Design and **Development of Fruits Washer**

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 the need to mechanize this process for ease of the operation and maintenance of hygiene. An attempt has been made to develop a fruits washer which is conceptualized to wash a range of fruits based on roundness or spherical shape. These fruits were orange, mango, apple, pineapple pawpaw, cashew and passion fruits. The machine is designed with an essential components being the feeding hopper, roller brushes, stainless tank, top cover, water jets system, control valve, chain drive, bearings, main frame and discharge outlet. The machine which was developed using locally available materials was powered by 3hp geared electric motor. Test carried out on the machine successfully revealed that the washing efficiency and the machine capacity were 89.73% & 480.57 kg/hr for orange and 90.16% & 326.63 kg/hr for pineapple**.**

Keywords: Fruits and vegetables washer, fruits, development, washing efficiency, machine capacity.

1.0 Introduction

Washing is a an important primary process unit operation, for removing of dirt's, harmful chemicals, extraneous materials and surface microbial load from food items such as fruits and vegetables prior to eating, preparation or further processing for value addition. Washing is highly necessary in order to improve product appearance, edibility, quality and hygiene. Washers may be 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 (Kenghe et. al., 2015).

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. Water with a turbidity of ≤ 5 NTU (WHO, 2004) 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, (Hassan, 1988) and (Hossain et al.,

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1991). Contamination of fruits and vegetables is generally due to unsanitary cultivation and marketing practices (Singh et. al., 1995). Produce wash is an important process employed commonly by the industry to remove soil and debris and to reduce microbial populations (Simons et. al., 1997). In general, the rate of microbial reduction is affected by the type of sanitizers used (Fatemi et. al., 2006), the mechanical force of washing (Younis et. al., 2005), and the affinity of microorganisms with the produce surfaces (Gonzalez et. al., 2004), as well as the combination of all these factors. (Wang et. al., 2007)

Papadopoulou et al., (1998) 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 (Davis et al., 2002). The WHO (2004) (World Health Organization), 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 (Lawler, 1995).

Adequately 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, domestically and commercially. This method involves a lot of drudgery; it is time consuming, tedious and lends itself to health hazard for the operator and sometimes may be unhygienic. Hence, efforts should be made to mechanize the washing operation for ease of the operation and maintenance of hygiene. Hence, the development of fruits and vegetables washer shall be a major breakthrough in this unit operation**.** Therefore the objective of this work was to design, develop and test a fruits washer for washing of fruits for small to medium scale fruits processors.

2.0 Description of the fruits and vegetables washer

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The fruits washer is designed to wash some selected fruits based on round and spherical shape. These fruits are orange, apple, mango, pineapple pawpaw, cashew and passion fruits etc. The equipment consists of the feeding hopper, the roller brush, top cover, stainless (water tank), main frame, water jets system, control valve, discharge outlet and 3hp electric gear motor. There are nine roller brushes which were made up of 110mm diameter PVC plastic pipe and rubber fibre materials as brush. 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 feeding the hopper onto the roller brushes. The roller brushes which 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 gear motor via the chain drive. The fruits and vegetables washer is as shown in Plate 1.

Plate 1. Fruits and vegetables washer

2.1 Design consideration

While designing the machine, considerations included: high washing efficiency and machine capacity, quality and hygiene of the products, availability and cost of fabrication materials. Other considerations included the desire to make the main components with food grade materials such as stainless steel, PVC plastic pipes and fibre brush to ensure safety and quality of products; to design the roller brushes 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. Also considered was a strong main frame to ensure structural stability and strong support for the machine.

2.1.1 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.

2.1.2 Design of Driving Sprocket Diameter

This was determined using the following standard formula:

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

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

Also, the Driven Sprocket Diameter

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

2.1.3 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 = 40×12.7 = 508mm [rough estimate].

To calculate the exact value of (a):

Calculate the Chain Link (ln)

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

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

a = 506.98 mm (centre distance)

NOTE: Small sag is essential for links to takes the best position on the sprocket wheel. Thus, the centre distance is reduced by a margin (0.002 – 0.004) × a, so as to account for the sag. Hence, the correct centre distance is given by

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

2.1.4 Determination of Tension on the shaft due to chain

The velocity of the sprocket is given by

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

Tension due to chain T_1

$$T_1 = (1000kW)/V \qquad (6)$$

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Where kW = kilowatt rating of Electric motor.

