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DEVELOPMENT OF A VEGETABLE SLICING MACHINE.FROM LOCALLY SOURCED MATERIALS.

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ABSTRACT

In an attempt to facilitate the processing of vegetable material which is a daily nutritional food requirement of man, a vegetable slicing machine has been developed. This paper therefore presents the development of a vegetable slicing machine which is a mechanical device that is used for slicing vegetable materials instead of the crude cumbersome and unhygienic method of manual slicing of vegetable materials. The developed machine consists of the hopper, the cutter housing, the cutting blades, the sprout, the shaft, and a wooden handle. The machine was designed to enhance the hygienic slicing vegetable materials for both domestic and commercial consumption and it can accommodate up to fifteen cutting blades made of high speed steel material.

Keywords: Vegetable Slicing, Unhygienic Method, Cutting Blade, High Speed Steel.

1.0 INTRODUCTION

Vegetable slicing is a process of cutting vegetable materials with a well sharp object such as knife, and it is usually done domestically or commercially using the various available methods of slicing. Vegetable slicing is usually done locally using a knife – like slicer to cut vegetable materials into bits or slices. The need for a more reliable and convenient method of slicing vegetable materials necessitates the design and manufacture of a local and portable vegetable slicing machine.

The principles of slicing machine is based on the action of shearing by blades and other types of cutters with principles as the slicing which include the impact-type cutter, the mower cutter bar and the knife drive system.

According to Frank (2004), Otto Rohwedder designed and manufactured the first slicing machine that would slice and wrap bread in 1925, while the first meat slicing machine was invented by an American in 1873. The machine made use of an oblique knife in a vertical sliding frame for slicing dry beef and it worked with the frame holding the meat while slicing it against the cutting blade, (Hardin, 2001). The conventional slicing machine was originally designed to slice meat into pieces of uniform thickness. It was also used for slicing cheese, vegetables, ham, onions green peppers and sandwich ingredients (Tannahill, 2003). There are basically three types of slicer; the gravity slicer, the horizontal slicer, and the bacon slicer and these three groups of slicer have their own shortcoming. The slicing machine for slicing food, such as meat, cheese, sausage and vegetable consists of a conveying device, a rotating blade and a knocking-off mechanism for transferring the slices from the conveying device to deposit area, (Odior, 2007). Ohaneche, et al.,(2005), studied a vegetable slicing machine and divided the operations into four stages, consisting of material intake, material transmission, material slicing and material ejection. He also stated that the vegetable slicing machine mechanism is simply the action of shearing by the blades just like that of meat slicing machine.

2.0 PARTS AND OPERATION OF VEGETABLE SLICING MACHINE.

The developed vegetable slicing machine was designed to slice all types of vegetables including; ham, onions, green peppers and sandwich ingredients. It can

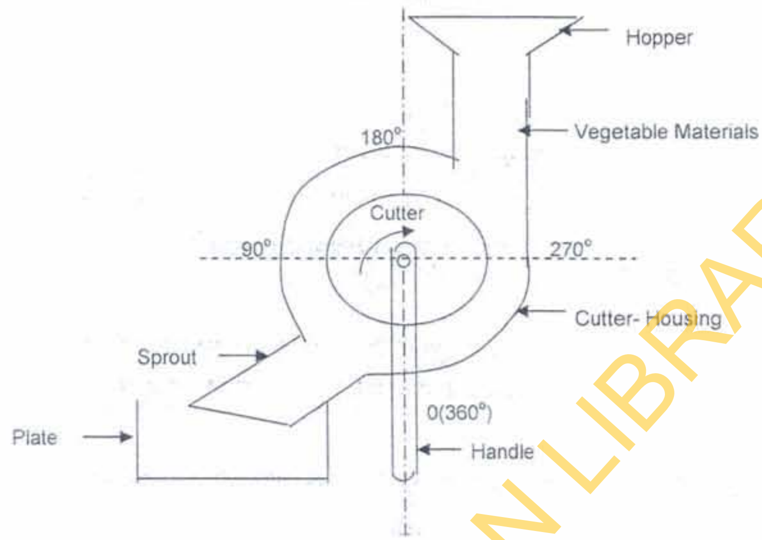


Fig.1. Sectional View of Vegetable Slicing Machine.

accommodate up to fifteen cutting blades. The machine consists of the following major components: the hopper, the cutter housing, the cutting blades, the sprout and a wooden handle. The machine is presented in Figure 1.

