Performance evaluation of three coconut cracking devices and comparison with conventional cracking technique

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Abstract: Performance of three coconut cracking devices; punch-split, impact-split, hydraulic-split were carried out and their comparison with conventional (hand cracking technique) evaluated. Each cracking technique was evaluated for capacity, efficiency, ergonomics, and time required to crack a unit of different coconut grades. The results showed that the average cracking efficiency for punch-split was 87.09 percent with a range of 86.76 to 95.00 percent, impact-split efficiency varied from 83.33 to 95.00 percent with the average of 90.08 percent while hydraulic-split varied from 90.00 to 95.00 percent. Comparing the performances of the three techniques with the conventional technique, the cracking efficiency varied from 86.67% to 100% with an average of 94.17 percent, indicating the devices compares favorably with the conventional technique. The convention cracking has the least output capacity of 110.09 kg hr^{-1} compared with the hydraulic-split with highest average capacity of 383.83 kg hr^{-1}. The output capacity varied for different grades of coconut with the hydraulic-split having the highest capacity of 389.33 kg hr^{-1} for grade B coconuts, while the conventional method has the lowest for grade D coconuts. Ergonomically, the hydraulic-split device compared favorably with other devices in risk factors, loading, operation, product handling and management.

Keywords: coconut grade, cracking, punch-split, impact-split, hydraulic-split, sphericity, efficiency, roundness

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1 Introduction

The term coconut (*Cocos nucifera*) often refers to the entire coconut palm, which include the seed, and the fruit. The seeds which is said to be a *drupe* and botanically not a true nut is the only accepted species in the genus *Cocos* (World Wildlife Fund, 2010). Coconut fruit is made up of a thin outer exocarp, a thick fibrous fruit (mesocarp) known as husk, the hard protective endocarp or shell and three depressions called “eyes” located at one end of the nut. The coconut is one of the world’s most useful and important perennial plants with multiple uses for thousands of years. As coconut enters today’s world, people over the world are becoming aware of its many health benefits and food uses in many facets of daily life, in some instances even as currency. Coconut has considerable significance in the national economy in view of rural employment and income generation.

Despite the several uses of coconut products, a common problem often faced by many coconut farmers in developing countries including Nigeria is splitting or cracking open of mature coconut. Cutting open a tender coconut and separate the kernels from the shell is not an easy task. However, it is still a tough nut to crack, in that hard work is involved in breaking fresh coconuts in many homes and restaurants for everyday cooking. There had been in existence different devices and mechanisms for splitting coconut, but involves direct human effort and aids. These methods ranges from manual splitting (by

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hitting them on hard surface), to punch-splitting (using the pointed end of the screw shaft (Bello, 2014), to impact (using an impact blow from impact tools such as a hammer), to more sophisticated devices as coconut splitters (Beloin, 2008, 2009). Throughout the history of mechanization of coconut, very few models are available in the market today.

The present trends and tools in use are ergonomically unsafe, unsustainable, and messy and often require skills and training, as such, deterring housewives, chefs or restaurant operators from using fresh coconuts in their cooking more often. The functional evaluation of these techniques and devices showed that most of these crackers are still deficient in their operations and evaluations. This work evaluats the performances of three devices developed and comparative assessment with conventional methods. Breaking the hard outer shell of the coconut fruit is a tedious job in the micro scale food processing enterprises. Several methods have been identified in the splitting of coconut, but widely practiced are the conventional techniques widely practiced using a sharp knife (Vinay et al., 2016), meat cleaver, or wooden mallet as well as hits it on a hard surface until it cracked. When breaking the coconut by hitting on a hard surface, put stress on the shoulders, hands, palms and upper back. Apart from the drudgery, the process is not hygienic in that most of the times fragments of the shattered coconuts flies and dropped on the ground, which are eventually picked up and added to the pile. This is a potential source of contamination. To reduce this drudgery and clean operations, mechanical splitting was developed.

