



Design and Development of Fruit Washer

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Authors' contributions

This work was carried out in collaboration between all authors. Author SAA is the principal investigator of the research, he coordinated the equipment testing, he did statistical analysis and put up the research report for publication. Author SKA supervised the implementation of the research. Author AOK is the co – supervisor on the project. Author MOS did engineering design analysis of the equipment. Author CFN did engineering drawing. Author AAO coordinated the implementation of the design. All authors read and approved the final manuscript.

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ABSTRACT

It has been observed that washing of fruits are mostly done manually. This method involves a lot of drudgery which is inefficient and time consuming. Hence, there is a need to mechanize this process for ease of operation and maintenance of hygiene. An attempt has been made to develop a fruit washer which is conceptualized to wash a range of fruits based on roundness or spherical shape. These fruits are orange, mango, apple, pineapple pawpaw, cashew and passion fruits. The machine is designed with essential components being the feed hopper, roller brushes, stainless tank, top cover, water jet system, control valve, chain drive, bearings, main frame and discharge outlet. The machine has been developed with the locally available materials powered by 3hp electric motor. Test carried out on the machine successfully revealed that the washing efficiency and the machine capacity were 89.73% & 480.57 kg/h respectively for orange and 90.16% & 326.63 kg/h respectively for pineapple.

Keywords: *Fruit washer; fruits; development; washing efficiency; machine capacity.*

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1. INTRODUCTION

Washing is an important primary process unit operation, for removing dirt, harmful chemicals, extraneous materials and surface microbial load from food items such as fruits and vegetables prior to consumption, preparation or further processing for value addition. Washing is highly necessary in order to improve product appearance, edibility, quality and hygiene. Washers may be of continuous type or batch type. The batch type washer is recommended only for small plants or community installations. Presently the fruits are being washed by one or the combination of various washing methods by manually or mechanically [1].

Water and probably soap is required to accomplish washing operation and only potable water is used in food operations. Potable water is the drinking water that is wholesome and clean and does not cause illness. It is free from any micro-organisms and parasites and from any substances that in numbers and concentrations constitute a potential danger to human health. Hence, water sanitizer is often added to the wash water. According to WHO [2], water with a turbidity of ≤ 5 NTU is required for washing in food processing operation.

The purpose of washing is to remove residues of field-applied chemicals harmful microorganisms that would shorten the life of the product [3,4]. Contamination of fruits and vegetables is generally due to unsanitary cultivation and marketing practices [5]. Produce wash is an important process employed commonly by the industry to remove soil and debris and to reduce microbial populations [6]. In general, the rate of microbial reduction is affected by the type of sanitizers used [7], the mechanical force of washing [8] and the affinity of microorganisms with the produce surfaces [9], as well as the combination of all these factors.

Papadopoulou et al. [10], mention that the clarity of the water which is affected by the concentration of suspended particles is a measure of its quality. Drinking water should have a turbidity of ≤ 5 NTU [11]. The WHO (2004) (World Health Organization), [3] established that the turbidity of drinking water should not be more than 5 NTU (Nephelometric Turbidity Units), and should ideally be below 1 NTU. Turbidity is an expression of the optical property of a medium, which causes light to be scattered and absorbed rather than transmitted

straight through a sample. The medium concerned is usually water in which light is scattered by suspended particles. Turbidity is defined by the International Standards Organization (ISO) as the "reduction of transparency of a liquid caused by the presence of undissolved matter". It is measured using the techniques of turbidimetry or nephelometry and is expressed in arbitrary units NTU (Nephelometric Turbidity Units). The direct relationship between turbidity data and suspended solids concentration depends on many factors, including particle size distribution, particle shape and surface condition, refractive index of the scattering particles and of the suspension medium and wavelength of the light [12].

Adequate cleaning is a critical operation in the production and distribution of fresh produce. It has been observed that washing of fruits and vegetables are mostly done manually, at domestic and commercial level. This method involves a lot of drudgery; time and also tedious and unhygienic. Hence, efforts should be made to mechanize the washing operation for ease of the operation and maintenance of hygiene. Hence, the development of fruit washer will be a major breakthrough in this unit operation. Therefore the objective of this work was to design, develop and evaluate a fruit washer for washing of fruits suitable for small to medium scale fruits processors.

