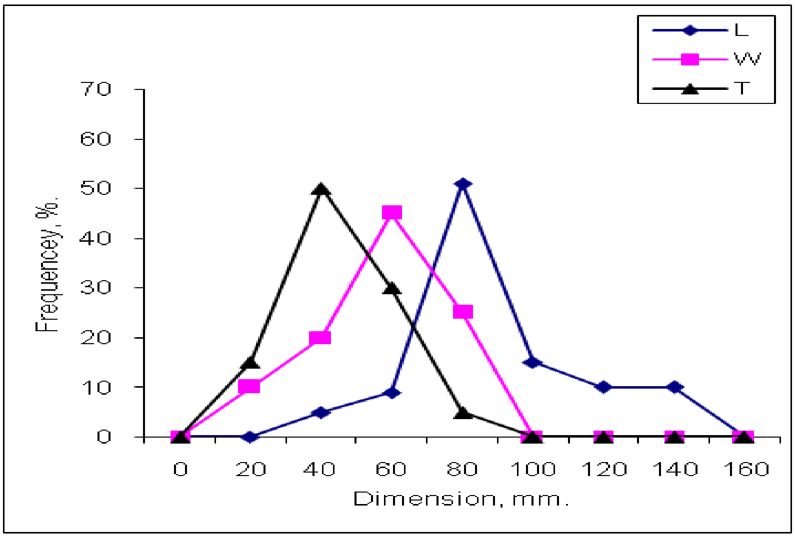


Fig. 2: Frequency curves distribution of fruit dimensions of Potatoes.

Shape and size of fruit:

If sphericity is less than 0.9, the fruit belongs to oblate group; if sphericity is greater than 1.1, it belongs to oblong group. From Table 2, the shape of diamant potatoes variety was described as oblate according to (Buyanov and Voronyuk, 1985).

2) Mechanical properties of the fruits:

Friction angle on galvanized steel surface and rubber surface, coefficient of friction and rolling angle are shown in Table 3.

Table 3: Mechanical properties of mandarin (Ponkan variety) and potatoes(Diamant variety).

Mechanical properties	mandarin (Ponkan variety)	Potatoes (Diamant variety)
Friction angle on galvanized steel surface, (degree)	15.2	18.26
Friction angle on rubber surface, (degree)	19	23
Coefficient of friction on galvanized steel surface	0.27	0.33
Coefficient of friction on rubber surface	0.31	0.42

3) Effect of operating speed and nozzle water-pressure on cleaning efficiency:

Data in Fig.3 shows the effect of operating-speed and nozzle water-pressure on cleaning efficiency at 28 nozzles.

By increasing nozzles water pressure the cleaning efficiency increased in general for Ponkan mandarin and potatoes.

There was a positive cleaning effect by increasing operating speed from 0.45 to 0.65 m/s and a negative cleaning effect of increasing operating speed from 0.65 to 0.85 m/s for Ponkan mandarin and potatoes.

The cleaning efficiency ranged between 86.52 - 98.33 % and 81.90 - 94.40 % for Ponkan mandarin and potatoes respectively,, when nozzle water pressure ranged between 0.30-0.40 MPa (3-4 bar) and operating speed ranged between 0.45-0.85 m/s.

The maximum cleaning efficiency values of 98.33 and 94.40 % were obtained with nozzle pressure of 0.40 MPa (4 bar) and operating speed of 0.65 m/s for Ponkan mandarin fruits and potato tubers respectively.

The increasing of cleaning efficiency is due to the following reasons:

1- Increasing effectiveness of water pressure to clean surface of fruits from undesirable materials.

2- The medium operating speed gave the optimum contact time between fruits and brushes to clean surface of fruits.

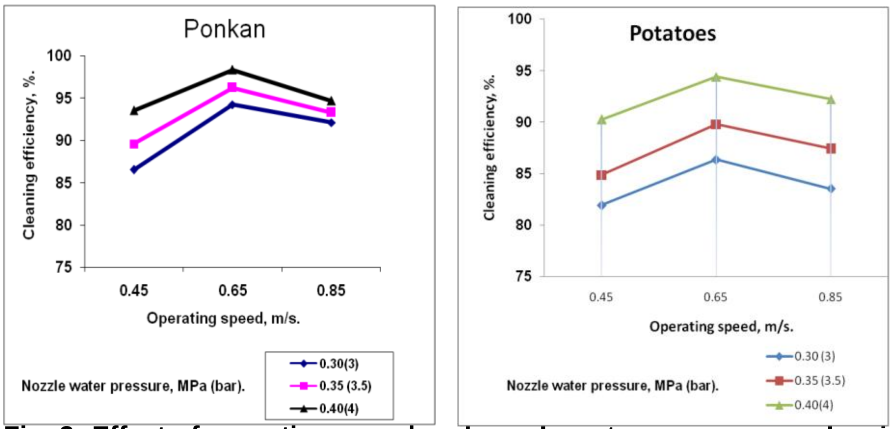


Fig. 3: Effect of operating speed and nozzle water pressure on cleaning efficiency of Ponkan mandarin and potatoes.