Over the century, several devices had been developed to split open coconut, so that the kernel can be easily removed from the shell (Anitha and Shamsudeen, 1997; Jippu, 1998; Shamsudeen et al., 1999; Roshni et al., 2009; and Unnikrishnan, 2010). These devices varied in output performance, ergonomic designs, cracking efficiencies and the number of coconuts split per hour. For instance, Food Innovation & Resource Centre, Singapore developed the 1st ever coconut cutting machine that is able to crack 450 coconuts per hour, a significant increase in productivity by 435%. More importantly, the machine is simple and safe to operate as the user presses a button to activate the cutter to cut the coconut into half with great precision in less than one minute. In 2009, Ketan et al., (2014) developed a cocosplit nutcracker that splits with one firm blow from a large hammer. Several other research efforts identified different cracking mechanisms to improve cracking performances, however this research seek to provide a comparison of three device-mechanisms for cracking coconuts. The objective of this work is to evaluate the performances of three coconut cracking device mechanisms; a punch-split, impact-split and hydraulic-split and compare its performance with the conventional craking technique and coconut dimensional properties.

2 Materials and method

2.1 Materials

Materials required for this study include:

Cracking devices: Three experimental cracking devices (Figure 1): Punch-split device, impact-split device and hydraulic-split device fabricated in the carpentry and metal fabrication workshops of the department of Agricultural & Bio-Environmental Engineering Technology, Federal College of Agriculture Ishiagu was employed in the experimentation.

The punch-split device cracking mechanism comprises of a circular drive wheel of 200mm diameter centrally welded to a 350 mm long, 25.4 mm diameter full threaded drive shaft, with a splitting head. The shaft is simply supported by two 24 mm nuts forming a channel through which the shaft travels. The distance between the point at which the punching tool is connected and the point at which effort is applied is 140 mm.

A G-shaped metal connecting the base plate to the screw shaft offers structural support for the device. A spring loaded wooden block attached to the shaft support restricts the movement of the coconut placed within the half-hollow wooden constrictor centrally positioned in alignment with the screw shaft to hold the coconut in place during cracking.

Impact-split device: The impact-split device splits coconut with a firm blow from a 2000 g spring loaded hammer. The mechanism consists of a lever supported by a link on a G-frame connected to the 2000 g spring loaded hammer and a sliding support bearing for translation movement of the lever, a base plate offers support for the coconut and a pipe drain to collect the water.

The load-pressure (hydraulic) device comprises of four galvanized pipes reinforced with MS rod trusses capped with 19mm bolt and nuts to lock the trusses in place rigidly. Two 50mm wooden end plates (one at the base and one at the top) provide the required solid frame for the device. The device cracking mechanism comprises of a 5 ton hydraulic jack (the main working unit of the device), lever/handle, the coconut chamber and a pressure bearing plate sliding within the metal frame. The coconut chamber comprises of a constrictor cup, a coconut cage and the pressure plate. The coconut constrictor is formed of a half-hollow wooden material centrally positioned on the lower movable pressure plate. The constrictor has a hole drilled centrally to channel the coconut water into the groove on the lower plate which is channeled through a pipe into the receptacle cup beside the device.

Coconut samples: Coconut samples were sourced from the local market and their geometric dimensions noted for the determination of physical as well as mechanical properties of coconut for this experimental purpose.

Figure 1. Experimental cracking devices

2.2 Methodology

Instrumentation: To evaluate the performance of the devices and techniques, the following instruments were required to measure different parameters tabulated in Table 1.

Table 1 Instrumentation for performance evaluation of coconut cracker

S/No.	Parameter	Instrument	Accuracy	Range
1	Time	Stop watch	0.5 Sec.	0-30 min
2	Weight	Weighing balance	0.01g	0-5000 g
3	Length, width	Steel rule	1mm	0-300 mm
4	Size	Vernier caliper	0.01 mm	0 - 300 mm
5	Projected area	Graph paper		

2.2.1 Determination of physical properties of coconut fruit

For the determination of physical properties of coconut for this experimental purpose the coconuts were obtained from the local market. A total 30 coconuts were randomly selected, sorted into four grades A, B, C, and D by sizes (Figure 2).