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

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

2.1.5 Tension Due to the chain is given by

T_1 = (1000kW)/V = 568,856N

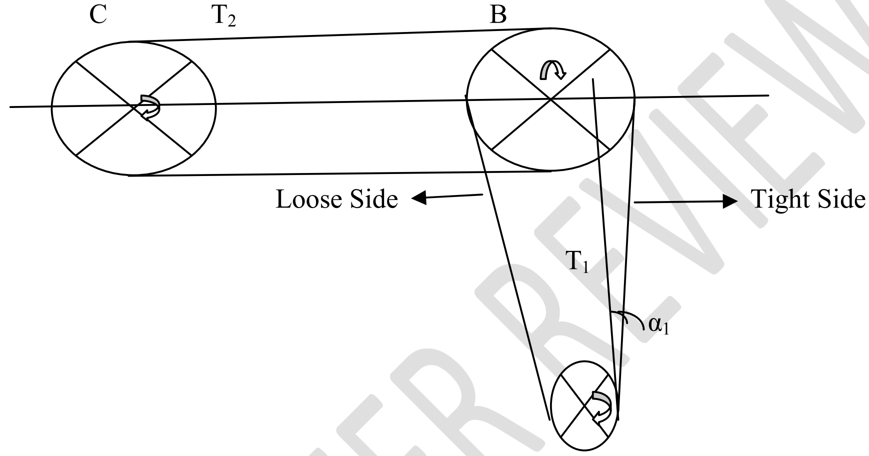

Figure 1. Chain Drive lay out

2.1.6 Determination of the load on the shaft

From Figure 1 Resultant Tension on the shaft is given by:

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

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

a = c – c = 506 = Distance between A and B

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

Vertical component of T_1 (T_y)

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

Horizontal component of T_1 (T_x)

$T_x = T_1 \text{Cosx}\ \alpha$ [on the tight side] (9) (T_x = 568,856Cos 2.5^o = 568,315N)

On the loose side of sprocket A and B

The Tension = 0 [By convention].

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2.1.7 The Power Transmitted by sprocket B on sprocket C

The chain velocity is given by

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

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

Tension due to the chain T_2

$T_2 = (1000kW)/V = (1000 \times 13.08)/0.023 = 568{,}856N$ $\sin \alpha = (D_C - D_B)/ 2a = 0/ (2 \times 506) = 0$, hence, $\alpha = \sin^{-1} 0 = 0$

The vertical component of T_2

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

Horizontal component of T_2

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

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

Overall Resultant Tension $T_R = \sqrt{(T_y)^2 + (T_x)^2}$ (11) (T_R = 24,825 N)

2.1.8 Shaft Design

Design Specification

$\tau_{max} = 0.3\int_{yt}$ (12) ($\tau_{max} = 0.3 \times 460N/m^2 = 138N/mm^2$)

$\tau_{max} = 0.18\int_{ut}$ (13) ($\tau_{max} = 0.18 \times 700 = 126\ N/mm^2$) ------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, $\tau_{max} = 0.25 \times 126\ N/mm^2 = 31.5 \times 10^{-6}N/m^2$

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

$M_t = (60 \times 10^2 \times kW)/ 2\pi n_1$ (14) ($M_t = 28.49\ N/m^2$)