4- Effect of number of nozzles on cleaning efficiency at optimum conditions:

Fig. 4 shows the effect of number of nozzles on cleaning efficiency of both mandarin and potato tubers at optimum conditions (operating speed of 0.65 m/s and water nozzle pressure of 0.4 MPa (4 bar).

The cleaning efficiency was found to decrease as the number of nozzle water pressure decreased.

The maximum cleaning efficiencies of 98.33 and 94.40 % were obtained by using 28 nozzles for both Ponkan mandarin and potatoes, whereas, the minimum cleaning efficiencies of 82.11 and 71.19 % was obtained by using 20 nozzles for Ponkan mandarin and potatoes tubers.

The increasing of cleaning efficiency is due to increasing the quantity of water required to clean surface of fruits from undesirable materials.

5- Effect of operating speed of sponge rolls on water removing efficiency:

Fig.5 shows the effect of operating speed on water removing efficiency by sponge rolls at water nozzle pressures of 0.40 MPa (4 bar).

There is a small difference between operating speeds at the range of 0.45 to 0.65 m/s on the removed water efficiency. Whereas, the removed water efficiency decreased by increasing operating speed from 0.65 to 0.85 m/s for all fruits. At lower speeds the increasing of removed water efficiency was due to the best contact time between fruit surface and sponge rolls. Whereas at higher speeds the decreasing of removed water is due to quick fruits passing over the sponge rolls.

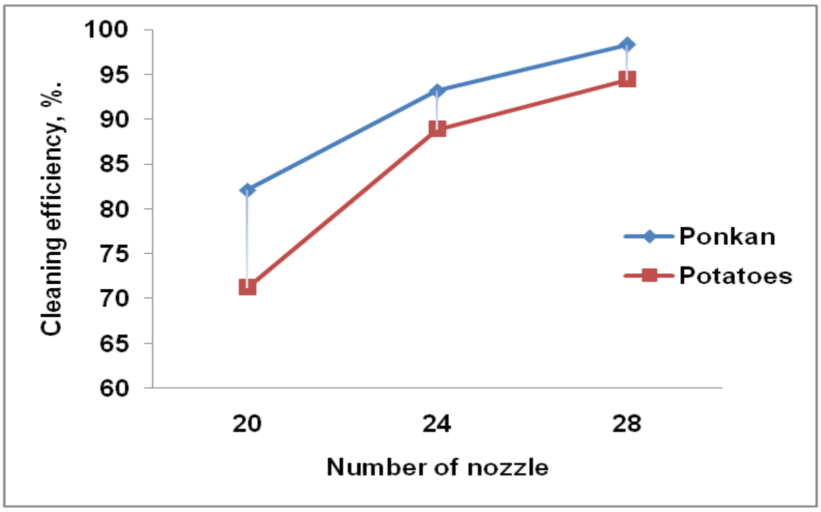


Fig. 4: Effect of number of nozzle on cleaning efficiency at optimum conditions for Ponkan mandarin and potatoes.

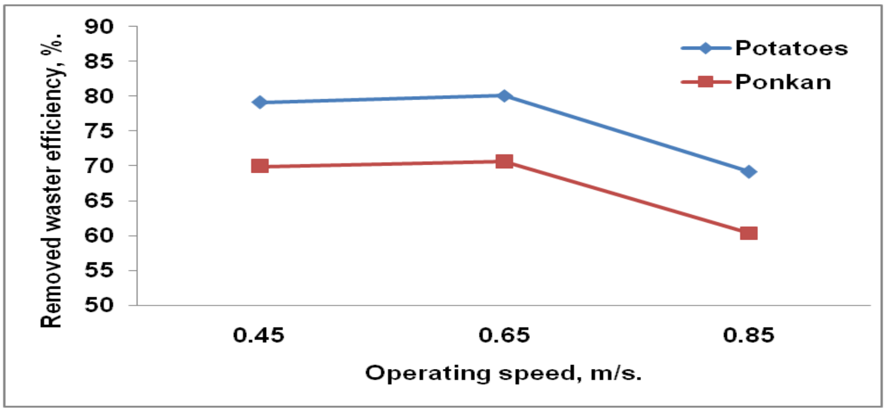


Fig. 5: Effect of operating speed on removed water efficiency by sponge rolls for Ponkan mandarin and potatoes.

