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DEVELOPMENT OF A MODIFIED NCAM TUBER DICING MACHINE

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ABSTRACT

An existing dicing machine for tubers developed by NCAM was modified to improve the dicing output of the machine by replacing the mobile cylindrical punchers with set of knives arranged in square shape to achieve the dicing operation and incorporating stationary spike teeth to push out diced tubers from the square knives. The machine was tested and evaluated using yam and sweet potatoes of length ranging between 305- 406mm and 127-156mm respectively and diameter 73-110mm and 78-101mm respectively with the tubers fed manually into the machine. Evaluation results show that the average dicing time for yam and sweet potatoes was 22.13s and 13.88 s respectively; the mean dicing efficiency was 68.18% and 60.49% while the mean machine capacity was 157.20kg/h and 79.57kg/h for yam and sweet potatoes respectively. The average uniformity of dicing for yam was 68.18% and 60.49% for sweet potatoes.

KEY WORDS: *Development, modification, dicing, efficiency and operation*

1.0. INTRODUCTION

Roots and tubers are rich mainly in carbohydrates, proteins, vitamins and minerals such as manganese, phosphorus and potassium. It is a staple food in sub-Sahara Africa and Nigeria is the highest producer of major roots and tubers such as cassava, yam, and cocoyam having 51%, 97% and 77% of world production respectively. Due to their perishable nature, poor postharvest handling and inadequate storage facilities, about 50% of roots and tubers are lost annually (IITA, 2008). According to Onebunne (2004), the factors responsible for postharvest losses of root and tuber crops are ineffective or inappropriate harvesting, postharvest handling practices, poor transportation media, bad market practices and lack of storage facilities.

As a result of this alarming rate of postharvest losses, many simple methods have been devised to extend the storage or shelf life of roots and tubers; these include peeling, slicing, chipping, dicing, etc.

These are operations carried out on roots and tuber crops just to open up the surface area and increase the drying rate (FAO, 2008). Most of these operation can be carried out locally using simple household tools such as knives, cutlasses, etc.

Dicing is introduced in tuber processing as an operation to further reduce the size of sliced or chipped roots and tubers for ease of handling, transportation and storage. Dicing is a culinary knife cut in which food items are cut into small blocks or dice. This may be done for aesthetic reasons or to create uniformly sized pieces to ensure even cooking or drying (www.cooksinfo.com, 2012).

Technically there are three types of dicing based on the size of the end product, these are: the large, medium and small dicing. Large dicing is usually a 20mm [3/4 inch] cube while medium dicing is 10mm [1/2 inch] and small dicing 5mm [1/4 inch] (www.cooksinfo.com, 2012). Dicing operation is achieved commonly by the use of knives and a dicing platform or board. The diced products are of varying thicknesses, shapes and sizes; also physical injuries like cuts can be inflicted on the user if done carelessly (Wikipedia, 2010).

The methods of dicing can broadly be classified into traditional and mechanical, based on the mode of the operation. The traditional method of dicing using the knife and board/platform involves a lot of labour and drudgery with low output, poor hygiene, produces non-uniform cubes, time consuming and hazardous. This and other challenges earlier mentioned necessitate the need for mechanization of this operation to eliminate the drudgery and ensure timeliness of operation.

In order to circumvent the associated dicing problems, there is the need to have a machine that can efficiently dice variety of crops (roots and tubers) for improved shelf live and value addition. In view of this, it is pertinent that the existing NCAM developed machine is modified so as to increase its efficiency, output and capacity. The project objective is to modify the mould and die mechanism of the existing NCAM dicing machine in order to improve the machine performance.

1.1. Postharvest Handling of Root and Tuber Crops

Most roots and tubers follow the same pattern of processing into dried form for viable storage and further preservation. The process flow line for most roots and tubers into storable products is highlighted in schematics as follows:

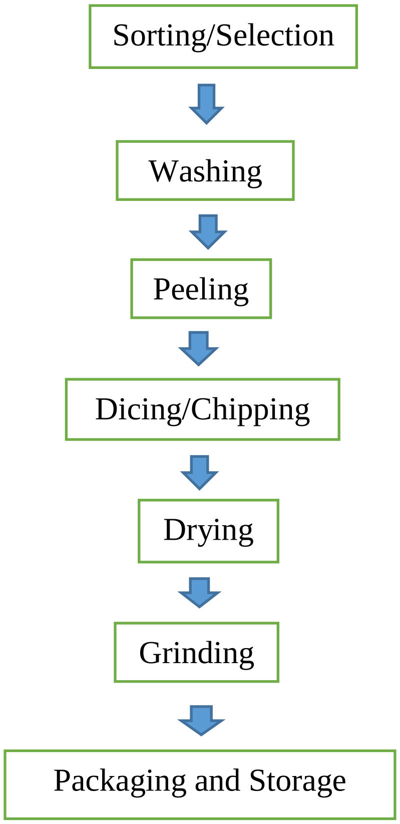

Figure 1: Block diagram for processing of roots and tubers.

