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Development and Performance Evaluation of a Yam Washing Machine for *Poundo* Yam Flour Processing Plant

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Abstract

Early processing of Yam (Dioscorea spp) tubers with adequate technique is necessary to prevent post-harvest food losses, in order to increase processed Yam products for future consumption, food processing operations have to be mechanized to improve processing technique. This research paper concentrates on development and performance evaluation of a Yam washing machine for a *poundo* Yam flour processing plant and its suitability to the food industrial applications. The machine consist of the following components: washing chamber; where the washing takes place, Pump of 0.8 hp (0.591 kW) to pump clean water into washing drum, washing brushes; that wipes away dirty from the Yam tuber, electric motor of 1410 rpm and 1.5Hp that transfers the Yam tuber from the loading point to the washing machine. The washing machine efficiency was estimated to be 77 % with capacity to wash 2 Yam tubers per minute. It was also found that the machine operation is simple, easy to maintain and can be automated.

Keywords: Design; Auger shaft; processing plant; Yam Flour; Washing Machine.

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1. Introduction

Yam (*Dioscorea spp.*) is one of the oldest known recipes to man. It is a tuber crop, which belongs to the class of carbohydrate and has been a part of the African meal for centuries [7]. It is cultivated in West Africa constituting more than 90 % of the world production [8]. It has increased steadily in the last decades from 18 million metric tons in 1990 to a recent estimate of over 39 million [4]. Yam is among the oldest recorded food crops and ranks second after cassava in supply of starch in West Africa. Yam tubers are high in vitamins, dietary fiber, potassium, and manganese whilst staying reduced in saturated fat and sodium. It helps to generate an excellent potassium-sodium balance in the human body; preventing osteoporosis and heart disorder [3]. The protein is low in *histidine*, *cystine, methionine* and *valine*. It is fairly a good source of vitamin C, high in Fe but low in Ca, Na and Zn. Protein and moisture level increases from head to tail end of the tuber with the peels containing more fibre, ash, protein, calcium, and iron, than the edible parts of tuber. Yams are superior to cassava as a source of protein consequently; the replacement of cassava with yam does reduce the incidence of kwashiorkor [9].

Its starchy nature allows it to bond together as pounded yam when beaten in a mortar with a pestle; an operation that is time consuming and laborious. Pounded yam being a popularly consumed food in West Africa has warranted the need for *poundo* yam flour production. *Poundo* yam flour production affords the ease of preparation of the food compared with the traditional method (mortar and pestle) and its preparation involves eight stages which are yam selection and weighing, washing, peeling, slicing, parboiling, drying, grinding and sieving.

Most processing technique adopted to process *poundo* yam flour from yam often wash the tuber manually after peeling and slicing which is ineffective and time consuming, however development of a washing machine to wash off the dirt from a newly harvested yam tuber is considered more viable because the final product is more hygienic. Consequently, this work addressed an effective, hygienic and quick mechanical method of washing Yam tuber as incorporated and automated in an existing *poundo* yam flour process plant [9]. The purpose of the research was achieved further proffering solutions to some pertinent questions which are; the conceptual design and functionality of the machine based on the yam geometry, the orientation of the machine to permit continuous flow of material and subsequent automation of the process plant and the optimal arrangement of machine components to permit effectiveness and efficiency of the machine in operation.

2. Materials and Method

2.1Design Concept and consideration

The major components of the yam washing machine include: the auger shaft, the power transmission system (belt and pulley drive), the washing brush, the spray jets, the washing chamber, the waste water exit, the clean water inlet, the machine frame, the pump and the clean water storage tank. The washing brushes are fitted to the sides of the machine frame so that it bristles is in contact with the yam being conveyed by the auger shaft. The auger shaft have helical flights whirled round it. The abrasion of brushes bristle and the spray from the water jet flushes the dirt from the tuber. The dirt subsequently flows out of the washing chamber through the waste water exit. Fig. 1.shows the exploded view of the machine. Material selected for fabrication of the machine is analyzed in Table 1. Factors considered in the design and material selection of the yam washing machine are as follows;

i. The material cost and availability
ii. The suitability of materials properties
iii. Proper maintenance
iv. Washing effectiveness
v. Free flow of Yam tubers for effective washing
vi. Capacity to be washed
vii. Integration of the washing machine to the *poundo* Yam processing plant
viii. Time taken to wash Yam tuber

The frame supports the washing chamber. The frame of the machine was designed using mild steel. The type of end connection used is the fixed type (welding method) to give the machine required rigidity.