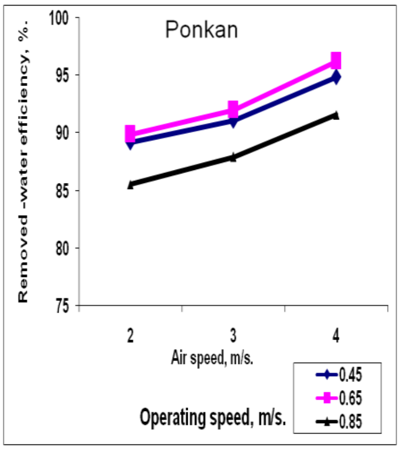
6- Effect of air and operation speeds on removed water efficiency:

Fig.6 shows the effect of air and operating speeds on removed water efficiency at water nozzle pressures of 0.40 MPa (4 bar).

By increasing air speed the removed water increased for Ponkan mandarin and potatoes in general.

There was a positive effect by increasing operating speed from 0.45 to 0.65 m/s and a negative effect of increasing operating speed from 0.65 to 0.85 m/s for Ponkan mandarin and potatoes.

The maximum removed water efficiencies of 96.23 and 97.87 % were obtained with air speed of 4 m/s and operating speed of 0.65 m/s for Ponkan mandarin and potatoes respectively.



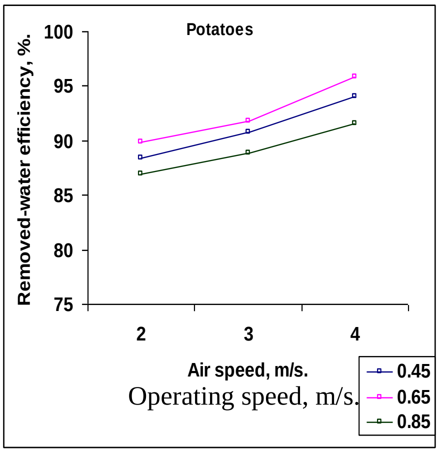


Fig. 6: Effect of air and operating speed on removed water efficiency for Ponkan mandarin and potatoes.

7) Damage of fruits:

Fig. 7 shows the effect of operating speed on mechanical damage at water nozzle pressures of 0.4 MPa (4 bar).

The fruit damage increased by increasing operating speed in general.

By increasing the operating speed from 0.45 to 0.85 m/s the mechanical damage of increased from 0.91 to 2.46 % and from 1.01 to 3.25 %for Ponkan mandarin and potatoes, respectively.

The increasing of fruit damage is due increasing friction among fruits surface and belt and sponge rolls.

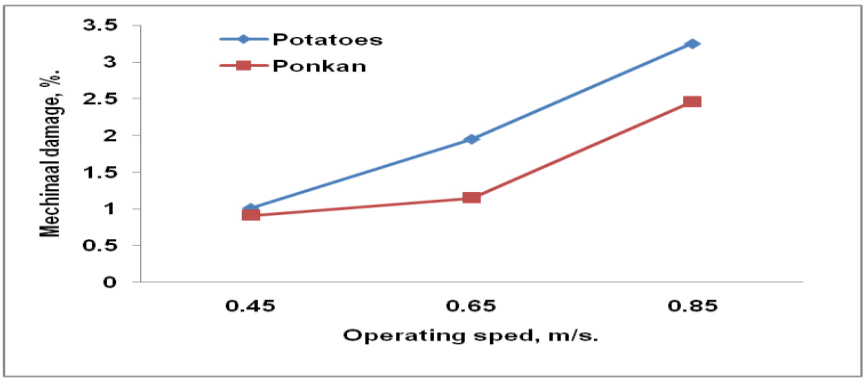


Fig. 7: Effect of operating speed on mechanical damage for Ponkan mandarin and potatoes.

8) Machine productivity:

The highest productivity values was 5.25 and 3.15 Mg/h, for for Ponkan mandarin and potatoes, respectively. These values were obtained by using high operating speed of 0.85 m/s. Meanwhile, the lowest productivity was 2.12 and 1.72 Mg/h. obtained by using low operating speed of 0.45 m/s (fig. 8).