2. MATERIALS AND METHODS

2.1 Description of Fruit Washer

The fruit washer is designed to wash some selected fruits based on their shape viz., round and spherical shape. These fruits are orange, apple, mango, pineapple pawpaw, cashew and passion fruits etc. The equipment consists of the feed hopper, the roller brush, top cover, stainless (water tank), main frame, water jets system, control valve, discharge outlet and 3hp electric motor. According to Fig. 1. No 1: delivery chute; 2: water jetting pipe; 3: top brush; 4: frame; 5: roller brush; 6: chain drive; 7: gear electric motor; 8: hopper. There are nine roller brushes which were made up of 110mm diameter PVC plastic pipe and rubber fibrous materials for brushing action. These roller brushes are mounted on nine stainless shafts which are also in turn mounted on the machine frame with two self-aligning pillow bearings at both ends for better support. The fruits are fed into the equipment through the

feed hopper onto the roller brushes. The roller brushes are partially immersed in water in the water tank which is the washing chamber where the washing is accomplished. The roller brushes also convey the products to the discharge chute. The washer is powered by the 3hp electric motor. The diagram of the fruit washer is shown in Plate 1.

2.2 Design Consideration

While designing the machine, the following parameters were taken into consideration: high

washing efficiency and machine capacity, quality and hygiene of the products, availability and cost of fabrication materials. Other Design consideration were using food grade materials such as stainless steel, PVC plastic pipes and Fibrous brushes to ensure safety and quality of products such as presented in the appendix; to design the roller based on the diameter of the product which shall ensure thorough washing of products (orange) whose diameter was used as an average and to ensure the conveyance of the products to the discharge chute. The fruit washer was designed according to standard procedures.



Plate 1. Fruit washer

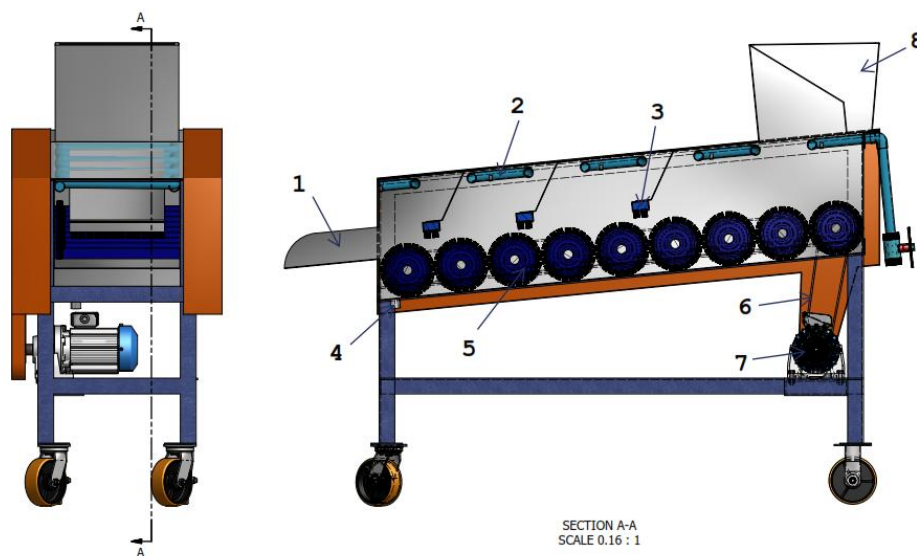


Fig. 1. The section view of the fruits and vegetables washers

2.2.1 Design of the chain drive

To determine the number of teeth of the Driven Sprocket Z_2 , the following relation was used:

$$Z_2 = Z_1 n_1 / n_2, \quad (1)$$

Where n_2 = Speed of driven sprocket = 5, n_1 = Speed of driving sprocket = 10, Z_1 = No of teeth of driving sprocket = 11, Z_2 = 22 teeth.