1.2. The Existing NCAM Tuber Dicing Machine

The existing NCAM dicing machine was designed with a mould and die mechanism which performs the dicing operation, a slicing device is incorporated inside the receiving chute where the tuber is placed and is sliced, the sliced tuber is then sent to the dicing chamber where a motor driven cylindrical-spiked die presses it against the stationary square mould for dicing. Preliminary test of the current model revealed that as a result of the bluntness of the mould, pressure applied on the tuber as it is pressed against the cylindrical die causes the tuber to rupture and eventually crushed before the dicing operation is achieved. As a result, there is excessive tuber loss, damages and production of non-uniform diced product.

Plate 1: The Existing NCAM Dicing Machine

Plate 2: Mould and die mechanism of the Dicing

2.0. MATERIALS AND METHODS

2.1. Design considerations

In the modification of the NCAM dicing machine, the following factors were put into consideration:

i. The shape and size of the crop to be diced.

ii. Availability and suitability of selected materials: The construction materials were locally sourced and selected based on their suitability for the project.

iii. Contamination: The cutting blades and the dicing chamber would be made from stainless steel which is corrosion resistant.

iv. The power requirement.

The modification of the NCAM dicing machine is centred on the need to make improvements to the dicing machine with the aim of increased efficiency and output.

2.2. Design calculations

i. The Hopper

The hopper constructed from 2.0 mm stainless steel has dimensions of 250 x 200 mm hexagon with a cylindrical frustum opening diameter of 100 mm and neck height of 60 mm into the dicing chamber. It was screwed to the machine for ease of dismantling.

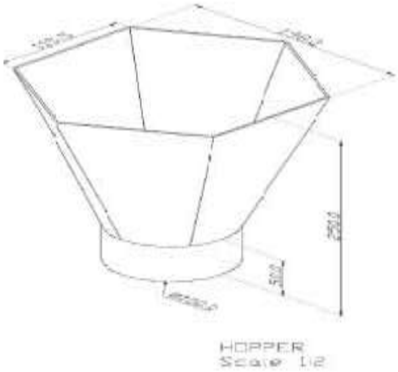

Figure 2: The hopper

ii. The Shaft

The design of shaft primarily involves in determining stresses at critical point in the shaft that is arising due to bending, torsional and axial forces. The following were considered in the design of the shaft using equations as described by Khurmi and Ghupta (2004) as follows:

a. Bending Stress

$$\sigma_b = \frac{32 M_b}{\pi d^3 \left(1 - k^4\right)} \tag{1}$$

Where, M_b is bending moment, N-m; d is outer diameter of shaft, m; k is ratio of inner to outer diameter of shaft; k is zero (0) for solid shaft.

b. Axial Stress

$$\sigma_a = \frac{4\alpha F}{\pi d^2 \left(1 - k^2\right)} \tag{2}$$

Where, F is axial force (tensile or compressive), N; α is column-action factor (1.0 for tensile load); d is outer diameter of shaft, m; k is ratio of inner to outer diameter of shaft; k is zero (0) for solid shaft.

c. Stress due to torsion

$$\tau_{xy} = \frac{16T}{\pi d^2 \left(1 - k^4\right)} \tag{3}$$

Where, T is torque on the shaft, N-m; τ_{xy} is shear stress due to torsion, Pa.

d. Combined Bending and Axial Stress

Both bending and axial stresses are normal stresses, hence the net normal stress is given by:

$$\sigma_x = \left[\frac{32M}{\pi d^3 \left(1 - k^4\right)} \pm \frac{4\alpha F}{\pi d^2 \left(1 - k^2\right)} \right] \tag{4}$$

The net normal stress can be either positive or negative. Normally, shear stress due to torsion is only considered in a shaft and shear stress due to load on the shaft is neglected.

e. Maximum Shear Stress

The shaft was designed using maximum shear stress theory which states that a machine member fails when the maximum shear stress at a point exceeds the maximum allowable shear stress for the shaft material. Therefore,

$$\tau_{\max} = \tau_{allowable} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2} \tag{5}$$

Substituting for $d\ \tau_{xy}$ the above equation becomes,

$$\tau_{allowable} = \frac{16}{\pi d^2 \left(1 - k^4\right)} + \sqrt{M + \frac{\alpha F d \left(1 - k^2\right)}{8} + T^2} \tag{6}$$

Therefore, the shaft diameter can be calculated in terms of external loads and material properties. However, the above equation is further standardised for steel shafting in terms of allowable design stress and load factors in ASME design code for shaft.