Figure 2. Coconut samples (grades A, B, C & D) used for the experiment

Physical properties like size, sphericity, roundness, weight, moisture content, etc. of sample coconuts from each grade were studied. The following physical properties of coconut fruits were measured and some derived parameters determined according to (Mohsenin, 1986).

1. *Coconut equivalent diameter:* The coconut size was determined by measuring the dimension of the principal axis; major, intermediate and minor of randomly selected coconut fruits using vernier calliper. The major, minor and intermediate axes for coconuts are shown in Figure 3. The dimensions of 6 selected coconuts from each sample grades was measured and recorded.

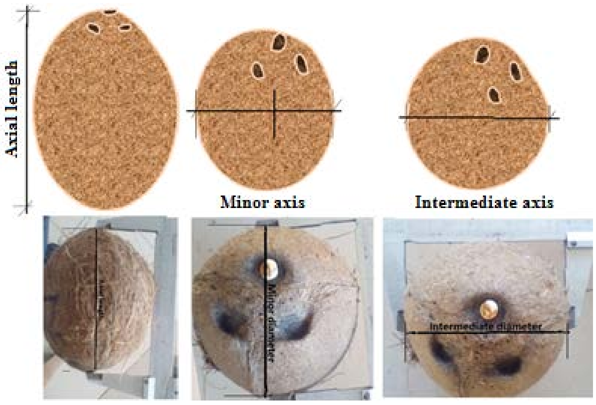

Figure 3. The three principal dimensions of coconut

The equivalent diameter d_p in mm considering a prolate spheroid shape of each grain, was calculated using the following expression (Varnamkhasti *et al.*, 2007; Dursun and Dursun, 2005):

$$d_p = \sqrt[3]{a\frac{(b+c)^2}{4}} \qquad (1)$$

Where

a = Major axis/length of coconut (mm)

b = Minor axis/width of coconut (mm)

c = Intermediate axis/thickness of coconut (mm)

Spher*icity of coconut*: Sphericity (ϕ) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain, was determined through equation (Varnamkhasti et al., 2007; Al-Mahasneh and Rababah, 2007):

$$Sphericity\ (\phi) = \frac{(a \times b \times c)^{\frac{1}{3}}}{a} \qquad (2)$$

Surface area of coconut: Surface area (S) was calculated using equations illustrated below (Al-Mahasneh and Rababah, 2007; Varnamkhasti et al., 2007):

$$S = \pi \times b \times c \times \frac{a^2}{(2a-b)} \qquad (3)$$

Roundness: The ratio of the projected area (A_p) to the area of circumscribing circle (A_c) gives the roundness of each seed.

$$Roundness = \frac{A_p}{A_c} \qquad (4)$$

Where

$$Area = \pi r^2 \qquad (5)$$

r = radius of the circle, mm

A_p= Projected area of tracing coconut seed, mm^2

A_c = Area of the smallest circumscribing circle, mm^2

To determine the areas, a coconut was selected randomly and placed on a graph sheet of paper on a horizontal table. The projected area of a coconut in its natural reset position was traced on the graph paper by mean of a pencil (Figure 4). The projected area was measured from the graph paper. The smallest circumscribing circle was drawn on the tracing of projected area.

Figure 4. Tracing the projected area of coconut

1. *Volume of coconut fruit:* Grain volume (*V*) was calculated using Bello *et al.*. (2018) equation:

$$V = \frac{\pi b^2 a^2}{6(2a-b)} \qquad (6)$$

2. *Weight of coconut:* The randomly selected 30 coconut samples were weighed on precision electronic weighing scale (SF-400, capacity 5000g × 1g/177oz × 0.1oz) and values recorded.

3. *Cracking time*: The cracking time is the total time required to crack a coconut. It is measured by the time lapse in cracking a nut.

4. *Total operating time:* This is the total time required to load, crack and unload the products from the device.

2.3 Device performance indicators

The following tests were carried out to evaluate the performance of these devices.

