Development of almond seed extractor for whole kernel recovery

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Abstract: Almond seed extraction from whole kernel recovery is a process which is usually performed manually thus making it laborious and time consuming. The purpose of this paper is to investigate a means for almond seed extraction for whole kernel recovery to close the gap in domestic, commercial and industrial demand of almond seeds for food and industrial processing. The machine comprises of four units: the hopper; the cracking chamber which embeds the shaft, the hammer and electric motor. SolidWorks software was used to determine the responses of the machine critical elements. The sample of almond fruit used was picked from the premises of the University of Ilorin, Kwara State. The fruit (almond) was properly prepared by removing the fleshy parts from it and subjecting its seeds to a drying period of 7 days to 10 days at an average temperature of 35°C before was loaded into the extractor where cracking of the seeds was effected. Performance evaluation of the machine was conducted; its efficiency was found to be 82% with a throughput capacity of 42 kg h^{-1} and whole kernel recovery of 70%. The machine is affordable to both peasant farmers and process industries.

Keywords: almond seed, kernel, impact strength, compressive strain and stress

Citation: S. Ojolo, A. Ogundare, A. Adesina, and O. Ibhadode. 2018. Development of almond seed extractor for whole kernel recovery. Agricultural Engineering International: CIGR Journal, 20(4): 195–201.

1 Introduction

The almond tree is a highly herbaceous annual crop and native of the tropical region of Western Asia and North Africa and is vastly distribution extends to near coastal areas of the Indian Ocean, through tropical Asia, and into the Pacific Ocean. The three is also grown in Italy, Spain, Morocco, France, Greece and Iran. It is predominantly a cultivated in the south-south and south-west regions of Nigeria (Akpakpan and Akpabio, 2012; Agunbiabe and Olanlokun, 2006). The almond fruit comprises of the outer skin (exocarp), the flesh (mesocarp) and the nut. The nut comprises of the shell (endocarp) and the kernel. The kernel or the seed is the edible part of the fruit with a lot of nutritional benefits (Thompson and Evans, 2006). The kernel is an important source of energy having 6 kcal g^{-1}, protein 15.64% and oil content from 35.27% to 40% (Pankaj and Robert, 2008). Oil of almond kernel is an important source of oleic acid with 40% (Aydin, 2003). Sweet almond oil is used in cosmetics products, while the cake from sweet almond kernel is used in animal feed (Akpakpan and Akpabio, 2012). Cakes and biscuits from Almond flour are used by diabetic patients because of zero starch content, and can also help lower cholesterol (Agunbiabe and Olanlokun, 2006).

The kernel is obtained by shelling the nut after the outer skin has been removed. The conventional, traditional or manual method of shelling almond is not only injurious but is also inefficient, tedious and time consuming, coupled with low output rates (Umogbai et al., 2011; Nkakini et al., 2007).

Thus, the quest for a satisfactory, cheap and effective means such as mechanized shelling technique. Sustainable means of production and the use of modern technological advancement to provide easier means of production in replacement of the traditionally adopted system (Ojolo et al., 2015) is thus ineffitable. The objective of the machine is to extract the almond seed from the whole kernel, thus saving energy and time being consumed while using the manual method.

In this study, a time and energy saving shelling machine was developed for whole kernel recovery from

Received date: 2018-02-22 **Accepted date:** 2018-07-15

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the almond fruit. The performance of the extractor was evaluated using dry almond fruits contained for 7 days and 10 days placeded in both longitudinal and transverse orientations.

2 Materials and methods

The machine is simple-to-operate device which allows for adjustment and proper alignment of the seeds before cracking them. The machine major parts are the hopper, which is detachable and consist of baffles to permit adjustment and alignment before cracking; the cracking chamber which house the shaft; the hammer blades and motor unit. The machine is constructed using locally available engineering materials and all the elements are made and joined to form a unit using basic engineering manufacturing techniques.

2.1 Design consideration

Two preliminary tests were first carried out. The first test is to determine the moisture contents of the almond nuts while the second test is an impact load test. These were done for 10 samples of almond seeds; the wet samples were handpicked and washed, after which the weight was taken and the fleshy part of the seed was scrapped off using a knife. The samples were divided into two and dried under the sun. Sample A was dried for 7 days and sample B was dried for 10 days in both longitudinal and transverse orientations.

