Design and preliminary evaluation of a snail shelling machine

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Abstract: Snail meat is an alternative source of rich protein in the tropics and an important part of many diets. Despite its wide popularity as a cheap source of dietary protein, very little investments have been made in the processing of snail meat in terms of processing equipment and other value addition technologies. Up till now, many farmers utilize manual methods in breaking snail shells which are very demanding and tiring. Furthermore, existing technology of snail shellers are not only expensive, but the technology is beyond the reach of many local farmers thereby discouraging many from exploring the abundant potentials of the processing value chain. Hence, this study designed and evaluated a snail shell cracking machine using standard engineering procedures and locally available materials that will specifically replace human efforts in snail shell removal. The components of the machine include: the hopper, cracking chamber, rollers, discharge chute transmission shaft, chain drive and a prime mover. Preliminary test of 20 mature snails at a constant speed of 410 r/min showed that the average cracking time for the snails was 1.73 seconds while a total of 34.65 seconds was spent in the process. A throughput achieved during testing translates to 330 kg hr^{-1} and an efficiency of 96.03% was also recorded during the testing. The total cost of producing the machine was ₦150, 000 the equivalent of $410.Hence, this study establishes that snail processing can be achieved using mechanical means at very reasonable cost and further processing opportunities can be explored using the technology.

Keywords: mechanical deshelling, snail processing, value addition

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1 Introduction

Snail meat is a high-quality food that is rich in protein (low in fats,) and a good source of iron, that is, 3.5 mg/100 g (USDA, 2006). Land snails are non-conventional wildlife protein sources in Nigeria and some parts of Africa (Fagbuaro et al., 2006). Snails are low-fat, protein-rich and a good source of a variety of essential vitamins and minerals, including magnesium, selenium, vitamin E and phosphorus (Kerns, 2018). Snail meat is a highly relished delicacy (also known as “Congo meat”) in Nigeria as they constitute an important source of animal protein for many coastal communities in Nigeria (Fagbuaro et al., 2006) who cannot afford conventional animal protein sources. Asides from its fibre-rich meat, the shell also serves as raw materials for different end uses ranging from animal feed, construction materials and as additives to many industrial processes. The comparative nutritive value of snail meat to

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some animal protein sources has been studied by some researchers where the protein contents of 88.37%, 82.42% and 92.75% were discovered in snail meat, pork and beef respectively (Imevbore and Ademosun, 1988; Adegoke et al., 2010).

It is estimated that snail is 15% protein, 2.4% fat and about 80% of water (Saldanha et al., 2001).

This makes snail healthy alternative food for people with high protein low-fat diet requirements (Adegoke et al., 2010).

Snails belong to the family of phylum mollusks or mollusks and to the class gastropods, a large group of invertebrate animals, mostly found in wet vegetation in damp and shady places, especially during rainy seasons in the tropics (Marinoni et al., 2012; Akande et al., 2018). Snails have a single usually spirally coiled shell, into which the body can withdraw when the snail's body is drawn into the shell, it is sealed by a Horney plate called the operculum. Land snails serve an important role in the ecosystem. They eat very low on the food web, as most land snails will consume rotting vegetation like moist leaf litter, and also fungi and sometimes eat soil directly. The land snail relies on a diet rich in calcium and other nutrients to support the growth and repair of its shell as well as its overall health (Coppolino, 2014). The major sources of animal protein for the Nigerian populace come mainly from livestock in the form of poultry, beef, mutton and pork (Fagbuaro et al., 2006). These major sources are currently being threatened by the multi-dimensional challenges of climate change-induced drought, epidemics, high cost of feed, primitive animal husbandry techniques and low investment in animal production technology. Similarly, the increasing growth of human populations together with the rising standard of living has also placed great pressure on the existing sources of animal protein (Fagbuaro et al., 2006). Hence, there is a need for the development of a sustainable processing value chain for snail meat production in Nigeria.