The time required to crack the coconut: The time required for cracking each coconut was measured using the stopwatch. The total time required for cracking includes time for coconut fixing and splitting.

a. Splitting efficiency: Splitting efficiency is expressed as the effect of splitting open a coconut compare to known device performance:

$$\boldsymbol{Splitting\ efficie} = \frac{\boldsymbol{Length\ of\ obervable\ crack}}{\boldsymbol{Diameter\ of\ cocnut\ along\ the\ axis}} \times \mathbf{100}\% \quad (7)$$

b. Device output capacity: The cracking capacity of the device was determined from the average cracking time required to crack the coconut. It is expressed as the quantity of coconut split per unit time of measurement:

$$Machine\ capacity = \frac{Total\ weight\ of\ cocnut\ split}{Time\ taken}\ (\frac{kg}{hr}) \quad (8)$$

Number of coconuts per hour: Total number of coconut split per unit time of measurement:

$$Total\ no\ of\ coconuts\ split = \frac{Machine\ capacity}{Mean\ unit\ weight\ of\ cocnut\ split} \quad (9)$$

3 Results and discussion

During the performance test, measured parameters viz. weight of whole coconut, cracking efficiency, time required to crack etc. were studied. The details of the results obtained are given and discussed below.

3.1 Physical properties of coconut samples

a. Physical features of samples: The physical properties (weight, axial length and diameters) of the randomly selected coconut samples in each grade A, B, C and D was carried out and the result shown in Table 2. The average weights of coconut in each grade were obtained in the range of 712.00 g for grade A, 511.67 g for grade B, 467.20 g for grade C and 337.80 g for grade D. The observed average dimensions of the major, minor and intermediate axis for all grades of coconuts are: A (130.74, 107.87, and 104.35mm), B (122.08, 95.71, and 94.18 mm), C (125.18, 91.10, and 93.81mm), D (103.06, 82.38 and 79.50 mm) respectively.

Table 2 Mean measured dimensional and weight properties of coconut samples

Samples	Mean of measured parameters				Roundness	Sphericity
	a(mm)	*b*(mm)	*c*(mm)	Weight (g)		
A	130.74	107.87	104.35	712.00	0.73	0.87
B	122.08	95.71	94.18	511.67	0.80	0.85
C	125.18	91.10	93.81	467.20	0.74	0.85
D	103.06	82.38	79.50	337.80	0.74	0.85
Mean	120.27	94.27	92.96	507.17	0.75	0.86

Coconut shape factors: The derived dimensions viz; the projected area, area of circumscribing circle, roundness and sphericity were measured for each grade of sample coconuts. The mean measured projected areas of the samples for A, B, C, and D respectively, are: 127.40, 117.00, 89.00, and 77.20 cm^2. The mean minimum and maximum values of projected area were 146 cm^2 and of 282 cm^2 respectively, while the mean minimum and maximum value of the circumscribing circle are 206 cm^2 and 400 cm^2 respectively. The average range of projected area and area of circumscribing circle was 201 and 295.31 cm^2 respectively. The roundness value ranged from 0.54 to 0.94 for the sample selected under this study was found with a mean of 0.75 while the sphericity is 0.86.

3.2 Devices performance test characteristics

a. Crack propagation in coconut samples: The pattern of propagation of the observed cracks in each coconut sample at each impact using each technique is shown in Table 3. On impact, hair pin/minor cracks appeared in most of the coconut samples, at subsequent impacts, the cracks developed progressively into major cracks and subsequently shattered cracks.Table 3 Patterns of crack propagations in coconut samples.

Samples	Length of crack at impact by hand					
	1st	*2nd*	*3rd*	*4th*	*5th*	*6th*
A	-	Minor	Major	-	-	
B	-	Hair pin	Major	Shatter	-	-
C	-	Minor	Major	Shatter		-