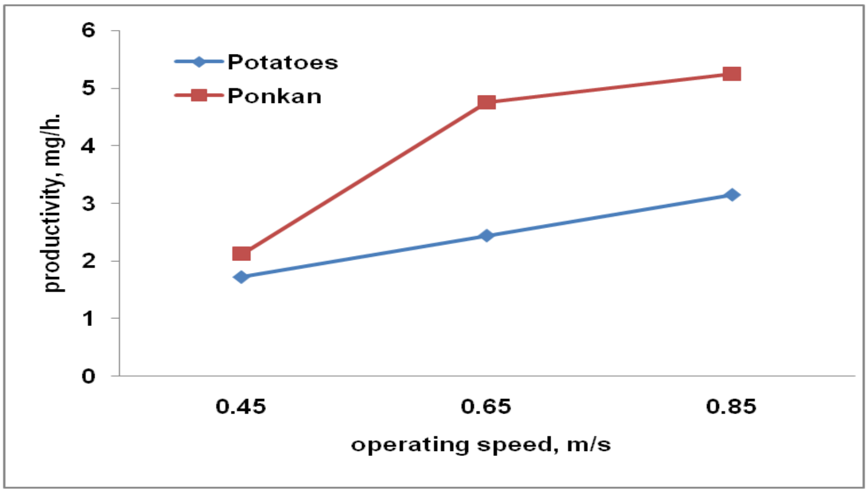


Fig. 8: Effect of operating speed on productivity of potatoes and Ponkan mandarin fruits.

It was found that the acceptable values for cleaning efficiency of 98.33 and 94.40 %, removed water efficiency (by sponge rollers and blower fan) of 96.23 and 97.87 %, achieved fruit damage of 1.15 and 1.95 %, and productivity of 4.75 and 2.44 Mg/h for Ponkan mandarin and potatoes. These values were obtained at operating speed of 0.65 m/s at water nozzle pressures of 0.4 MPa (4 bar), number of nozzles of 28 and air speed of 4 m/s.

9) Estimating the cost:

It was found that the operation costs of the washing machine were 1.92 and 2.47 LE/Mg for washing and drying Ponkan mandarin and potatoes, respectively.

COUNCLUSION

The obtained results from the experiment indicated that the optimum performance of developed washing machine was at operating speed of. 0.65 m/s, nozzles water pressure of 0.4 MPa (4 bar), number of nozzles 28 and drying air speed of 4 m/s .Cleaning efficiencies at these conditions was 98.33 and 94.40 %, removed water efficiency (by sponge rollers and blower fan) of 96.23 and 97.87 %, achieved fruit damage of 1.15 and 1.95 %, and productivity of 4.75 and 2.44 Mg/h for Ponkan mandarin and potatoes.

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دراسات هندسية على تنظيف بعض الثمارالبستانية

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يتناول هذا البحث دراسة العوامل المؤثرة فى كفاءة عملية غسيل وتنظيف الثمار وإزالة الماء من الثمار بعد عملية الغسيل وتقدير نسبة التلف الميكانيكي للثمار وحساب تكاليف التشغيل وتقدير الإنتاجية، وذلك للخروج بتصميم مناسب واقتصادي ملائم مع ظروفنا المحلية والتوصيات بأفضل عوامل تشغيل على نوعين من المحاصيل التصديرية الهامة فى مصر وهما البطاطس (صنف ديامونت) **ثمار اليوسفى الصينى.**كما تم دراسة بعض الخصائص الطبيعية والميكانيكية لهذه الثمار.

وقد تم تقييم أداء الآلة بتشغيلها بمتغيرت دراسية هى:-

- ضغط رشاشات الماء : 3، 3.5، 4جوى (0.30، 0.35، 0.40 ميجاباسكال)
- سرعة التشغيل: 0.45، 0.65، 0.85 م/ث (50، 75، 100 ل/د).
- سرعة هواء التجفيف: 2، 3، 4 م/ث (600، 650، 700 ل/د).
- وعدد الرشاشات 20، 24، 28 رشاشا.

وكانت النتائج المتحصل عليها كالآتى:

- أوضحت النتائج إمكانية استخدام آلة الغسيل الميكانيكية (محل الدراسة) فى غسيل ثمار اليوسفى والبطاطس. حيث أعطت أعلى نسبة النظافة 98.33، 94.40 ٪، وكفاءة التجفيف بواسطة البكرات الإسفنجية والهواء 96.23، 97.87٪، ونسبة التلف الميكانيكي 1.15، 1.95٪ وتكلفة التشغيل 1.92 ،2.47 جنيها/ميجاجرام ، الإنتاجية4.75 ، 2.44 ميجاجرام /ساعة لكل من ثمار اليوسفى والبطاطس على الترتيب.
- وجد آن انسب ظروف لتشغيل الآلة هى سرعة التشغيل 0.65 م/ث،45. م/ث ضغط الرشاشات 40. 35 . ميجاباسكال وسرعة هواء التجفيف 4 م/ث، وعدد الرشاشات 28 رشاشا. وذلك للحصول على كفاءة تنظيف عالية وأقل تلف ميكانيكي لثمار اليوسفى والبطاطس على التوالى .