2.1 The Hopper.

The hopper is the component of the machine which receives the vegetable materials to be sliced before discharging them into the slicing zone. Slicing does not take place in the hopper as it is only for the vegetable materials intake.

2.2 The Slicing Cutter.

The slicing cutter consists of some helical grooves which pick up the vegetable materials to be sliced from the hopper for onward transmission to the cutting zone.

2.3 Cutter Housing.

The cutter housing consists of the cutter down pipe and the set of cutters. The set of fifteen cutting teeth mounted on the cutter drum are all enclosed in the cutter housing. The actual slicing of the vegetable materials is performed within the cutter housing.

2.4 The Cutting Blades.

The cutting blades are incorporated on the cutter drum which is fixed within the cutting housing. There are fifteen cutting blades which are spaced 10 mm from each other. Each of the blades is 15 mm high and 90 mm long.

2.5 The Sprout.

The sprout is located at the bottom of the slicing machine. It is 180 mm in length, 88 mm wide and 45 mm in height. The sliced vegetable materials are collected through the sprout into the basin.

3.0. SLICING MECHANISM.

The cutting mechanism of the vegetable slicing machine is similar to down - cut action of a milling process. The teeth on the cutter are helical so that each tooth cuts with a progressive action instead of its whole length coming into action at once. The helical nature of the cutting edge also brings side rake into the cutting action.

The slicing mechanism of a cutter with radius R mm, taking a cut h mm on the vegetable material over a width b mm of the cutter is shown in Figure 2.

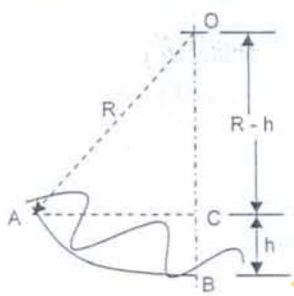


Fig. 2: Slicing Mechanism of the Machine.

$AB^2 = AC^2 + CB2$

but $AC2 = OA^2 - OC^2$

$\therefore AB^2 = OA^2 - OC^2 + CB^2$

$= R^2 - (R - h)^2 + h^2$

$= R^2 - R^2 + 2Rh - h^2 + h^2$

$= 2Rh$

Hence, $AB = \sqrt{2Rh} = \sqrt{Dh}$. (1)

where D is the diameter of the cutter.

When the pitch of the teeth is more than this, the cutting conditions become as shown in Figure 3, where T_1, T_2, T_3 etc are the teeth with helix angle Ψ . As can be seen from

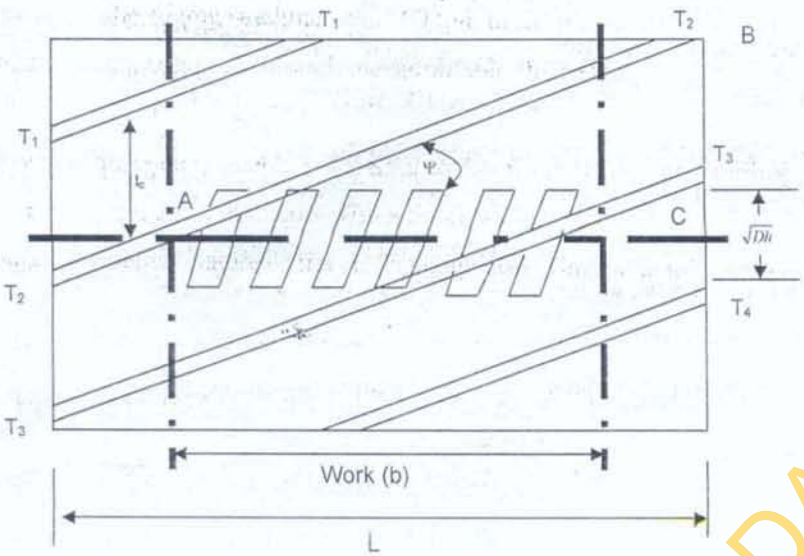


Fig. 3, The Pitch of the Cutter.