The shafts are normally acted upon by gradual and sudden loads. Hence, the equation is modified in ASME code by suitable load factors,

$$\tau_{allowable} = \frac{16}{\pi d^3 \left(1 - k^4\right)} \sqrt{M C_{bm} + \frac{\alpha F d \left(1 - k^2\right)}{8} + \left(C_t T\right)^2} \tag{7}$$

Where, C_{bm} and C_t are 1.5 and 1.0 respectively. (ASME code).

f. Determination of Shaft Displacement

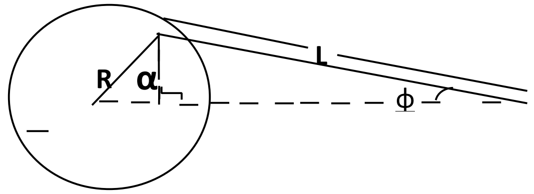

Figure 3: Schematic diagram for the Shaft displacement.

According to Hamitton and Ocrirk (1963), the maximum displacement (x) that can be generated at an angle of displacement (α) is given as,

$$x = R\left(1-\cos 180^\circ\right)+\frac{R^2}{2L}\sin^2 180^\circ \qquad (8)$$

Where, R is the radius of the shaft, m; L is the length of connecting rod/coupler, m; α is the angle of displacement, rad/s.

iii. Power requirement, Pulley and Belt Design.

a. The pulley and belt length was determined using equation stated by Aaron (1975),

$$N_1 D_1 = N_2 D_2 \qquad (9)$$

Where, N_1 – speed of driven pulley, rpm; N_2 – speed of driving pulley, rpm; D_1 – diameter of driven pulley, mm; D_2 – diameter of driving pulley, mm.

$$L = 2C + 1.57\left(D_2 + D_1\right) + \frac{D_2 - D_1}{4C} \qquad (10)$$

Where, L is length of belt, mm; C is distance between driving and driven pulley, mm; D_1 is the diameter of driving pulley, mm; D_2 is the diameter of the driven pulley, mm.

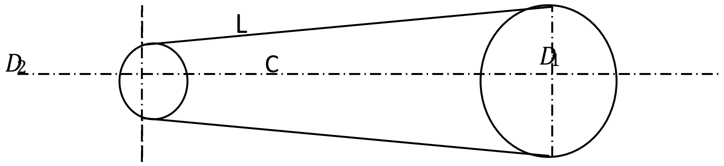

Figure 4: Pulley and Belt Arrangement.

b. Power requirement of the machine

$$P = F_T \omega \qquad (11)$$

Where, F_T is the total force to be overcome, N; ω is the angular velocity, rad/s.

$$F_T = F_M + F_D \qquad (12)$$

Where, F_M is the force generated by the mechanism, N; F_D is the force/resistance produced by the tuber, N.

$$\omega = \frac{\pi N D}{60} \qquad (13)$$

iv. The Blade Shear Impact

The kinetic energy (K.E) of the moving blade mesh is determined by shear impart equation given by Norton (2006):

$$E = \eta\left(\frac{1}{2} m v_i^2\right) \qquad (14)$$

Where, m is the mass of the cutting blade mesh, kg; v_i is the velocity of impact, *m/s*; η is the correction factor for energy dissipation.

Assume all the K.E transferred from the moving shaft is converted, the impact force F_i is calculated as:

$$\frac{(F_i)^2}{2k} = \eta \frac{m v_i^2}{2} \qquad (15)$$

$$F_i = v_i \sqrt{\eta m k} \qquad (16)$$

Where, k is the linear relationship between F, (the blade tensile strength) and resulting deflection δ, i.e.

$$k = \frac{F}{\delta} \qquad (17)$$

2.3. Working Principle and Description of the Machine.

The machine operates on crank and slider principle. The main components of the modified dicing machine are, the frame, an outlet chute, a hopper, the dicing chamber which consists of set of blades arranged in square, a link, a shaft and pulley for power transmission from the electric prime mover. The frame was constructed from 45 X 45 mm mild steel angle bar to give rigidity and stability that will withstand load and vibration. A frustum hopper was incorporated to allow loading of more roots and tubers.