From Figure 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

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

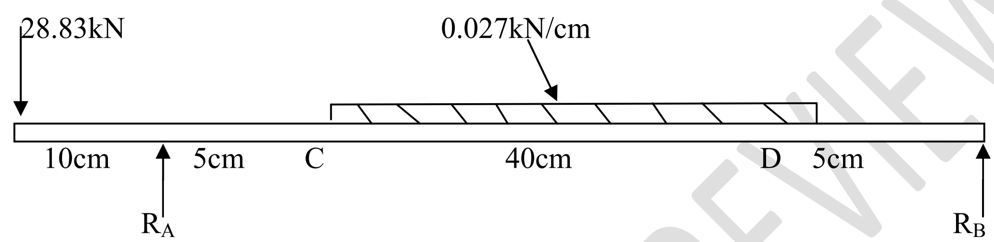
$R_B = -261.3/50 = -5.23$kN

$R_A = 29.91 - (-5.23) = 35.14$kN

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

$F_A = RA = 35.14 - 28.83 = 6.31$ kN, Also, $F_C = 6.31$kN

$F_B = R_B = -5.23$kN



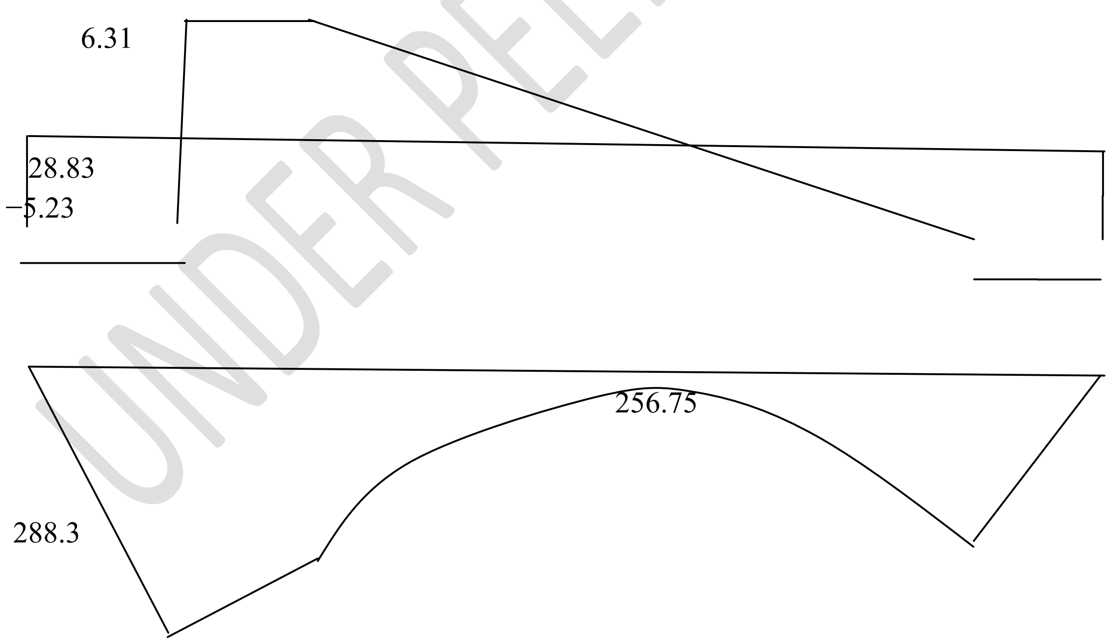


Figure 2. Shear force and bending moment diagram.

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

Therefore x = 21.87cm

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

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

M_E is the point where the maximum bending moment occurred.