D	Hair pin	Minor	Major	-	-	-
Length of crack at impact by punch-split device						
A	-	Hair pin	Major	Shatter	-	-
B	-	-	Hair pin	Major	Shatter	-
C	Hair pin	Minor	Major	Shatter	-	-
D	-	-	Hair pin	Minor	Major	Shatter
Length of crack at impact by impact-split device						
A	-	Hair pin	Major	Shatter	-	-
B	-	-	Hair pin	Minor	Major	Shatter
C	Hair pin	Minor	Major	Shatter	-	-
D	-	Hair pin	Minor	Major	Shatter	-
Length of crack at impact by hydraulic-split device						
A	-	-	-	Minor	Major	Shatter
B	-	-	Minor	Major	Shatter	-
C	-	-	Hair pin	Minor	Major	Shatter
D	-	-	Minor	Major	Shatter	-

b. Device performance, efficiency: The mean cracking efficiency of different methods for different grades of coconut is given in Table 4. The cracking efficiency of conventional technique for different grades of coconut varied from 86.67% to 100% with an average value of 94.17%, while average cracking efficiency for punch-split was 87.09 percent with a range of 86.76% to 95.00%, and for impact-split, it varied from 83.33% to 95.00% with the average of 90.08% , while hydraulic-split varied from 90.00% to 95.00% .

Table 4 Mean cracking efficiency of each technique in coconut samples

Sample	Cracking efficiency (%)			
	Conventional	Punch-split	Impact-split	Hydraulic
A	86.67	95.00	95.00	95.00
B	95.00	80.00	83.33	90.00
C	95.00	86.67	88.67	91.43
D	100.00	86.67	93.33	82.50
Mean	94.17	87.09	90.08	92.23

Also, from the table, gradually A coconuts have higher cracking efficiencies for punch, impact-split and hydraulic-split devices, the conventional method recorded the highest efficiency of 100.00 percent for grade D coconuts while grade C coconuts had the lowest efficiencies for the devices. The differences in sizes of coconuts affect the cracking efficiencies of the devices. The relationships between different grades of coconut and cracking efficiencies in each of the techniques is shown in Figure 5.

Higher cracking efficiencies were obtained for bigger-size coconuts and reduiced cracking efficiencies for smaller-size coconuts throughout the experimentation. The effect of human control in conventional cracking technique is considered a critical factor responsible for higher cracking efficiency, while machine factors such as mechanical accuracies and component machining have some influence on the lower cracking efficiency in the three devices.

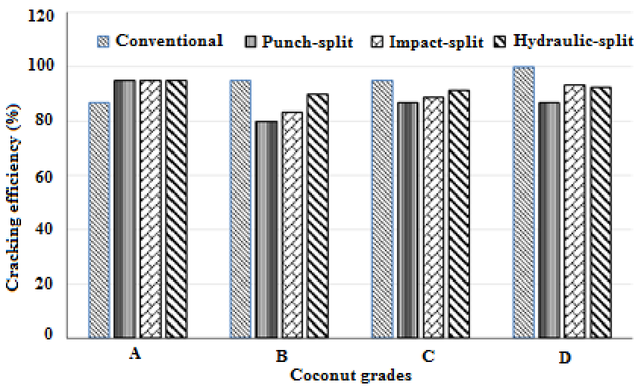

Figure 5. Cracking efficiency of each device on different coconut grades

a. Cracking time: Table 5 shows the cracking time in each of the techniques and the cracking time generally varied from 15 to 23 seconds for conventional method, while the devices varied from 4.2 seconds to 5.8 seconds to crack various grades of coconut samples. The variation in cracking time is obviously due to variation in size of a coconut. The average cracking time varied from maximum 17.73 seconds for conventional method to 4.6 seconds minimum time for hydraulic method.

Table 5 Time taken to crack different grades of coconut samples for each method

Sample	Conventional	*Punch-split	*Impact-split	Hydraulic-split
A	15.3	5.5	6.5	4.6
B	18.45	4.8	5.8	4.4
C	13.85	4.3	4.8	5.2
D	23.3	5.2	5.2	4.2
Mean	17.73	4.95	5.58	4.6

*Data sourced from Bello et al., (2018).

For grade B coconuts, the cracking time varied from 22 to 33 seconds and average time was 28.28 seconds while for grade C coconuts, the average cracking time was 30.58 seconds with a range of 27 seconds to 39 seconds. The trend is shown graphically in Figure 6.

a. Cracking capacity: The cracking capacity of device was determined from the time required to crack the coconut. The result of output capacity of the evaluation carried out is presented in Table 6. Conventional method of cracking has the least output capacity of 110.09 kg hr^{-1} while hydraulic-split has the highest capacity of 385.83 kg hr^{-1}. the capacity varies for different grades of coconut with the hydraulic-split recording the highest capacity of 389.33 kg hr^{-1} for grade B coconut while the conventional method recorded the lowest for grade D coconuts.