A number of studies have been carried out on snail production in Nigeria. Adegoke et al. (2010) investigated the epidemiological and nutritional parameters of land snails with significant attention on the microbial loads and nutritional benefits of the African giant land snails. They discovered that the African giant snail had the best nutritional composition of the snail species that were considered. Similarly, Fagbuaro et al. (2006) highlighted that the component of crude protein in four elected snail species ranged from 18.66% to 20.56% respectively. The work of Ituen (2015) highlighted some mechanical and chemical properties of selected molusc shells where the maximum crushing loads for the land snail, clam, water snail, and periwinkle were found to be 85 KN, 65 KN 31 KN, and 6 KN respectively.

Despite the rich nutritional benefits of snail meat and its rising popularity as a nutritional and dietary alternative, snail meat processing has not received significant attention through innovations, research, and investments in processing technology and facilities respectively. One major activity required in snail meat processing is shell removal which is commonly carried out through manually crushing of the shell in order to retrieve the meat. Traditional methods of meat removal require the destructive crushing of the shell with heavy tools or the utilization of sharp pointed tools while others depend on the use of high-temperature water (78^0C-90^0C) in the removal of the meat from the shell. These methods require significant time and effort in their operation which cannot sustainably meet the demands of a rapidly expanding consumer base. Currently, there is no literature on the design, fabrication and testing of a small scale snail meat processing machine. Hence this study aims to design a snail shell cracker cum meat separator that will separate the snails from the shell using locally available materials. Specifically, the study will fabricate the designed machine as well as test it to specify its efficiency.

2 Materials and methods

The shell cracker cum meat separator is an improvement of the stone crusher machine in the mining industry. It is a machine that will eliminate the drudgery associated with the manual processing of snail meats. The snails are assumed as solid stones that will need to be crushed by a double roller rolling at a uniform speed. The factors considered in the design of the machine include physical characteristics of the product, (size, weight etc), Feed rate of the product, crushing strength, the velocity of the product towards the hard wall, the torque required to cause shell failure, motor speed and clearance between the rotor and the cracking wall respectively. The unit operations of snail meat processing are shown below.

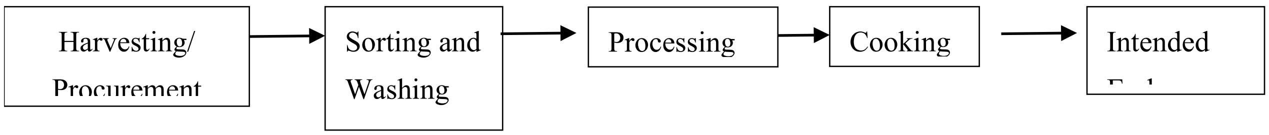


Figure 1 Unit operations of snail meat processing.

2.1 Design calculations and components selection

The major principle that will be applied in the shelling of the snail shells is size reduction.

The components of the machine include:

Hopper: serves as the opening where fresh snails are fed into the machine during operation.

Cracking chamber: is where the cracking of the snails takes place.

Chassis: is the rigid structure that provides support to the machine during operation. It is the frame used to carry all the parts of the machine.

Adjusters: allow the flexible movement of the rollers during the cracking of the Snail shells.

Rollers: serve as the cracking components of the machine

Shaft: is attached to the roller, and is used to transmit power from the electric motor through its transmitting gears.

Chain drive: is used to transmit motion from the electric motor to the rollers.

Prime mover: serves as the prime mover of the cracking machine, and is used to drive the rollers.