2.1.1 Moisture content calculation

The average weight of the seed before drying was measured to be 18.89 g while the average weight of samples A and B were measured to be 6.66 g and 5.81 g respectively.

$$\%\ \text{Moisture content} = \frac{(\text{Weight before drying} - \text{Weight after drying})}{\text{Weight before drying}} \times 100\% \quad (1)$$

The percentage moisture content for samples A and B was estimated to be 69.24% and 64.74% respectively.

2.1.2 Impact load test

The impact load test was conducted using the Instrom universal testing machine located at the Centre for Energy Research and Development CERD, Ile-Ife, Osun State, Nigeria. This test is to determine the various stress, strain and energy required to break the seed upon impact at both longitudinal and transverse orientations of the seed due to the tumbling action desired for cracking the seeds. The impact load test was carried out to check for different behaviour of the nut in both longitudinal and transverse orientations for both samples A and B.

Table 1(a) Compressive stress at break point for longitudinal orientation

	Sample A				Sample B			
	X	σ_B	P_B	e_B	x	σ_B	P_B	e_B
1	9.4836	9.0726	3448.80	0.1733	9.9836	6.1645	2343.32	0.1814
2	9.1418	7.9251	3012.63	0.1554	9.8501	7.0405	2676.33	0.1842
3	8.0749	7.4654	2837.83	0.1424	9.3419	8.4748	3221.56	0.1582
Mean	**8.9001**	**8.1544**	**3099.75**	**0.1570**	**9.7252**	**7.2266**	**2747.10**	**0.1746**

Table 1(b) Compressive stress at break point for transverse orientation

	Sample A				Sample B			
	X	σ_B	P_B	e_B	x	σ_B	P_B	e_B
1	10.3253	7.9872	3036.19	0.1815	9.7503	6.6271	2519.16	0.1728
2	10.3753	7.0622	2684.59	0.1849	9.9001	7.0987	2698.44	0.1767
3	10.4086	8.2353	3130.49	0.1854	11.3836	8.4732	3220.96	0.1896
Mean	**10.3697**	**7.7616**	**2950.42**	**0.1839**	**10.3447**	**7.3997**	**2812.85**	**0.1797**

Note: x = Extension at Maximum compressive stress (mm); σ_B = Compressive Stress at Break (MPa); P_B = Compressive Load at Break (N); e_B = Compressive Strain at Break.

2.2 Design analysis

The materials for the fabrication of the machine were chosen based on strength, suitability, availability, overall weight and the resistance to corrosion and rust. The machine elements were carefully chosen and designed without compromising the efficiency of the machine and to reduce cost so that it could be affordable for both commercial and domestic uses.

2.2.1 Determination of crushing torque

The torque required by the crusher necessary for cracking the seed is estimated as (Ojolo et al., 2015):

$$M_t = F_{MCL} \times x \quad (2)$$

where, F_{MCL} is the Mean compressive load at break estimated to be 3099.75 N from Table 1; and x has been deduced to be 0.06 m.

The crushing torque M_t is 186 Nm.

2.2.2 Shaft design

The driven pulley is mounted on the shaft on one end and the hammer blade on the opposite end.

The shaft is designed to ensure satisfactory strength and rigidity when the shaft is transmitting power under different operating and loading conditions. The shaft diameter is determined using ASME code equation for solid shaft design (Ologunagba, 2012).

$$d^3 = \frac{16}{\pi S_s}[(k_b M_b)^2 + (k_t M_t)^2] \quad (3)$$

where, d is shaft diameter; M_b is maximum bending moment; K_b is combined shock and fatigue factor applied to bending and is taken to be 2; K_t is the combined shock and fatigue factor applied to torsional moment is taken to be 1.5 and S_s is the ultimate stress of mild steel with feather key way taken to be 40 N m^{-2}.

The shaft diameter is estimated to be 32.99 mm but for safe value, a shaft diameter of 40 mm is selected.

2.2.3 Determination of shaft/ driven pulley speeds

Torque, M_t applied on shaft and the Radius, r of shaft has been estimated to be 186 Nm and 0.02 m respectively. The force, F applied on the shaft is obtained by (Ojolo et al., 2015):

$$M_t = F \times r \quad (4)$$

Thus, the force, F is estimated to be 9300 N.

$$F = mw^2 r \quad (5)$$

where, m, the mass of shaft/crusher is 1.48 kg and w is the angular speed of the shaft.