$$d^3 = 16/\pi\tau_{max} \sqrt{(K_bM_b)^2 + (K_tM_t)^2} \qquad (15)$$

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

$d = 0.019m = 19mm \approx 20mm.$

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

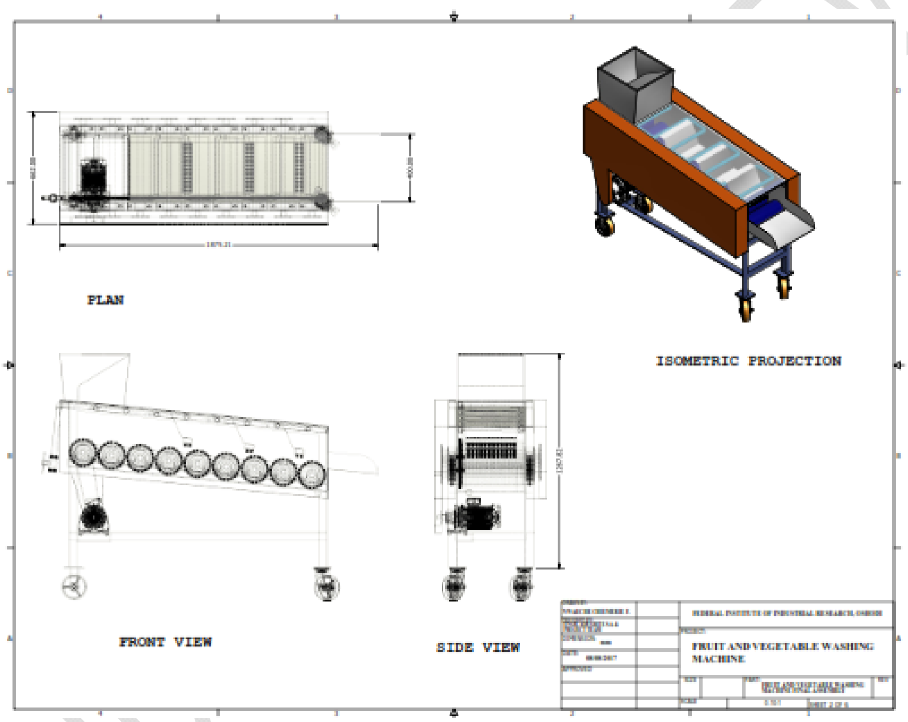

Figure 3: The orthographic and the (3D) isometric view of the fruits and vegetables washer

3.0 Performance Evaluation

3.1 Materials and Method

3.2 Materials include:

Weighing balance, stop watch, recording materials, fruits Sample products (orange, and tomato) and the fruits and vegetables washer.

3.3 Method.

Orange and tomato were bought from Oshodi market, Lagos, Nigeria. The products were prepared by introducing more dirt's 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 FIIRO 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.

3.4 Machine Washing Capacity

The Washing capacity was determined according to Amin (1995) as follows:

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

$$C = Washing\ Capacity\ of\ the\ machine\ \left({}^{Kg}/_{h}\right)$$

$$M = Mass\ of\ the\ prodcut\ fed\ into\ the\ machine (Kg)$$

$$T_w = Washing\ Time (min)$$

3.5 Machine Washing Efficiency

The Washing Efficiency was determined by using turbidity method according to AI-Katary *et. al.,* (2010) as follows:

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

$$Where \quad W_E = Machine\ Washing\ Efficiency\ (\%)$$

T
$= Turbidity\ ratio\ in\ water\ after\ washing\ by\ machine, NTU\ for\ 1Kg\ {}^{fruit}/_{1\ litre\ of\ pure\ water}$

t
$= Turbidity\ ratio\ after\ washing\ by\ hand, NTU\ for\ 1Kg\ {}^{fruit}/_{1\ litre\ of\ pure\ water}$

3.6 Analysis of Turbidity.

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

3.7 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.

3.8 Result 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 Tables 1.

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

	Product Type					
Turbidity (NTU)	**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

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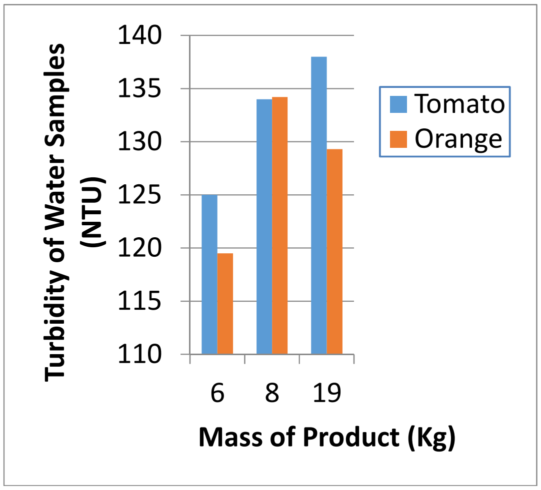

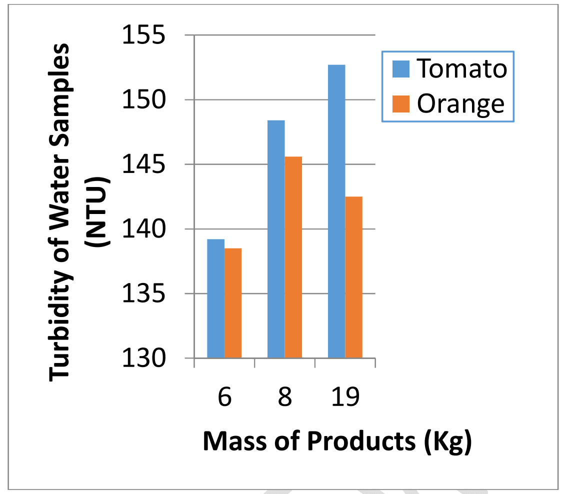

Figure. 4a: Turbidity of machine washed water. **Figure. 4b: Turbidity of manually washed water**

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 Figure 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. AI-Katary *et. al.,* (2010) reported washing efficiency of 90 to 92.4 % for Navel Orange and Nicola Potato. Kenghe *et. al.,* 2015 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.