2.1.1 Power requirement

The theoretical energy required to break a solid to smaller particles is related to the energy required for the formation of new surfaces out of the originally available ones (Anonymous, 2017b). Therefore, the power requirement is given by the equation (Khurmi and Gupta, 2005):

$$P = \frac{2\pi NT}{60} \quad (1)$$

Where P, is the power requirement (Watts)

T is the Torque (N m)

N is the speed of revolution of the rotating mechanism

The crushing Torque (N m) is given by

$$T = F.r \quad (2)$$

Where F is the cracking force exerted by the rotating element on the shell and r is the radius of the impact. The maximum cracking force reported by Ituen (2015) was 8.5 KN with a maximum radius of impact of 5.05 mm. Therefore, a torque of at least 42.93 N m is required to drive the cracking procedure in the machine. Assuming a speed of 300 r/min is the minimum speed needed to achieve cracking of the snails, hence the power requirement becomes 1, 348 Watts(1.79 hp).

2.1.2 Nip angle

The geometry of the roller is given in Figure 2. From the the nip angle 2α between the two rollers of radius R, the size of the particle to be crushed (d) and the distance between the two rollers L is given by Egbe and Olugboji (2016).

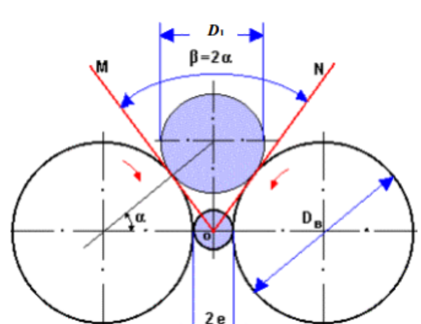


Figure 2 Roller geometry (Anonymous, 2017b)

$$Cos\alpha = \left(\frac{R + \frac{L}{2}}{R + \frac{d}{2}} \right) \quad (3)$$

Where, d =diameter of feed particle (mm), R = radius of the rollers (mm), L =distance between the two rollers (roll gap) (mm). Thus d becomes

$$d = 2\left(\frac{\left(R + \frac{L}{2} \right)}{Cos\alpha} - R \right) \quad (4)$$

The nip angle 2α depends on the coefficient of friction μ between the roll surface and the particle surface. The relationship between compressive force, F, coefficient of friction, μ and nip angle is given by Egbe and Olugboji (2016)

$$F \sin\alpha = F\mu \cos\alpha \quad (5)$$

$$\sin\alpha = \mu \cos\alpha$$

$$\mu = \frac{\cos\alpha}{\sin\alpha} = \tan\alpha$$

$$\alpha = \tan^{-1}\mu \quad (6)$$

Average coefficient of friction μ of snail shell was given to be 0.554 by Ituen (2015)

$$\alpha = \tan^{-1}0.554{=}28.99^o$$

$$2\alpha{=}57.97^o$$

The specifications for the diameter of each roller is 90 mm, and width of 110 mm W, of each roll is 10 mm, and the maximum roll clearance between the rollers is 5 mm.

2.1.3 Thickness of the roll

A hollow cylindrical shaft of known thickness, t was used to build the roller, and its ability to withstand the compressive strength of the snail is determined by (Khurnmi and Gupta, 2005).

$$\sigma_t = \frac{p \times d}{2t} \quad (7)$$

Where t= thickness of the roller,

σ_t= tensile strength of steel roller

P= compressive stress required to crush a sample snail shell.

The maximum compressive strength of land snails as reported by Ituen (2015) was 16.56 MPa (16.65 N mm^{-2}). And the tensile strength of steel is 410 MPa (Khurmi and Gupta, 2005),

Therefore, the thickness of the roller is given by

$t = \frac{16.65 \times 90}{410 \times 2} = 1.83$ mm say 3.5 mm thick plate should be used for the rollers.

2.1.4 Determination of particle size that can be fed into the roll crusher

The maximum size of the particle that can be fed into the roll crusher is determined by the radius of the roller R, roll gap, L and the angle of nip. According to Ituen (2015), the maximum diameter of an African giant land snail (Achatina) was 91.23 mm. Therefore this information was vital in the design of the hopper.

2.1.5 Hopper design

The hopper design was based on the volume of a frustum. The volume of frustum can be obtained as follows:

$$V = \frac{h}{3}\left[\left(A_1 + A_2 \right) \sqrt{A_1 + A_2} \right] \quad (8)$$

Where;

V is the volume of the frustum in m^3,

h is the height of the frustum in m

A_1 is the area of upper base in m^2

A_2 is the area of the lower base in m^2.