Thus, we can estimate w to be 396.35 rad s^{-1} from Equation (5)

$$w = \frac{2\pi N_s}{60} \quad (6)$$

N_s is the rotational speed of the shaft and is estimated from Equation 6 as 3784 rpm.

The shaft pulley diameter, D_s and the driven pulley diameter, D_{p2} are 40 mm and 150 mm respectively, thus the driven pulley rotational speed can be obtained from (Khurmi, 2005):

$$\frac{D_s}{D_{p2}} = \frac{N_{p2}}{N_s} \quad (7)$$

N_{p2} is 1010 rpm.

2.2.4 Power delivered by the crushing shaft

The power developed by the crushing shaft is estimated as (Childs, 2004):

Power, $$P = \frac{M_t w}{60} \quad (8)$$

P = 1.23 kW.

2.2.5 Feed hopper design

The hopper is made up of four welded mild steel metal sheets slanting towards the smaller opening. It has two openings that can hold a reasonable amount of almond seeds and the outlet throat connects the hopper to the feeder line (Figures 1-2). The hopper is detachable to allow varying sizes of hopper to be used on the machine as well as making it compact. The material used for its construction is mild steel sheet. The hopper is designed such that the almond seed finds its way into the feeder line through two sets of baffles to reduce the inflow so as not to clog the cracking chamber and thereby improving the efficiency of machine. Inside the hopper feeder line are baffles to control the feed rate as recommended by Ghafari et al. (2011).

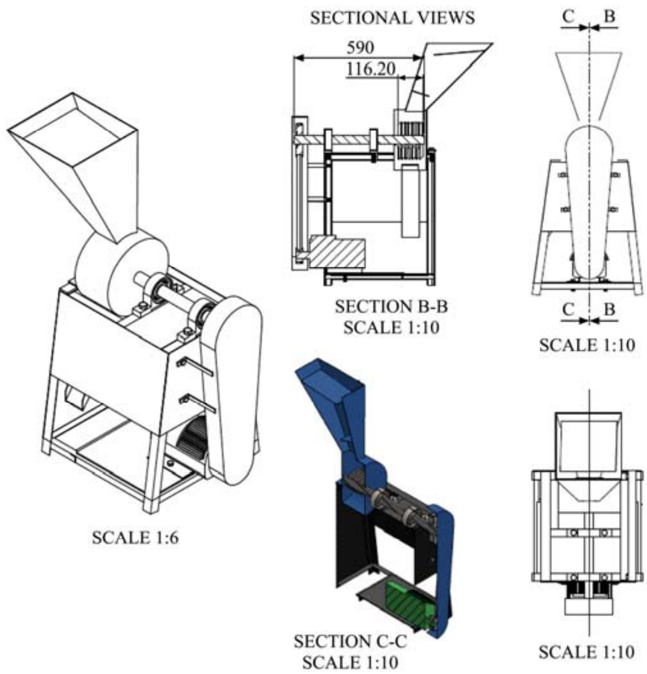
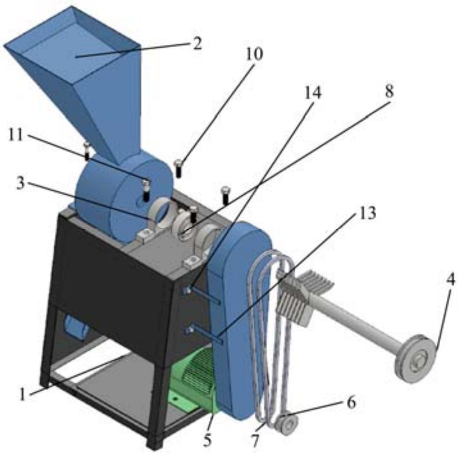


Figure 1 Isometric, orthographic and sectional views of machine model



1. Electric motor base 2. Hopper 3. Bearing casing 4. Shaft pulley 5. Electric motor 6. Electric motor pulley 7. Belt 8. Bearing 9. Bolt 10. Assembly bolt 11. Belt casing 12. Casing hanger

Figure 2 Exploded view of machine showing its components

3 Results and discussion

3.1 Impact load tests

The results of impact load tests (Figures 3-4) show that the different samples had similar Young's modulus and an average of 3099 N and 2747 N compressive is load required to break the almond seed in the longitudinal orientation for both Sample A and B respectively. However, the results for Sample A in longitudinal orientation were used in the design to accommodate extreme case scenario that may be encountered.