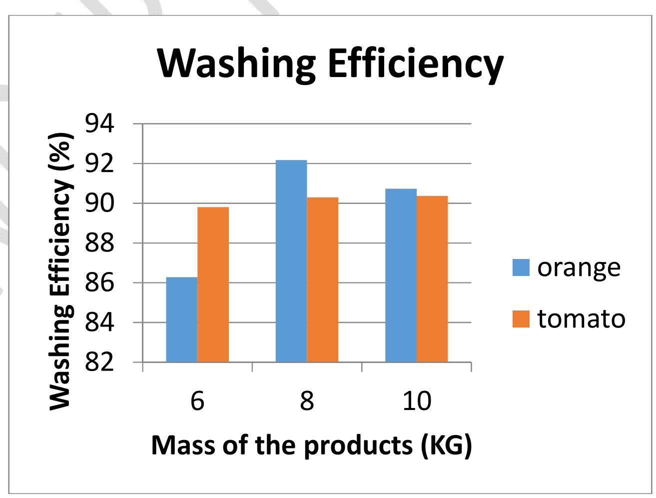

Figure 5: Washing Efficiency of Tomato and Orange against the mass of products.

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Statistical analysis of the effect of operating parameters (mass of products and turbidity of 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 3. The analysis of variance shows that all the variables were not significantly different at all.

Table 3. ANOVA for the performance of the Fruits & Vegetables Washer

Parameter	Source	DF	Type I SS	Mean Square	F Value	Pr > F
Washing Eff	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		
Cap. Tomato	Wash. Mtd	1	4118.14	4118.14	0.21	0.65
	Rep	2	7244.28	3622.14	0.19	0.83
Cap. Orange	Wash. Mtd	1	440.08	440.08	0.02	0.90
	Rep	2	6555.41	3277.71	0.12	0.89

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 Figures 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.

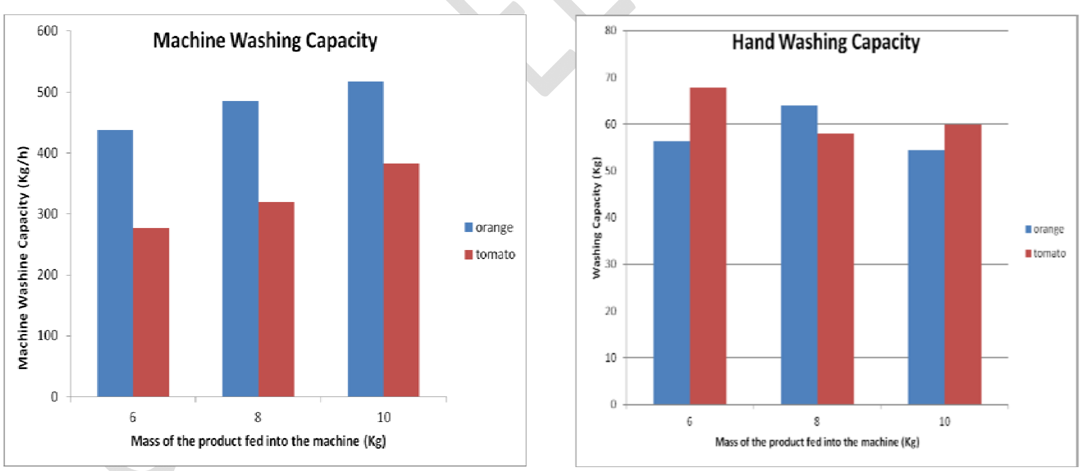

Figure 6a: Machine capacity against product mass. Figure. 6b: Manual capacity against product mass

4.0 Conclusion

The fruits and vegetables washer has been developed. The machine is functional and well efficient equipment which performed very well during operation. 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.

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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_2O 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	517.986	437.25
		Manual	3	58.27 ± 5.04	64.00	54.55
	Washing Efficiency		3	89.73 ± 3.07	92.17	86.28
Tomato	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		3	90.16 ± 0.31	90.37	89.80

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