Figure 3, T_3 is just leaving the cutting zone while T_2 is coming into action on the length.

The pitch of cutter of the vegetable slicing machine is small so there are always two or more teeth in engagement during cutting operation.

Let t_c = pitch

Z = number of teeth on the cutter,

D = cutter diameter,

Ψ = helix angle.

$$\text{Then} \quad t_c = \frac{\text{Circumference of cutter}}{\text{Number of teeth}}$$

$$= \frac{\pi D}{Z}$$

$$\text{But} \quad \tan\Psi = \frac{BC}{AC} = \frac{t_c - \sqrt{Dh}}{b},$$

$$= \frac{\frac{\pi D}{Z} - \sqrt{Dh}}{b},$$

$$\tan\Psi = \frac{\pi D - Z\sqrt{Dh}}{bZ},$$

The lead of tooth helix is obtained from

$$\tan\psi = \frac{\text{Circumference of cutter}}{\text{Lead of tooth helix}} \qquad \text{Lead of tooth helix} = \frac{\text{Circumference of cutter}}{\tan\psi}$$

$$= \frac{\pi D}{\frac{\pi D - Z\sqrt{Dh}}{bZ}}$$

$$= \frac{\pi DbZ}{\pi D - Z\sqrt{Dh}} \qquad (2)$$

where D = cutter diameter (mm)

b = working length (mm)

Z – number of teeth on the cutter,

H = depth of cut per tooth (mm).

Ψ = helix angle.

3.1. Forces on the Cutter

The normal force, tangential force and the end thrust on the cutter are shown in Figure 4.

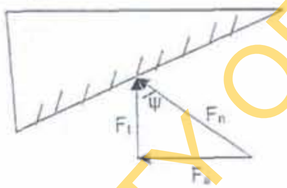


Fig. 4: Forces on Cutter Tooth.

Here, F_n = normal force on the tooth.

F_t = tangential force on the tooth.

F_a = axial force or thrust on the tooth.

Ψ = helix angle.

3.1: Computation of the Number of Cutting Blades.

Let p = pitch or spacing of blades (mm)

n = Number of blades required

D = Outer diameter of drum (mm)

But p = 10mm (specified)

D = 48mm

From $n = \frac{\pi D}{p}$

$$n = \frac{48\pi}{10} = 15.0796 = 15$$

Therefore the required number of cutting blades is 15.

3.0. OPERATION OF THE MACHINE.

The principle of operation of the vegetable slicing machine is by the action of shearing by the cutter blades. The blades are mounted vertically on the cutter down with a distance of 10 mm from each other. The blades are 15 mm high with a length of 90 mm. A thick plate with a slot is incorporated at the base of the hopper and is constrained to move up or down in a vertical form. During the intake stage, the vegetable materials are collected between the pitch of the blades. Actual slicing occurs when a force is applied to the handle and the shearing of the vegetable materials at a suitable clearance occurs between the thick plate and the blades. Each of the blades engages lumps of vegetable materials until the fifteenth blade mounted on the cutter drum finally engages a sizable amount of the vegetable materials and when the handle crank moves one complete turn, the cutter blade will cut fifteen times. The sliced vegetable materials are collected at the bottom of the machine through the sprout.

4.0. SHAFT ANALYSIS DESIGN.

The point of maximum bending moment of the uniformly distributed loading on the shaft, can be determined by considering Figure 5.