2.2.2 Design of driving sprocket diameter

This was determined using the following standard formula:

$$D_1 = P / \sin(180/Z_1) \quad (2)$$

Where D_1 = Diameter of the driving sprocket (45.09mm), P = Pitch of the driving sprocket = Chain Pitch = $0.31n = 12.7$ mm (Given from roller chain Table) and n = Speed of the Driving Sprocket $n_1 = 10$ rpm.

Also, the Driven Sprocket Diameter

$$D_2 = P / \sin(180/Z_2) = 89.25\text{mm}$$

2.2.3 Determination of centre distance between the sprockets

In practice, the durable Centre Distance is between 30-50 Chain Pitch.

$$30p < a < 50p.$$

For this design 40p is selected. Therefore, $a = 40p = 40 \times 12.7 = 508$ mm [rough estimate]. To calculate the exact value of (a):

Calculate the Chain Link (ln)

$$ln = \frac{(a/p) + [(Z_1+Z_2)/2 + (Z_1-Z_2)/2 + (Z_2-Z_1)^2 / 2\pi \times P/a]}{(3)} \quad (ln = 96.58 \text{ links})$$

$$\therefore a = P/4 \{ [ln - (Z_1 + Z_2)/2] + \sqrt{ [ln - [(Z_1 + Z_2)/2]^2] - 8[(Z_2 - Z_1)/2\pi]^2} \} \quad (4)$$

$$a = 506.98 \text{ mm (centre distance)}$$

Note: Small sag is essential for links to take the best position on the sprocket wheel. Thus, the centre distance is reduced by a margin $(0.002 - 0.004) \times a$, so as to account for the sag. Hence, the correct centre distance is given by

$$a = 0.998 \times 506.88 = 505.9 \Rightarrow 506\text{mm}$$

2.2.4 Determination of tension on the shaft due to chain

The velocity of the sprocket is given by

$$V = (Z_1 \times P \times n_1) / 60 \times 10^3 \quad (5) \quad (V = 0.023 \text{ ms}^{-1})$$

Tension due to chain T_1

$$T_1 = (1000\text{kW})/V \quad (6)$$

Where kW = kilowatt rating of Electric motor.

kW rating of Electric motor = [kW (rating of the chain)] / $K_s \times k_1 \times k_2 = 13.08\text{kW}$

Where $k_1 = 1.0$ (Multiple strand factor), $K_2 = 0.57$ (Tooth correction factor) for 11 teeth sprocket. From table, through interpolation, $K_s = 1.3$ (Service factor for moderate shock) and kW (chain) = 40 Hp (From chain rating table) = 29.84 kW

2.2.5 Tension due to the chain is given by

$$T_1 = (1000\text{kW})/V = 568,856\text{N}$$

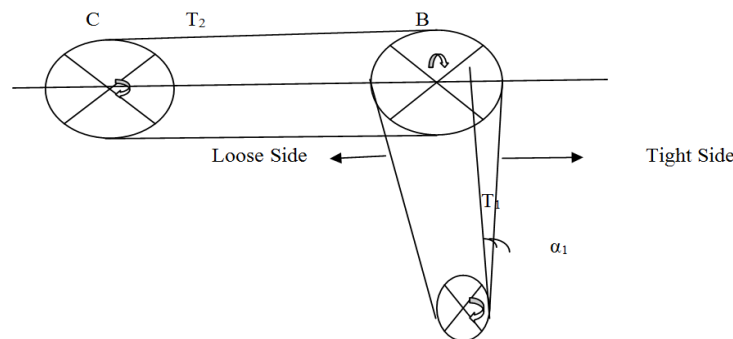


Fig. 2. Chain drive lay out

2.2.6 Determination of the load on the shaft

From Fig. 1 Resultant Tension on the shaft is given by:

$$\sin \alpha = (D_B - D_A) / 2a \quad (7) \quad (\sin \alpha = 0.04363)$$

Where D_B = Diameter of sprocket B = 89.25, D_A = Diameter of sprocket A = 45.1,

$$a = c - c = 506 = \text{Distance between A and B}$$

$$\therefore \alpha = \sin^{-1} 0.04363 = 2.5^\circ$$

Vertical component of T_1 (T_y)

$$T_y = T_1 \sin \alpha \text{ [on the tight side]} \quad (8) \quad (T_y = 24.819.2\text{N})$$

Horizontal component of T_1 (T_x)

$$T_x = T_1 \cos \alpha \text{ [on the tight side]} \quad (9)$$

$$(T_x = 568,856 \cos 2.5^\circ = 568,315\text{N})$$

On the loose side of sprocket A and B

The Tension = 0 [By convention].