2.2 Design Analysis and Material selection

2.2.1 The Frame Design

The polar moment of area of the section was obtained as follows:

$$I_{XX} = \frac{1}{12}(BD^3 - bd^3) \quad (1)$$

$$I_{XX} = 23213.25\, mm^4$$

$$I_{YY} = \frac{1}{12}(B^3D - db^3) \quad (2)$$

Where $I_{YY} = I_{XX}$ the polar moment of area

$$I_{YY} = 23213.25\, mm^4$$

Since $I_{YY} = I_{XX}$ therefore the section will tend to buckle along the $Y - Y\ axis\ and\ X - X\ axis$.

$I = I_{YY} = I_{XX}$ which is $23213.25\ mm^4$ was taken and area of the column was obtained from

$$A = (d + B)t \quad (3)$$

A = 171mm^2

Where;

A is the area of the column

d is the diameter of the column

B is the breath of the column

t is the breath of the column

2.2.2 The Washing Brush Design

The washing brush wipes away the dirt from the yam as the auger moves the yam linear against it. The washing brushes are arranged linearly on both sides of the machine wall. Young's modulus of elasticity for mild steel = 0.21×10^6 N/mm^2. The length of the Colum supporting the washing chamber and its components = 900mm

$$W_{cr_{washer}} = \frac{C\,\pi^2 E\,A}{(l_{washer}/k)^2} \quad (4)$$

$\therefore\ W_{cr_{washer}} = 237607\ N \simeq 238\ KN W_{cr_{washer}}$

The length of the column supporting the washing chamber $l_{washer} = 900mm$ using the buckling load 238KN on the column ($W_{cr_{washer}}$) using equations (4) [5].

Where;

C, the Constant representing the end conditions of the column, end fixity coefficient = 4 for welded and bolted joints.

E is the modulus of elasticity of young's modulus for the material of the column

A is the area of cross section.

k is the least radius of gyration of the cross section.

l is the length of the column supporting the washing chamber and its component.

2.2.3 The Pump Design

The pump lifts clean water from the tank and moves it into washing chamber through PVC pipe. The total head lift (H_l) of the pump used in the washing machine was obtained using (5),

$$H_l = T_{d_{lw}} + T_{s_{lw}} + H_{ls} + H_{ld} \tag{5}$$

Where;

$T_{d_{lw}}$ represents the Total discharge lifts of the washing machine.

$T_{s_{lw}}$ represents the total suction lifts of the washing machine.

H_{is} represents the Head loss in suction lifts.

H_{ld} represents the Head loss in the discharge lift.

The power input to the pump from the electric motor $P_{ew=3hp}$ (this is the power of the electric motor driving the pump), this value is called shaft horse power (SHP).

SHP=1HP=2239.5w

The power output of the pump is as follows in equation (6)

$$WHP = \omega Q_w H_{mh} \tag{6}$$

Where H_{mh} is the manometric height

Q_w is the flow rate of the water (7)

$Q_w = \rho g Q_w H_{mh}$

Where ρ and g is the density of water and acceleration due to gravity respectively.

WHP = 1931 W

Diameter of the auger shaft

The $$(D_{auger})^3 = \frac{16}{\pi s_s}\sqrt{\{(K_b M_b)^2 + (K_t M_t)^2\}} \tag{8}$$

$(D_{auger})^3$ is the cube of diameter of the shaft (m^3)

K_b is the combined shock and fatigue factor applied to bending moment

M_b is the the Bending moment (*Nm)*

K_t is the the combined shock and fatigue factor applied to torsional moment

M_t is the Torsional moment (*Nm)*

s_s is the Allowable shear stress (N/m^2)

D_{auger} =16*mm*

The diameter of the auger shaft is 16*mm*

2.2.4 The Selection of Electric Motor Design

The selection of the electric motor for the washing machine was based on the following factors;

1. The motor duty (continuous)

2. The power rating and speed required

3. The type of enclosure (closed)

$$P = \frac{2\pi N_m T}{60} \tag{9}$$

Equation (10) was used to determine speed of the motor [5]. Where Dm is the diameter of the motor pulley,

D_A is the diameter of the pulley on the auger shaft and Nm represents the speed of the electric motor in rpm, power (P) in Watts of the electric motor. T represents the torque on the driving (electric motor) pulley in N-m defined in equation (9)

$$\frac{D_A}{D_m} = \frac{N_m}{N_A} \tag{10}$$

2.2.5 The Nozzles Design

A nozzle is a device that increases the velocity, momentum and acceleration of a flowing fluid. This increase the velocity with which the clean water strikes the yam. The actual selection of a nozzle is based on the diameter of coverage required, pressure available and nozzle discharge. The nozzle selected for the yam washing machine has an entry diameter(d_{entry}) $50mm$, the volumetric discharge of the nozzles (q_{nozzle})used in the yam washing machine is equal to the volumetric discharge rate of the pump (Q_w) hence, using (11),

$$q_{nozzle} = Q_{w=c\, a_{exit}\sqrt{2gh}} \tag{11}$$

Where;