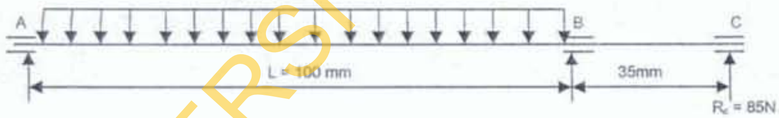
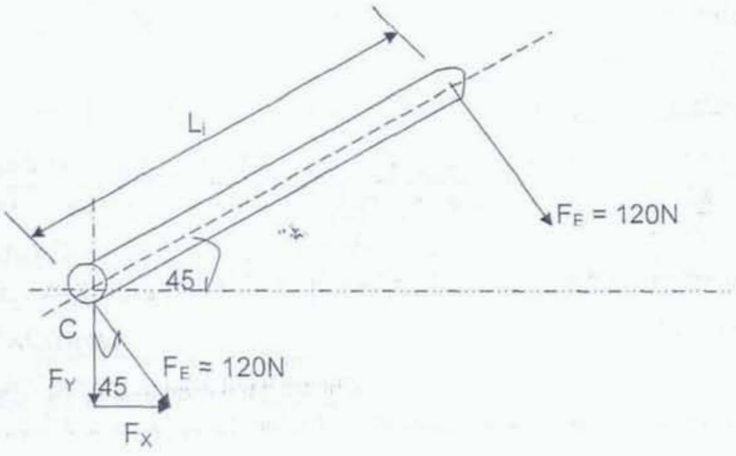


Fig.5. Uniformly Loaded Shaft.



L_l = length of handle and F_E = applied force.

Fig. 6. Reaction Forces at Point C.

From the force analysis, it can be seen that the reaction at point C is given by;

$R_C = F_V = F_Y = 120 \cos 45^0 = 85$ N

$\therefore F_V = R_C = 85$ N. ---------------------------------- (3)

Also from the force analysis of the cutter – housing in Figure 7, we have the following;

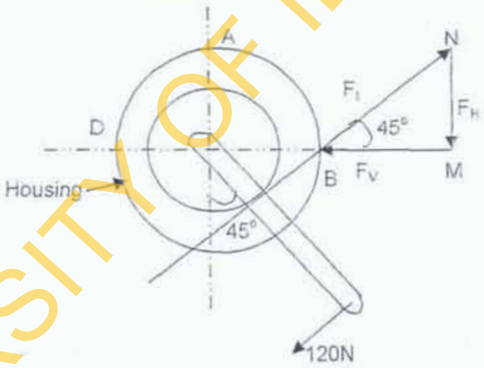


Fig.7. Forces on Cutter – Housing.

where F_t = tangential cutting force,

F_H = horizontal cutting force,

F_V = Vertical cutting force,

W_H = uniformly distributed horizontal loading,

W_V = uniformly distributed vertical loading.

r_c = radius of cutter,

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T = applied torque,
L = length of shaft
M = bending moment.

Also from the Figure we have that $F_t = \frac{T}{r_c}$ (4)

but $r_c = 9mm$

T = 120 x 140 = 16.8KN mm

From Equation 4, the cutting force can

we have $F_t = \frac{T}{r_c}$ (5)

$\therefore F_t = \frac{16.8}{9} = 1.87KN$

Also $F_H = F_t Cos45^0 = F_V = 1.87Cos45^0$.

$\therefore F_H = F_V = 1.32KN$.

So from the horizontal and vertical forces, the uniformly distributed loading is given as

$W_H = W_V = \frac{F_H}{l} = \frac{1.32}{100} = 1.32 \times 10^{-2}$ KN/mm (since $F_H = F_V$) (6)

$\therefore W_H = W_V = 13.2$ N/mm.