A galvanized steel sheet was used in the development of the hopper.

2.1.6 Shaft Design

The weight of the shaft will have an effect on the critical speed of the critical shaft (Khurmi and Gupta, 2005).

$$\text{Critical Speed of Shaft } (\acute{\omega}_s) = \sqrt{\frac{48EI}{ML^2}} \quad (9)$$

Where, E is modulus of elasticity of steel (GPa), L is the shaft length (m) and.

I is moment of inertia (kgm^2) which is given by

$$I = \frac{\pi d^4}{64} \quad (10)$$

The diameter of the shaft is given by Egbe and Roland (2016):

$$D = \left[\frac{32N}{\pi} \sqrt{\left[\frac{K_t M}{S_n'}\right]^2 \oplus \frac{3}{4}\left[\frac{T}{S_y}\right]^2} \right]^{\frac{1}{3}} \quad (11)$$

Where N is the design factor accounting for safety, K_t is the factor of stress concentration, M is the bending moment (Nm), S_n is the endurance limit (0.35-0.60 of tensile strength Mpa), T is the torque (Nm) and S_y is the yield strength (Gpa). The shaft is one of the main components of the machine and is acted upon by weights of material being processed, pulley, cracking rollers and the bars. A mild steel rod of diameter 20 mm and length 450 mm was used for the shaft.

2.1.7 Chain design

The velocity ratio of the chain drive is given as

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \quad (12)$$

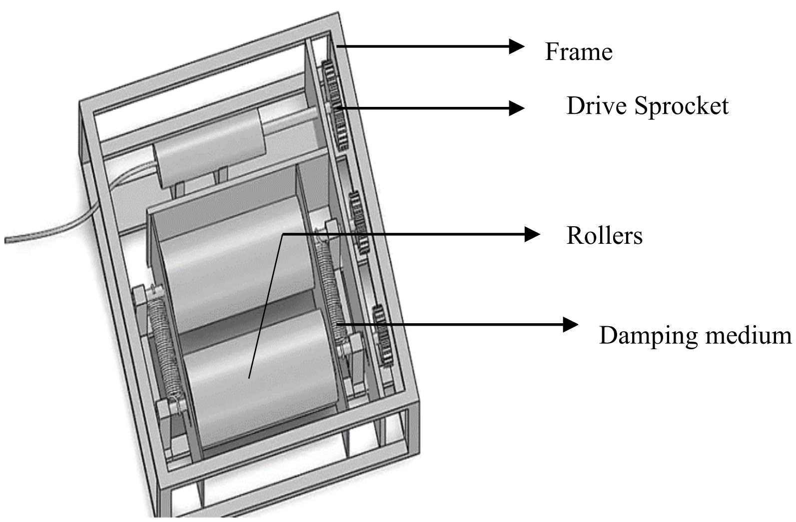
Where N_1 and N_2 are the speed of rotation of motor sprocket (r/min) and speed of roller sprocket respectively (r/min). T_1 and T_2 represent the number of teeth on the motor sprocket and the number of teeth on the roller sprocket respectively. The smaller sprockets selected consists of 15 teeth while the larger sprockets consist of 60 teeth ensuring a velocity ratio of 1:4.

Fabrication Method

The use of cutting, welding and bolting methods was adopted in the fabrication of the machine.

2.1.8 Size determination.

The size parameters of the snails which include linear dimensions of length, width, and thickness were measured using a venier caliper (Ituen, 2015).