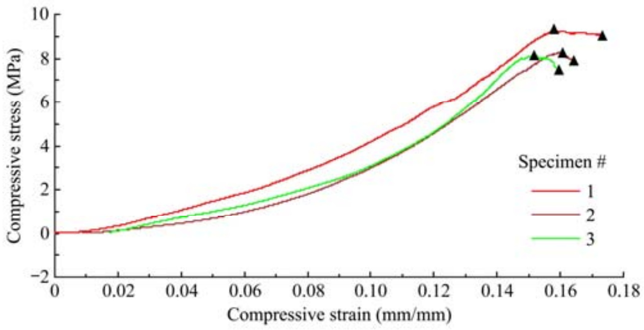


Figure 3 Compressive stress against compressive strain after 7 days drying

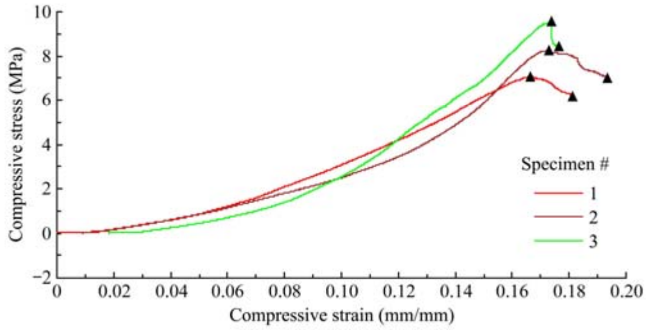


Figure 4 Compressive stress against compressive strain after 10 days drying

3.2 Shaft and Hammer responses

The hammer blade in Figure 5 impacting on the almond seed for a period of 2 seconds produces a response due to the reactive force of the shaft against the wall of the cylindrical slot as the almond seeds are approach the hammer blades. The response is shown Figure 6, from which it was observed that between 0 and 0.6 second, there are quantifiable reactive forces by the shaft. This is the period of reaction between the hammer blades and the almond seeds during the simulation. The maximum reactive force experienced by the shaft against the cylindrical wall during this period is 33 N.

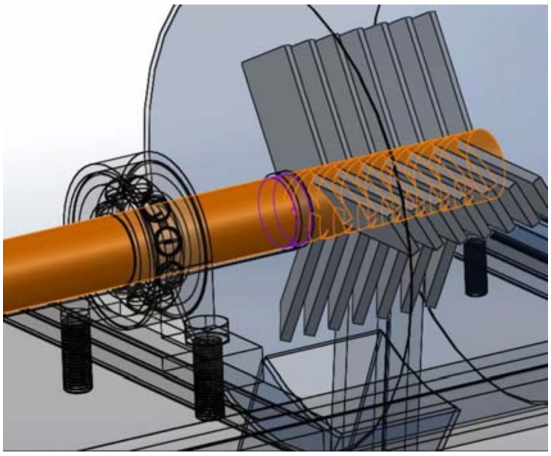


Figure 5 Concentric mate condition between the shaft and cylindrical slot in the cracking chamber

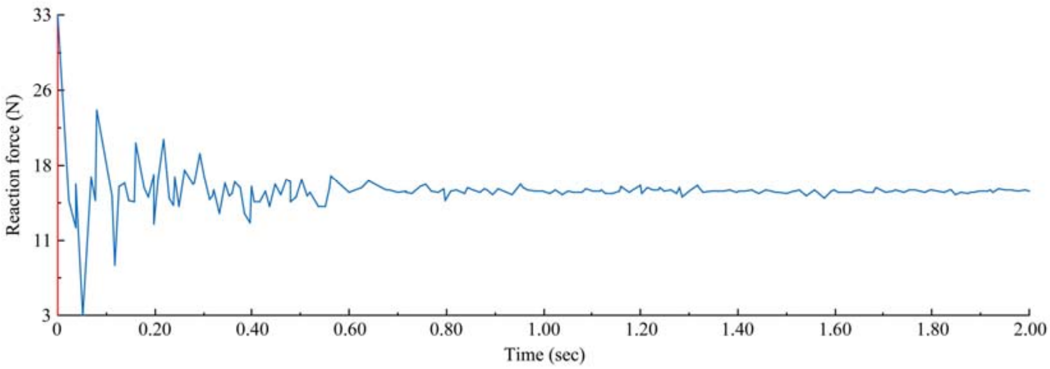


Figure 6 Shaft-cracking chamber mate force reaction response to cracking of almond seeds for a period of 2 seconds