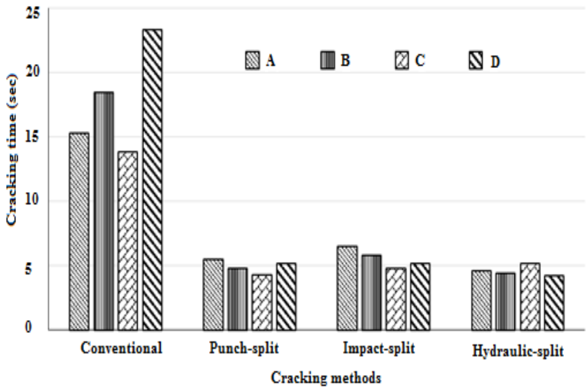

Figure 6. Time-based cracking performance of different methods on different grades of coconutTable 6 Output capacities of each method

Table 6. Output capacities of each method

Samples	Weight (g)	Conventional		Punch-split		Impact-split		Hydraulic-split	
		Time (sec)	Cap. (kg hr^{-1})	Time (sec)	Cap. (kg hr^{-1})	Time (sec)	Cap. (kg hr^{-1})	Time (sec)	Cap. (kg hr^{-1})
A	712.00	15.3	165.58	5.5	145.34	6.5	395.56	4.6	547.69
B	467.20	18.45	91.61	4.8	359.39	5.8	292.00	4.4	389.33
C	511.67	13.85	131.20	4.3	425.83	4.8	393.08	5.2	365.00
D	337.80	23.3	51.97	5.2	241.29	5.2	241.29	4.2	241.29
Mean	507.17	17.73	110.09	4.95	292.96	5.58	330.48	4.6	385.83

The average cracking capacity of each method was evaluated by the total number of coconuts split per hour and the result is presented in Table 7. Conventional method recorded the all-time low and a mean average of 110 coconuts split per hour. The hydraulic device recorded the highest number of coconut split per hour for all grades of coconut with the highest at 833.33 coconuts per hour. The variation in cracking time for different sizes of coconut resulted in variation in the cracking capacities of different grades of nuts. This indicated that the higher cracking time resulted into low output capacity and vice versa.

Table 7 Number of coconuts split per hour by each method

Samples	Conventional	Punch-split	Impact-split	Hyd-press
A	232.56	204.13	555.48	769.23
B	196.08	769.24	625.00	833.33
C	256.42	832.24	768.23	706.41
D	153.85	714.30	714.30	7i4.30
Mean	209.73	209.73	209.73	769.66

a. Comparative performance: Comparing the four different methods, the Table 8 below represents the operational performance index for each method.

Table 8 Operational performance of cracking methods

Performance index	Conventional	Punch-splitter	Impact-splitter	Hydraulic-split
Power	Very high	High	Less	Low
Cracking time	17.73 Sec.	4.95 Sec.	5.58 Sec.	4.6 Sec.
Operating time	17.73 Sec.	Longer (~35 Sec.)	Lesser (~15 Sec.)	Lesser (~15 Sec.)
Damage	Shatter	Puncture	Clean split	Clean split
Capacity (kg hr^{-1})	110.09	292.96	330.48	385.83
No. per hour	209.73	629.98	665.75	769.66
Ergonomic factors				
Risk factors	High	Less	Much less	No risk
Health injuries	High	Less	Much less	Less
Ease of use	Difficult	Easy	Quite easy	Very easy
Effort required	Very high	Less	Much less	Much less
Wastage	More	Few	Less	Much less

4 Summary and conclusion

4.1 Summary

Based on the overall objective of evaluating three coconut devices and comparing their performances with the conventional technique, the following conclusions are made;

1. The physical properties of coconut fruits, axial dimensions and weights have been measured and mean equivalent diameter, sphericity and roundness determined.