C is the Coefficient of discharge which is a function of friction and contraction losses [5]. **C**oefficient discharge of a good nozzle is usually taken to be 0.95

a_{exit} is the Cross sectional area of nozzle orifice (m^2) (area of the nozzle at exit)

g is the Acceleration due to gravity

h is the Pressure head at nozzle

$$a_{exist} = \frac{Q_W}{C\sqrt{2gT_{dtw}}} \qquad (12)$$

The diameter of the nozzle at exit d_{exist} can be obtained using Equation (13) and (14);

$$a_{exist} = \pi\{\frac{(d_{exist})^2}{4}\} \qquad (13)$$

Hence,

$$d_{exist} = \sqrt[2]{\frac{a_{exist}}{\pi}} \qquad (14)$$

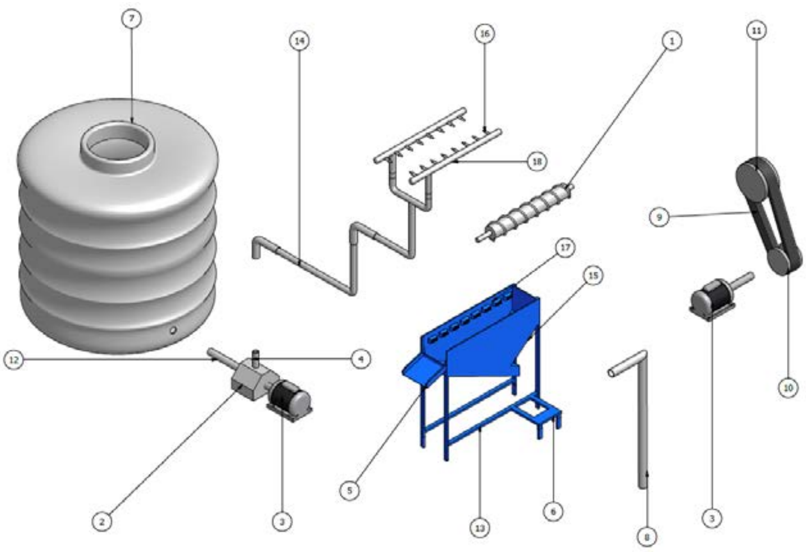

Figure 1: Exploded view of the yam washing machine

Table 1: The Parts List of Materials Used

Item	Description	Quantity
15	Auger shaft	1
14	Pump	1
13	Electric motor	1
12	Clean water delivery pipe	3
11	Delivery chute pipe	1
10	Electric motor bases	1
9	PVC Tank	1
8	Waste water delivery pipe	1
7	Belt	1
6	Driver pulley	1
5	Driven pulley	1
4	Clean water suction pipe	1
3	Frame	8
2	Spray water jet	16
1	Washing brush	20