Figure 5: Isometric view of the modified Tuber Dicing machine.

2.4. TESTING AND EVALUATION

Yam and sweet potatoes were used in the testing and evaluation of the machine performance. The operational efficiency of the machine was calculated at each instance in order to evaluate the performance of the machine and make recommendations for future modifications.

2.4.1. Apparatus

Digital weighing scale, stopwatch, knife, bowls.

2.4.2. Test Procedure

Specified unpeeled tubers were selected and weighed out, five (5) in number each for yam and sweet potatoes on the digital scale and recorded. The tubers were manually peeled using knife, re-weighed and recorded. The peeled tubers were subsequently washed in clean water and fed manually through the hopper into the machine one after the other. The operational time was taken using the digital stopwatch and recorded at each instance. The uniformly and non-uniformly diced tubers were weighed and recorded.

2.4.3. Evaluation

The machine performance was evaluated using the following parameters:

i. Dicing efficiency, $D_E(\%) = \dfrac{W_U}{W_A} \times 100\%$ (18)

Where, W_U is the weight of uniformly diced tuber, g; W_{FT} is weight of the peeled tuber fed into the machine, g.

ii. Dicing Capacity, $D_C = \dfrac{W_U}{T_D} \times 3600$ (19)

Where, W_U is weight of uniformly diced tuber, g; T_D is operational dicing time, s.

iii. Uniformity of Dicing, $D_U(\%) = \dfrac{W_U}{W_{FT}} \times 100\%$ (20)

Where, W_U is the weight of uniformly diced tuber, g; W_{FT} is weight of fed peeled tuber, g.

3.0. RESULTS AND DISCUSSION

Tables 1 and 2 show the result of the measured parameters for yam and sweet potatoes respectively. The machine has an average dicing efficiency of 68.18 % and 60.49 %; the average dicing capacity of 157.20 kg/h and 79.57 kg/h respectively; while the average percentage of non–uniformly diced tubers was 31.82 % and 39.51 % respectively.

It was observed that tubers of diameters close to that of the feeding chute (100mm) have higher dicing efficiency than those of lower diameter. For instance, yam tubers diameter of 99.00 mm and 86.00 mm have efficiency of 69.42 % and 68.64 %; while sweet potatoes of diameter 86.00mm and 83.00mm have efficiency of 61.10 % and 60.85 % respectively. According to Ehiem and Obetta (2011), this could be due to reduced wobbling effect of the tubers with the chute walls as the tuber diameters are close to that of chute wall.

There was high percentage of non- uniform dicing efficiency for tubers whose diameter is far less or more than the chute diameter. For example, yam tuber with diameter of 73 mm and 110 mm had non–uniform dicing efficiency of 32.20 % and 33.15 %; while sweet potatoes diameters 78 mm and 101 mm had non-uniform dicing efficiency of 40.32 % and 42.36 % respectively. These could be as a result of rocking effect of the tubers and chute walls resulting in wobbling as slicing is in progress which in turn affects the dicing operation.

Table 1: Result of measured parameters for yam.

W_B (g)	W_{FT}(g)	W_U(g)	W_N(g)	W_A(g)	M_N(%)	E_D(%)	M_T (g)	L_Y(mm)	C_T(mm)	r(mm)	D_Y(mm)	T_D (s)
1490.00	1290.00	879.78	410.22	1290.00	31.80	68.20	610.22	305.00	250.00	40.00	80.00	22.32
1680.00	1450.00	995.28	454.72	1450.00	31.64	68.64	684.72	381.00	270.00	43.00	86.00	21.82
1560.00	1372.80	917.72	455.08	1372.80	33.15	66.85	642.28	381.00	350.00	55.00	110.00	23.60
1630.00	1385.50	939.37	446.13	1385.50	32.20	67.80	690.63	406.00	230.00	36.50	73.00	22.41
1800.00	1584.00	1099.61	484.39	1584.00	30.58	69.42	700.39	368.00	310.00	49.50	99.00	20.51
Average	1416.46	966.35	450.11	1416.46	31.82	68.18	665.65	368.20	282.00	44.80	89.60	22.13

Table 2: Result of measured parameters for sweet potatoes.