2.2.7 The power transmitted by sprocket B on sprocket C

The chain velocity is given by

$$V = Z_2 \times P \times n_2 / 60 \times 10^3 \quad (10) \quad (V = 0.02328\text{ms}^{-1})$$

Where, Z_2 = number of teeth of sprocket B = 22, P = Chain Pitch = 12.7 & n_2 = speed of sprocket B = 5ms^{-1}

Tension due to the chain T_2

$$T_2 = (1000\text{kW}) / V = (1000 \times 13.08) / 0.023 = 568,856\text{N}$$

$$\sin \alpha = (D_C - D_B) / 2a = 0 / (2 \times 506) = 0, \text{ hence, } \alpha = \sin^{-1} 0 = 0$$

The vertical component of T_2

$$T_y = T_2 \sin \alpha \text{ [on the tight side]} = 568,856 \times 0 = 0\text{N}$$

Horizontal component of T_2

$$T_x = T_2 \cos \alpha = 568,856 \cos 0 = 568,856\text{N}$$

On the loose side of T_2 ; The Tension = 0N (by convention.)

Resolving the horizontal component of the T_1 and T_2

Since they move in the opposite direction, we have

$$\text{Overall Resultant Tension } T_R = \sqrt{(T_y)^2 + (T_x)^2} \quad (11)$$

$$(T_R = 24,825\text{N})$$

2.2.8 Shaft design

Design Specification

$$T_{\max} = 0.3 f_{yt} \quad (12)$$

$$(T_{\max} = 0.3 \times 460\text{N/mm}^2 = 138\text{N/mm}^2)$$

$$T_{\max} = 0.18 f_{ut} \quad (13)$$

$$(T_{\max} = 0.18 \times 700 = 126\text{N/mm}^2)$$

This is the lower value, hence it is selected. Since there is key ways on the shafts, 25% of the shear stress is considered according to standard. Therefore, $\tau_{\max} = 0.25 \times 126\text{N/mm}^2 = 31.5 \times 10^{-6}\text{N/m}^2$

Maximum Torque (M_t) transmitted by the shaft is determined using the following relation.

$$M_t = (60 \times 10^2 \times \text{kW}) / 2\pi n_1 \quad (14)$$

$$(M_t = 28.49\text{N/m}^2)$$

From Fig. 2. The analysis of the forces acting on the shafts are explain as thus:

$$R_A + R_B = 28.83 + 0.027 \times 40 = 29.91$$

Taking moment about R_A

$$28.83 \times 10 + (-0.027 \times 40 \times 25) + R_B \times 50 = 0$$

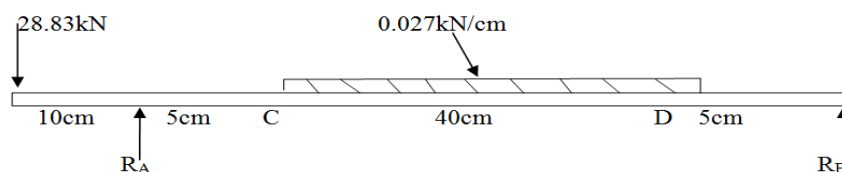
$$R_B = -261.3 / 50 = -5.23\text{kN}$$

$$R_A = 29.91 - (-5.23) = 35.14\text{kN}$$

$$R_o = 28,83\text{kN}, \text{ therefore } F_o = 28.83\text{kN}$$

$$F_A = R_A = 35.14 - 28.83 = 6.31\text{ kN}, \text{ Also, } F_C = 6.31\text{kN}$$