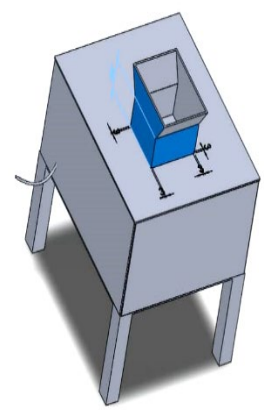


Figure 3 Some components and isometric view of the machine

2.2 Performance tests

An optical tachometer was used to measure the input speed from the electric motor, weighing machine was used to measure the weight of the snails before being fed into the machine. A digital stopwatch was used to measure the time for the throughput. The size of the land snails which are shown by Equivalent diameter D_E, Sphericity, ϕ and aspect ratio, were determined using the relationship established by (Gupta and Das, 1997; Joshi et al., 2003; Faleye and Atere, 2009; Ituen, 2015)

$$D_E = (LWT)^{\frac{1}{3}} \quad (13)$$

$$\varphi = \frac{D_E}{L} \quad (14)$$

$$Aspect\ ratio = \frac{W}{L} \quad (15)$$

Machine Operation.

The machine elements (roller drum) are enclosed in a rectangular shaped box with lateral iron bars welded to them to act as the cutting edge which will be responsible for the delivering cracking impact to the snails. The delivery chute located beneath the oppositely rotating rollers.

2.3 Performance evaluation

Optical tachometer was used to determine the speed of the rollers while the efficiency of the cracking process will be evaluated by

$$\text{Efficiency (\%)} = \frac{Weight\ output}{Weight\ input} \times 100 \qquad (16)$$

The operational capacity will be determined by

Operational Capacity: This will be determined by

$$I = \frac{Total\ weight\ of\ the\ snail\ meat}{Time\ taken}\ kg/_{hr} \qquad (17)$$

The snails were procured from open markets and they were kept in s very cool environment to preserve their moisture content at an average of 82.5% before the test procedure. A digital moisture meter was used to keep track of the food burrow sand where the snails were kept.

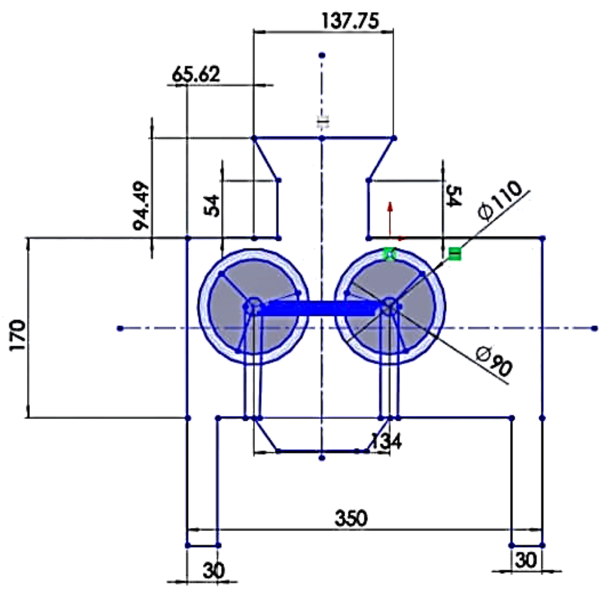


Figure 4 Side view of the machine with dimensions in mm

2.3.1 Test Procedure

A total of 20 mature snails were each fed individually into the machine in a continuous manner to determine the cracking time for each snail. The snails were labeled 1-20 for easy identification while the physical parameters were taken before being fed into the machine. The first group of 10 was laid beside the machine in order to prevent errors in measurement. The machine was operated at no load as parts needing adjustments were noted and promptly fixed before introducing the snails. The time taken for snail to be cracked and ejected from the chute of the machine was recorded while the total weight of the shell was recorded after the runs. The fabricated machine is shown in the Figure 4 below.

Figure 4 The manufacturing process of the machine and the fabricated machine

3 Results and discussion

The physical parameters of each sample and time taken are presented in Table 1 below. At a constant speed of 410 r/min, the following observations were recorded in the machine performance.