2. The cracking efficiency of conventional technique for different grades of coconut varied from 86.67% to 100% with an average value of 94.17 percent, punch-splitvaried from 86.76 to 95.00 percent with mean value of 87.09 percent, impact-split varied from 83.33 to 95.00 percent with a mean value of 90.08 percent while hydraulic-split varied from 90.00 to 95.00 percent with a mean value of 82.50 percent.

3. The machine capacity varied for different grades of coconut with the hydraulic-split having the highest capacity of 389.33 kg hr^{-1} for grade B coconut and conventional method having the least capacity of 110.09 kg hr^{-1} for grade D coconuts.

4. Ergonomically, hydraulic-split device is safer, more hygenic and convenient in operation hence more preffered.

4.2 Conclusion

In conclusion, the three cracking devices showed improvement in material handling, cracking time, capacity and efficiency, over the conventional technique. Ergonomic assessment prefered hydraulic-split device over other devices and methods. Conventional method of cracking has the least cracking capacity measured per unit time, highest cracking efficiency, while the hydraulic-split has the highest number of coconut split per hour for all grades of coconut with the highest handling capacity of 833 coconuts per hour.

References

Al-Mahasneh, M. A., and T. M. Rababah. 2007. Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering*, 79(4): 1467–1473.

Anitha, J., and K. P. Shamsudeen. 1997. Development and testing of a tender coconut unch and splitter. Unpublished B. Tech Project Report. Kerala. India: Kerala Agricultural University.

Bello, R. S., and A. Emmanuel. 2014. Development and Construction of punch-splitting device for coconut. Unpublished diplomat project in partial fulfilment of the requirements for the award of national diploma in agricultural and bio-environmental engineering. Ishiagu: Federal College of Agriculture.

Bello, R. S., S. J. Jauro, and M. B. Bello. 2018. Development, construction and technology adoption valuation of a dual mechanism coconut splitter. In *Proceedings of the 3rd conference of the Nigeria Institution of Agricultural Engineers*, 472-482. South East Region (NIAE-SER), UNN, Nsukka, 27-30, August..

Beloin, P. 2008. A coconut splitting device. United States Patent No.WO/2008/067653.

Beloin, P. 2009. Coconut splitting device. United States patient: US 200930139094A1 cultivars for tender nut waters for West Bengal. *Indian Coconut Journa*l, 29(1): 3-4.

Dursun, E., and I. Dursun. 2005. Some physical properties of caper seed. *Biosystems Engineering*, 92(2): 237-245.

Jippu, J. 1998. KAU tender coconut punch. *Indian Coconut Journal*, 29(3): 9-10.

Ketan, K. T., V. P. Sakhare, and C. N. Sakhale. 2014. Design and performances of coconut de-shelling machine. *International Journal of Engineering Research and Applications*, 4(7): 39-44.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Material*s. New York: Gordon and Breach Science Publishers.

Roshni, T., J. Jippu, C. S. Ratheesh, J. Sachin, and K. L. Sreevisakh. 2009. Development of a household coconut punch-cum-splitter. *CIGR Journal*, 10(1): manuscript No. 1188.

Shamsudeen, K. P., J. Anitha, and J. Jippu. 1999. KAU tender coconut cutter. *Indian Coconut Journal*, 30(6): 9.

Unnikrishnan, N., 2010. Patent for coconut cutter., Science reporter, pp 17. 10 November.

Varnamkhasti, M. G., H. Mobli, A. Jafari, M. H. Soltanabadi, S. Rafiee, and R. Sadeghi. 2007. Some physical properties of rough rice (Oryza Sativa L.) grain. *Journal of Cereal Science*, 47(3): 496-501.

Vinay, M. J., J. James, J. Joy, S. Abin, and B. Chandy. 2016. Design and fabrication of coconut breaker extractor grater machine. *International Journal for Innovative Research in Science and Technology (IJIRST)*, 2(11): 2349-6010.

World Wildlife Fund. 2010. *Petenes Mangroves, Encyclopedia of Earth*. Washington DC: National Council for Science and the Environment.