$$F_B = R_B = -5.23\text{kN}$$



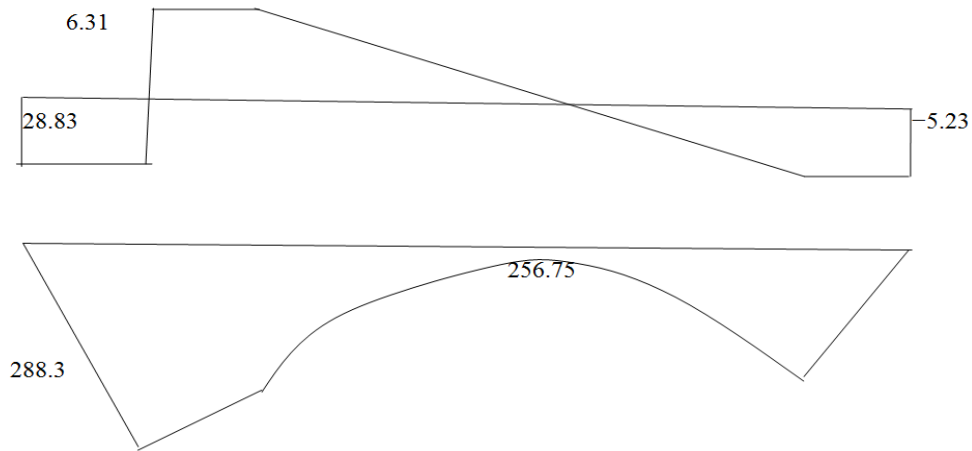


Fig. 3. Shear force and bending moment diagram

$x/6.31 = (40 - x)/ 5.23$ (x is determined through interpolation)

Therefore $x = 21.87\text{cm}$

$M_A = 288.3 - 35.14 \times 5 = 256.75$ (bending moment at point A)

$M_E = 256.75 (20 + 21) - 0.027 \times 21.37 \times (21.87)/2 = 10.52 \text{ kNm}$ (bending moment at point E)

M_E is the point where the maximum bending moment occurred.

$$d^3 = 16/ \pi \tau_{\max} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (15)$$

Where $K_b = K_t = 1.5$, $M_b = 10.52 \text{ kNm}$, $M_t = 28.49 \text{ N/m}^2$

$d = 0.019\text{m} = 19\text{mm} = 20\text{mm}$.

Therefore 20mm or 25mm shaft is recommended. (There are nine of this shaft).