Table 1 Results of observation in machine testing

Sample	Mass kg	Equiv Diam cm	Sphericity	Aspect Ratio	Cracking Time
1	0.104	1.90	0.16	0.55	2.4
2	0.198	1.57	0.13	0.37	2.65
3	0.154	1.42	0.14	0.53	1.67
4	0.122	1.61	0.14	0.65	1.36
5	0.096	1.71	0.17	0.54	1.06
6	0.124	1.21	0.12	0.61	2.16
7	0.132	1.44	0.13	0.51	1.45
8	0.106	1.61	0.15	0.59	1.44
9	0.096	1.39	0.14	0.56	1.35
10	0.072	1.38	0.15	0.49	1.04
11	0.185	1.75	0.14	0.43	1.56
12	0.175	1.69	0.13	0.44	1.48
13	0.16	1.75	0.14	0.46	2.08
14	0.275	1.57	0.12	0.49	1.76
15	0.185	1.71	0.14	0.50	2.4
16	0.2	1.52	0.14	0.56	2.03
17	0.18	1.66	0.15	0.56	2.12
18	0.235	1.65	0.14	0.52	1.59
19	0.195	1.77	0.16	0.49	1.82
20	0.19	1.67	0.15	0.57	1.23

The statistical analysis of the observations was carried out and the summary of the outcomes is highlighted in Table 2. Table 3 shows the descriptive statistics of the variables while the correlation of measured variables is presented in Table 3. The single factor Analysis of Variance (ANOVA) of the observations (at uniform speed) is shown Table 4.

Table 2 Statistical Summary of the Observations

Groups	Count	Sum	Average	Variance
Mass	20	3.184	0.1592	0.002707
Equiv Diam	20	31.97854827	1.59892741	0.027146
Sphericity	20	2.833536031	0.1416768	0.00014
Aspect Ratio	20	10.3972541	0.5198627	0.004336
Time	20	34.65	1.7325	0.21242

Table 3 Correlation of the Observations

	Mass	Equiv Diam	Sphericity	Aspect Ratio	Time
Mass	1				
Equiv Diam	0.25	1			
Sphericity	-0.38	0.60	1		
Aspect Ratio	-0.37	-0.25	0.22	1	
Time	0.351	0.18	-0.25	-0.27	1

The correlation of the variables indicates that the aspect ratio correlates to sphericity (0.221), sphericity strongly correlates with equivalent diameter (0.598) of each snail while the Time required for snails to be processed is dependent on the Mass (0.345) and Equivalent diameters (0.1779) of the snails respectively.

Table 4 ANOVA of the Test Variables

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	48.51	4	12.13	245.77	3.45E-49	2.47
Within Groups	4.69	95	0.05			
Total	53.20	99				

The ANOVA results show there is a significant level of interaction within the parameters of study which is indicated by P-value of $3.45\text{x}10^{-49}$ (α=0.05) which further emphasizes the correlation values obtained in Table 3. From the second evaluation of the efficiency of the machine relating to time, the time snail and machine parameters showed that a total time of 34.65 seconds was required to crack the total snail weight of 3.18 kg.

Therefore, the machine is capable of a throughput of 330 kg hr^{-1} and an efficiency of 96.03% was recorded.

The total cost of fabricating the machine was N150, 000 ($410) at an exchange rate of 365-1$ as at December 2019.

Figure 5 Some snails before and after the processing operation

4 Conclusion and recommendations

An original mechanical snail shell cracker was designed and tested at 410 r/min drum roller speed and processing a total of 3.18 kg in 34.65 seconds. The aim of this project in replacing human efforts in snail processing by helping to reduce drudgery was achieved ensuring snail shells and its safer in terms of cracking the snails shell without harming or causing injury to the hand during processing of snail meat.

During the testing the snail meat and cracked, shells came out of the chute together. Hence, further work can be carried out to identify the physical properties of the shell that can be used for the separation of the shells in other studies. Similarly, a comprehensive testing using different speed inputs will go a long way in helping to standardize the operations of the processing machine for industrial purposes.

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