The point of maximum bending moment is now determined from Figure 6 as follows;

From the loading diagram of the shaft we have;

$M_{11} = R_{Y11}X$

$M_{12} = R_{Y12}X$

but the total bending moment is given as;

$M = M_{11} + M_{12} = R_{Y11}X + R_{Y12}X = (R_{Y11} \times L + R_{Y12})X$

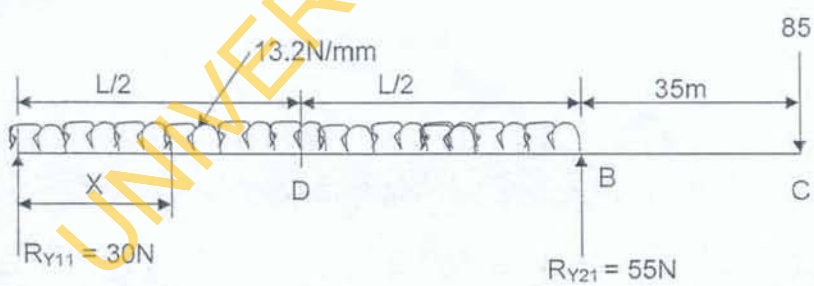

Fig. 8. Point of Maximum Bending Moment.

$$\therefore M = \{R_{Y11} + \frac{w}{2}(L - X)\}X \quad (7)$$

The point of maximum bending moment is obtained by differentiating Equation****

$$\frac{dM}{dx} = 0$$

$$\therefore \frac{dM}{dx} = \frac{d}{dx}\{R_{Y11} + \frac{W}{2}(1 - X)\}X = 0$$

$$\therefore X = \frac{L}{2} + \frac{R_{Y11}}{W}.$$

But L = 100mm, R_{Y11} = 30N and W = 13.2N/m;

$\therefore$ X = 52.3mm.

Therefore the maximum bending moment M is obtained as follows;

$$M = \sqrt{M_X^2 + M_Y^2} \quad (8)$$

but $M_X = M_Y = \{R_{Y11} + \frac{w}{2}(L - X)\}X = \{30 + \frac{13.2}{2}(100 - 52.3)\} \times 52.3 = 1803$mm.

$\therefore M_X = M_Y = 18.03$ m

$\therefore M = \{(18.03)^2 + (18.03)^2\}^{1/2} = 25.5$ Nm.

The Torque T = F_E x h,

where F_E = 120 N = force acting on the handle and h = 140 mm = length of handle.

$\therefore$ T = 120 x 140 Nmm = 16800 Nmm or 16.8 Nm.

The shaft diameter is estimated from the given equation;

$$d_o \geq \{\frac{32x10^3}{\pi\sigma_y}\sqrt{(k_b M)^2 + (k_t T)^2}\}^{1/3} \quad (9)$$

where d_o = diameter of shaft

σ_y = yield strength of shaft material,

K_b = bending load factor,

K_t = torsional load factor,

M = maximum bending moment.

$$\therefore d_o \geq \{\frac{32x10^3}{280\pi}\sqrt{(2.36)(25.5))^2 + ((1.95)(16.8))^2}\}^{1/3},$$

$\therefore d_o \geq \sqrt[3]{2492.601975}$,

$\therefore$ $d_o \geq 13.5587$ mm, and d_o was taken to be 18.00mm.

The bending moment diagram resulting from the shaft design is presented in Figure 9.