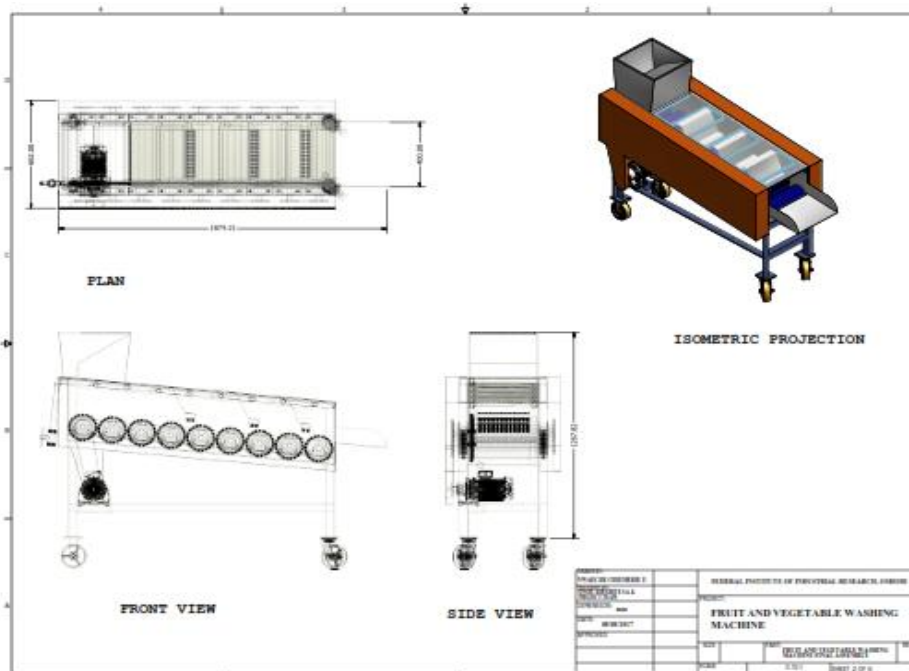


Fig. 4. The orthographic and the (3D) isometric view of the fruit washer

2.3 Performance Evaluation

Oranges and tomatoes were bought from Oshodi market, Lagos, Nigeria. The products were simulated to field condition by introducing more dirt onto the products by immersing them into muddy water. The products were then left for about 14 hours to allow them to dry. Masses of 6, 8 & 10 kg of each of these products were weighed and fed into the equipment for washing operation. Another set of 6, 8 & 10 kg of each of these products were weighed and washed by hand (manually). The weight of the cleaned products was noted and recorded. The time taken for the washing was noted and recorded. 50ml of samples of clean water and washed water for each of the washing methods was taken. These water samples were analyzed for turbidity in the FIRO analytical laboratory. The performance indices evaluated were washing efficiency and washing capacity. Method of turbidity was used to determine the washing efficiency according to equation 2 while the washing capacity was determined according to equation 1.

2.3.1 Machine washing capacity

The Washing capacity was determined as follows:

$$C = M \times 60 / T_w \text{-----(16)}$$

C = Washing Capacity of the machine (Kg/h)

M = Mass of the product fed into the machine(Kg)
T_w = Washing Time(min)

2.3.2 Machine washing efficiency

The Washing Efficiency was determined by using turbidity method according to Al-Katary et al., [13] as follows:

$$W_E = T/t \times 100\% \text{----- (17)}$$

Where *W_E = Machine Washing Efficiency (%)*

T = Turbidity ratio in water after washing by machine, NTU for 1Kg fruit / 1 litre of pure water

t = Turbidity ratio after washing by hand, NTU for 1Kg fruit / 1 litre of pure water

2.3.3 Analysis of turbidity

After completion of washing process samples of the washed water was collected for 1 liter per 1 kg fruit that was washed by the machine and the sample of the washed water of 1 liter per 1 kg fruit that was washed by hand method.

2.4 Data Analysis

Analysis of variance by the GLM procedure (SAS/STAT software version 9.4) was used to assess differences in treatment for both tomato and orange (turbidity of product type, mass of the product fed into the equipment and time of washing). Duncan Multiple Range Test was used to separate the means at P=0.05.

3. RESULTS AND DISCUSSION

The mean operating parameters of the machine performance for the washing of tomato and orange using manual and mechanized method are presented in Appendix 1. The turbidity for machine washed water samples ranged from 119.50 NTU to 134.2 NTU for tomato, while that of orange ranged from 125.00 NTU to 138.00 NTU h for orange. The turbidity of manual washed water samples ranged from 139.20 NTU to 152.70 NTU for tomato while that of orange ranged from 138.50 NTU to 152.70 NTU as shown in Figures 4a and 4b. The turbidity of the cleaned water used fall within the international standard as shown in Table 1.

Table 1. Turbidity of washed water samples for tomato and orange

Turbidity (NTU)	Product type					
	Tomato			Orange		
WHO Standard	≤ 5 NTU	≤ 5 NTU	≤ 5 NTU	≤ 5 NTU	≤ 5 NTU	≤ 5 NTU
Clean Water	1.07 ± 0.09	1.07 ± 0.09	1.07 ± 0.09	1.07 ± 0.09	1.07 ± 0.09	1.07 ± 0.09
Mass (Kg)	6.00	8.00	10.00	6.00	8.00	10.00
Machine	125.0	134.0	138.0	119.5	134.2	129.3
Manual	139.2	148.4	152.7	138.5	145.6	142.5