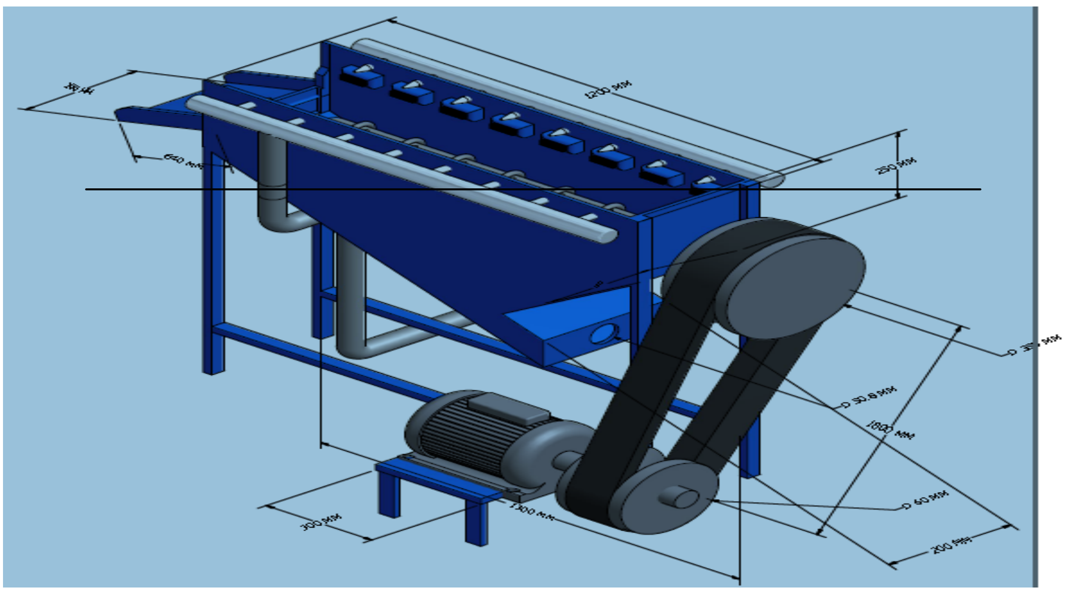

Figure 2: Designed Yam Washing Machine

Figure 3a: Developed Yam Washing Machine

Figure 3b: Developed Yam Washing Machine

2.2.5 Material Selection

The materials selected for the fabrication of the washing machine are shown in Table 2. Mild steel was chosen for the body frame and the auger spiral/coiled plate since the components are not in contact with the food material; the essence of the machine is to wash away dirt from the body of the yam. The other materials chosen for other components were due to their cheap cost and economic viability.

Table 2: Summary of Material Selection For The Yam Washing Machine

S/N	Machines Component	Materials Used	Reasons for selecting the materials
1	Body frame	Mild steel	❖ Good tensile properties ❖ Low cost ❖ Readily available
2	Auger Spiral /Coiled Plate	Mild steel	❖ Good tensile properties ❖ Low cost ❖ Readily available ❖ Resistant to shock
3	Hopper	Stainless steel	❖ Excellent corrosion resistant ❖ Good tensile properties ❖ Readily available
4	Electric Motor	Standard	❖ Suitable for drive
6	Water Pipe	PVC	❖ Excellent corrosion resistant ❖ Very cheap ❖ Good for cold piping
7	Washing Brush	Polymers	❖ Suitable for yam ❖ Excellent corrosion resistant ❖ Good texture properties

3. Results and Discussion

The performance of the fabricated machine was evaluated by measuring the rate at which the fabricated machine washes the dirt's away, and the time use to perform the washing activities. The volume of water and the time required by the machine for washing a tuber of yam was noted and compared with the manual washing of Yam tuber. Table 3 shows the results obtained from the performance evaluation. Figure 3.0 shows the picture of the machine during testing. The fabricated yam washing machine was run without load for about 5minutes to test for any vibration with a one-phase 1410 rpm, 1.5HP electric motor. The electric motor powers the auger shaft and the pump lift clean water from the water reservoir through the nozzles to the yam tuber to be washed. The washing brush wipes away the dirt when sprayed with water from the jet spray. The test was repeated for four times using different Yam tuber and the time for each batch was recorded in Table 3. The efficiency (77%) of the washing machine was obtained using equation (15) with machine capacity of 28kg of tuber per hour, improving the poundo yam processing chain for a better and clean poundo yam product. This research has generated data for designing a yam washing machine for poundo yam processing stages.

i. The material cost and availability
ii. The suitability of materials properties
iii. Proper maintenance
iv. Washing effectiveness
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vii. Integration of the washing machine to the *poundo* Yam processing plant

viii. Time taken to wash Yam tuber

Table 3: Results and Performance Evaluation

Mass of Fresh Yam (Kg) A	Mass of Fresh Yam after machine washing (Kg) B	Mass of Fresh Yam after manual washing (Kg) C	Time of washing (sec) Machine	Time of washing (sec) Hand
2.00	1.88	1.92	30	61
2.21	2.05	2.10	31	63
2.18	2.10	2.14	34	62
1.80	1.30	1.50	29	65
8.20	7.80	7.66	124	247
A=2.05	B=1.95	C=1.92	31	61

$$W.E = \frac{B-C}{B-D} 100\ \% \qquad (15)$$

D is the Mass of yam after manual washing (kg)

$W.E$ = **77%**

4. Conclusion

A Yam washing machine for a *poundo* Yam flour process plant has been developed which is functionally viable for washing and continuous flow of yam tubers through the process plant; consequently permitting the process automation and continuous flow of material through the process plant. The machine comprises of major parts; the hopper, body frame, washing brush, water pipe, auger shaft optimally arranged and powered by The electric motor (one-phase 1410 rpm, 1.5 HP) and water pump which permit effective washing operation of yam tubers in *poundo* yam production with an efficiency of 77% at the ratings of 2 yams per minute.

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