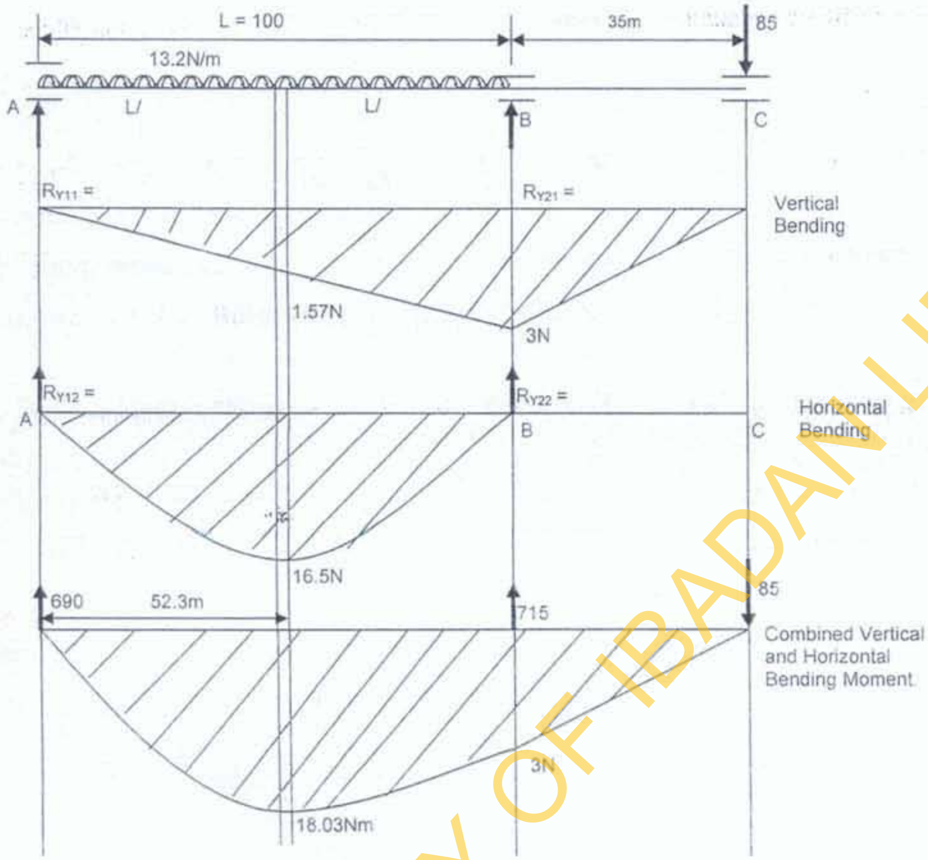

Fig. 9. The Bending Moment Diagram

5. TEST AND OBSERVATION.

Some vegetables were loaded in the hooper while the crank handle was wound round as fast as 35 revolutions per minute while pressure was applied on the vegetable materials inside the hooper. This action was repeated four times and fine sliced bits of vegetable were obtained. Three different types of vegetable were sliced with the machine and the time taken to slice the same quantity of vegetables recorded as presented in Table 1.

Table 1: Time Taken to Slice Some Quantity of Vegetable.

S/No.	TYPE OF VEGETABLE	WEIGTH (gm)	SLICING TIME (min)
01	Pumpkin leaf	475	2.0
03	Bitter leaf	475	1.5
02	Green Vegetable	475	1.0

MODELING THE MACHINE SLICING TIME.

The pumpkin leaf vegetable was selected to model the time require to slice a given weight of vegetables. The process involved the slicing of different known weights of pumpkin vegetables using the fabricated machine while the slicing time is recorded at each stage. The result is presented in Table 2.

Table 2: Machine Slicing Time for Pumpkin Leaf Vegetable.

Weight, x (gm)	100	150	200	250	300	350	400	450	500	550
Slicing Time, y (min)	0.55	0.75	1.00	1.50	1.85	2.05	2.50	3.00	3.25	3.75

In our modeling, y (slicing time) is the depended variable while x (weight) is the predictor and the results from our modeling is presented in Table 3.

Table 3: Summary of Results from the Model.

Model Factors	Coefficients	Mean	Standard Deviation	Standard Error of Reg.
Constant	0.007212	2.02	1.0960	0.3466
Weight (x)	-0.323939	325	151.3825	47.8714
N = 10, R^2 = 0.99,	Stand Error (s) = 0.1018,	DurbinWatson = 1.716913		

The resulting equation from the model for the machine slicing time is therefore,

$$y = 0.007212 - 0.323936x. \quad (10).$$

The actual values, predicted values and the residual values of machine slicing time are presented in Table 4, while the plot for the actual, predicted and residual values of slicing time is presented in Figure 10.

Table 4: Actual and Predicted Values of Slicing Time.