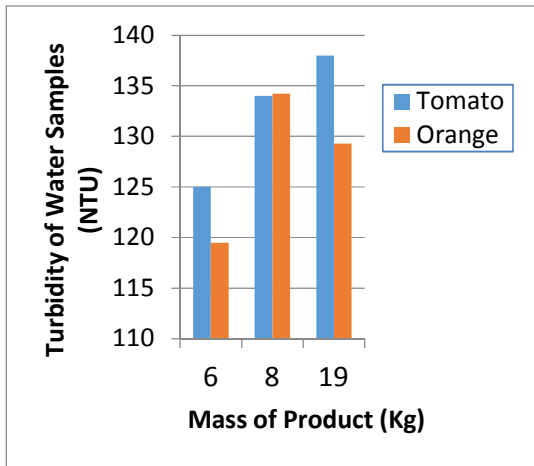


Fig. 4a. Turbidity of machine washed water

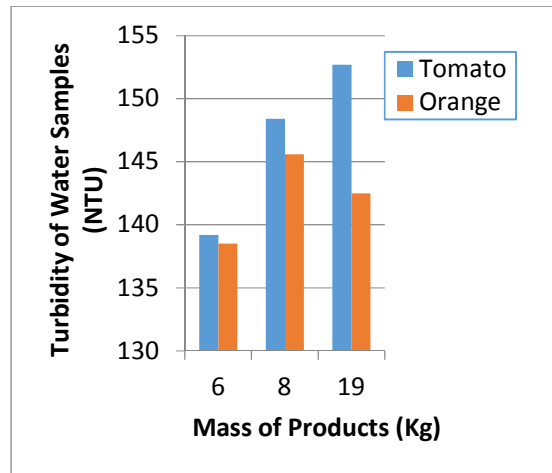


Fig. 4b. Turbidity of manually washed water

The washing efficiency for tomato ranged from 89.80 to 90.37% with a mean value of 89.73% while that of orange ranged from 86.28 to 92.17% with a mean value of 90.16% as shown in Fig. 5. These range of values of the washing efficiency for both products are closely related; hence, the equipment is very suitable for fruits and vegetables products with round or spherical shape. Al-Katary *et al.*, (2010), [13], reported washing efficiency of 90 to 92.4 % for Navel Orange and Nicola Potato. Kenghe *et al.*, 2015 [1] reported washing efficiency of 96.36 to 98.18 % for small scale mechanical fruits washer for potato. Thus the performance of this design compared favorably with the existing mechanical fruits washing equipment.

water samples) on washing efficiency and (mass of the products, and time of washing) on capacity for both tomato and orange is presented in Table 2. The analysis of variance shows that all the variables were not significantly different at all.

The machine capacity ranged from 276.92 Kg/h to 320.00 kg/h for tomato, while that of orange ranged from 437.25 Kg/h to 517.99 Kg/h for orange. The capacity of manual method of washing ranged from 57.97 Kg/h to 67.92 Kg/h for tomato while that of orange ranged from 54.55 Kg/h to 64.00 Kg/h as shown in Figs. 6 a and 6 b. These values of capacity have justified the use of the developed fruits & vegetables washer to replace manual method of washing these products.

Statistical analysis of the effect of operating parameters (mass of products and turbidity of

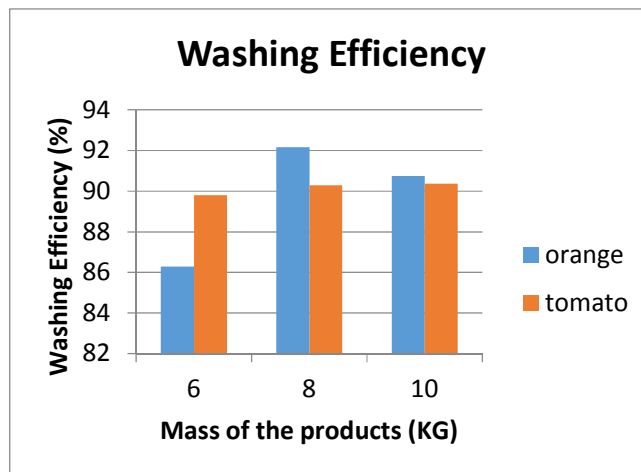


Fig. 5. Washing efficiency of tomato and orange against the mass of products

Table 2. ANOVA for the performance of the fruits & vegetables washer

Parameter	Source	DF	Type I SS	Mean square	F value	Pr > F
Washing efficiency	Tomato	3	11362.40	3787.47	0.20	0.90
	Orange	3	6995.50	2331.83	0.08	0.97
	Error	41	786184.00	19175.20		
Capacity (Tomato)	Wash. Mtd	1	4118.14	4118.14	0.21	0.65
	Rep	2	7244.28	3622.14	0.19	0.83
Capacity (Orange)	Wash. Mtd	1	440.08	440.08	0.02	0.90
	Rep	2	6555.41	3277.71	0.12	0.89