W_B (g)	W_{FT}(g)	W_U(g)	W_N(g)	W_A(g)	M_N(%)	E_D(%)	M_T (g)	L_Y(mm)	C_T(mm)	r(mm)	D_Y(mm)	T_D (s)
578.10	514.60	314.42	200.18	514.60	38.90	61.10	263.68	152.40	270.00	43.00	86.00	12.96
450.40	407.61	243.26	164.35	407.61	40.32	59.68	207.14	127.00	245.20	39.00	78.00	14.31
680.00	603.16	347.66	255.50	603.16	42.36	57.64	332.34	134.62	320.00	50.50	101.00	14.50
640.00	564.48	356.75	207.73	564.48	36.80	63.20	283.25	129.54	315.40	50.20	100.40	13.98
500.00	446.85	271.91	174.94	446.85	39.15	60.85	228.09	156.21	260.65	41.50	83.00	13.65
Average	507.34	306.80	200.54	507.34	39.51	60.49	262.90	139.95	282.25	44.80	89.60	13.88

4.0. CONCLUSIONS

With this machine in place, the problems associated with manual dicing such as varying thicknesses, shapes and sizes of diced products; drudgery when large quantity is involved, and physical injuries on the operator have been minimized. Also dicing as a processing method can be encouraged among processors by propagating it as a faster means of drying roots and tubers as it opens up the surface area and enhances drying. Full-automation of this operation is recommended to achieve better results in future.

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APPENDIX

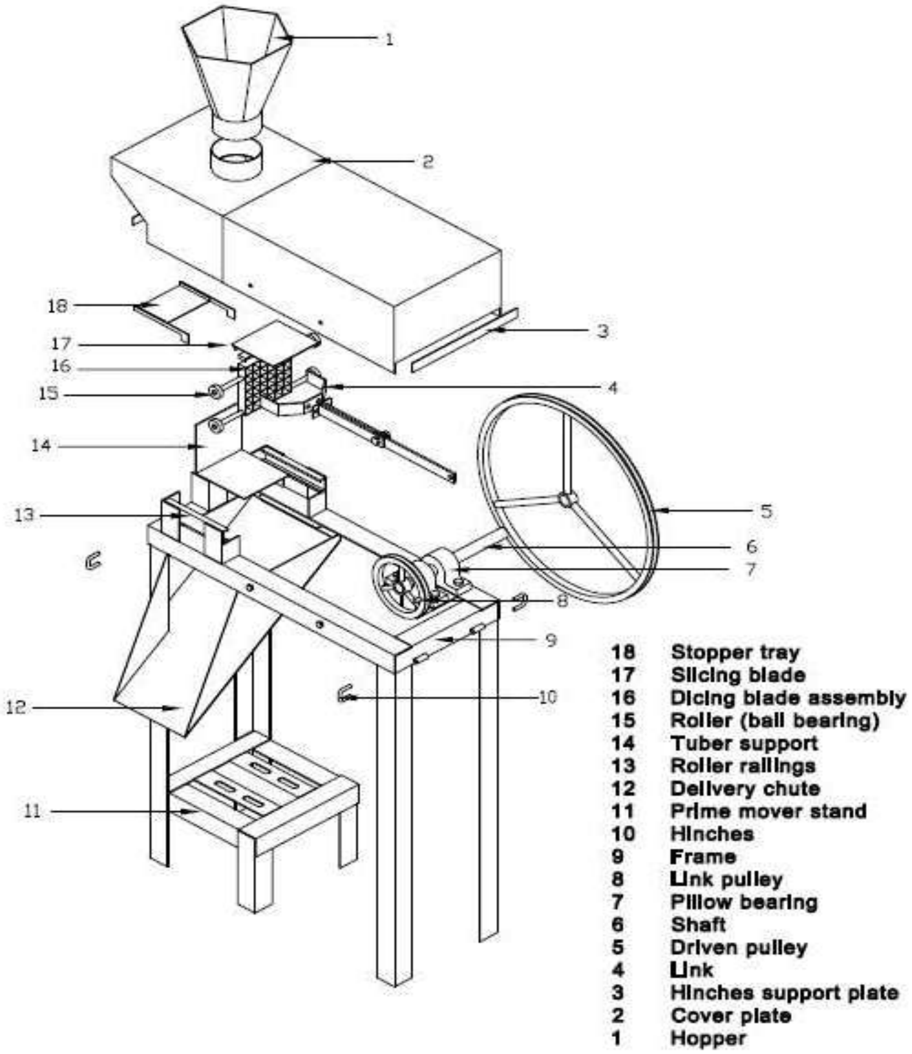

Figure 6: Exploded view of the Modified NCAM Dicing Machine