Actual Value	Predicted Value	Residual Value
0.55	0.35636	0.19364
0.75	0.72606	0.02394
1	1.0958	-0.0958
1.5	1.4655	0.0345
1.85	1.8352	0.0148
2.05	2.2048	-0.1548
2.5	2.5745	-0.0745
3	2.9442	0.0558
3.25	3.3139	-0.0639
3.75	3.6836	0.0664

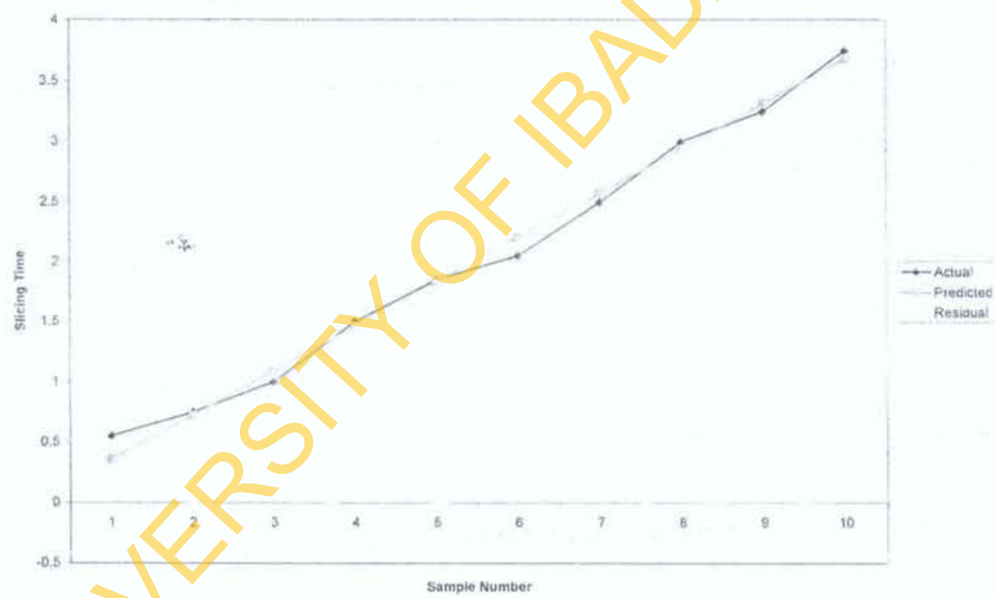

Fig. 10: Actual, Predicted and Residual Values of Slicing Time.

It was observed that it takes two minutes to slice 475gm of pumpkin leaves which are harder than bitter leaves. Also it takes 1.5 minutes to slice the same weight of bitter leaves while the same 475gm of green vegetables take only 1.0 minute to slice.

6.0. CONCLUSION

The food processing equipment helps in producing large quantities and keeps cost under control. The vegetable slicing machine was developed to enhance the local processing of vegetables by consumers. The major components of the machine which were fabricated using locally sourced materials include; the hopper, the cutter housing, the cutting blades, the sprout, the shaft and a wooden handle.

The development of the vegetable slicing machine demonstrated the fact that such food processing equipment helps in producing large quantities and keeps cost under control. The machine is designed to slice cheese, vegetables, ham, onions, green peppers and sandwich ingredients under good and hygienic conditions and it is designed to accommodate up to fifteen cutting blades made of mild steel material.

REFERENCES:

Frank, P., 2004. Historical Albion Michigan, Albion History / Genealogy Resources. Morning Star, February 15, 2004. pp16.

Hardin, C.W., 2001. The Principles of Slicing Machines. Journal of Manufacturing Engineering. Vol.6, No.13, pp.31- 42.

Odior, A. O., 2007.Design and Prototype Development of a Meat Slicing Machine. Global Journal of Engineering Research. Vol.6, No.2. pp 127 – 132.

Ohaneche, F.C., Ogbeide, O.O and Oyeniyi, A.G., 2005. Design and Manufacture of a Meat Slicing Machine. B.Eng. Thesis, Univ. Benin, Nigeria, 65pp.

Tannahill, R., 2003. Food in History. 5th Edition. Three Rivers Press, New York.