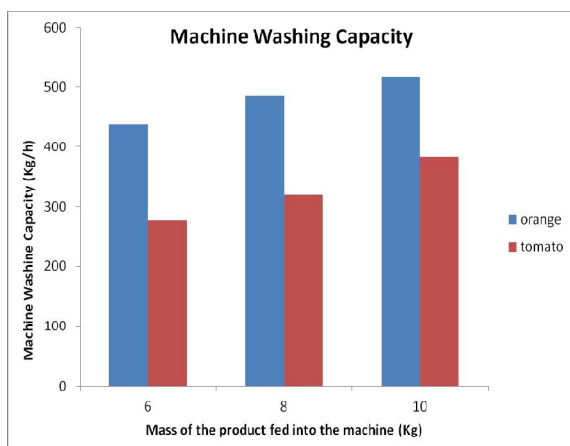


Fig. 6a. Machine capacity against product mass.

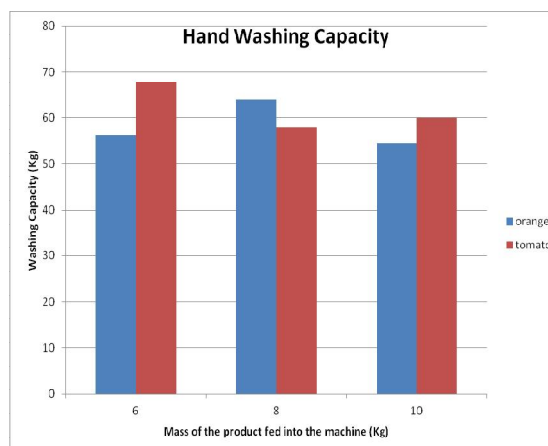


Fig. 6b. Manual capacity against product mass

4. CONCLUSION

A small scale fruit washer was developed and tested for tomatoes and oranges. The preliminary tests carried out on the prototype indicate a satisfactory performance. The machine capacity for both products indicates that the equipment is suitable for medium to large scale operations. Hence, the adoption of this equipment will go a long way to assist food processors in providing safe food at affordable price. However, the performance of the equipment could be improved, especially with respect to increasing the washing efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix 1. Machine operating parameters

Prod	Indices	Washing method	N Obs	Mean ± SD	Max	Min
Orange	Mass of prod. fed into m/c	Mechanized	3	8.00 ± 2.00	10.00	6.00
		Manual	3	8.00 ± 2.00	10.00	6.00
	Turbidity of H ₂ O sample	Mechanized	3	127.67 ± 7.48	134.20	119.50
		Manual	3	142.2 ± 3.56	145.60	138.50
	Time of washing	Mechanized	3	59.37 ± 10.05	69.50	49.40
		Manual	3	498 ± 144.13	660.00	384.00
Capacity	Mechanized	3	480.57 ± 40.69	517.98	437.25	
Tomato	Washing Efficiency	Manual	3	58.27 ± 5.04	64.00	54.55
		Mechanized	3	89.73 ± 3.07	92.17	86.28
	Mass of prod. fed into m/c	Mechanized	3	8.00 ± 2.00	10.00	6.00
		Manual	3	8.00 ± 2.00	10.00	6.00
	Turbidity of water sample	Mechanized	3	132.33 ± 6.66	138.00	125.00
		Manual	3	146.77 ± 6.90	152.70	139.20
	Time of washing	Mechanized	3	87.33 ± 8.33	94.00	78.00
		Manual	3	498.00 ± 144.13	660.00	384.00
	Capacity	Mechanized	3	326.63 ± 53.34	382.98	276.92
		Manual	3	61.97 ± 5.26	67.92	57.97
Washing Efficiency	Mechanized	3	90.16 ± 0.31	90.37	89.80	

Appendix 2. Testing of the fruit washer



Product before and after machine wash

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