3.3 Almond seed responses

An important response observed is the reactive force on the seed resulting from the impact of the hammer blade. This gives an idea of the cracking force on the seed at the rotational speed of the shaft and hammer blade. Figure 7 shows the reactive force on two almond seeds represented by red and blue plots. For duration of 2 seconds, it is observed that there are substantive reactive forces on each of the seeds which are at 489 and 245 N for the red and blue plots respectively. The values of the kinetic energy of the two seeds are very low as shown in Figure 8 due to the small mass of the seeds. For the red plot, the kinetic energy increases steadily but significantly relative to the blue plot after 0.2 seconds. This shows considerable impact after 2 seconds.

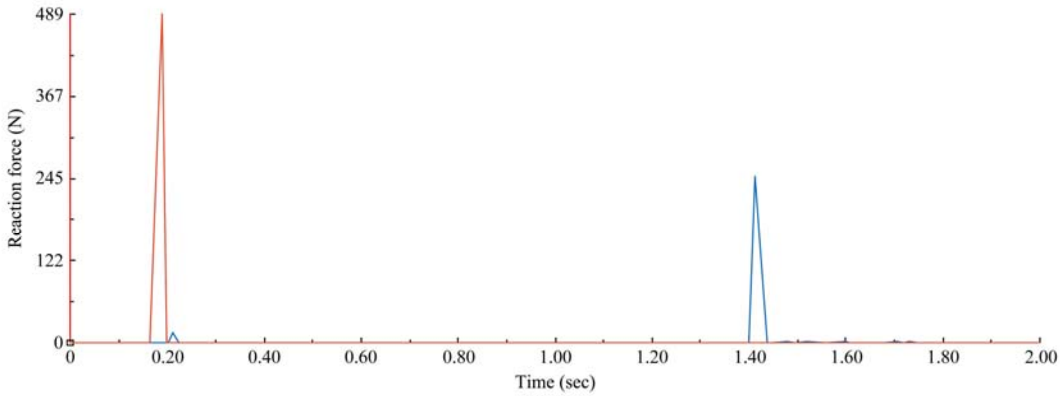


Figure 7 Almond seed reaction force

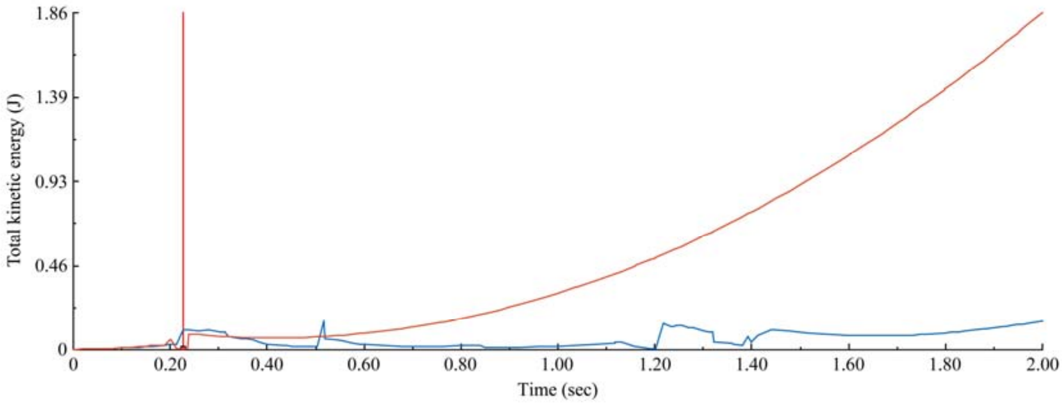


Figure 8 Kinetic Energy of two almond seeds investigated

3.4 The machine test and performance evaluation

The almond seed extractor (Figure 9) was tested and its performance was evaluated by the cracking efficiency, whole kernel recovery and throughput capacity. The feeding efficiency was found to be dependent on the feeding rate (nuts/minute) which in turn determined the throughput of the machine. The baffles in the hopper control the feed rate to about 2 nuts per second. Tables 2-3 show the results obtained from the machine performance evaluation.

$$\text{Throughput capacity} = \text{Average mass (kg)} \times \text{Cracking rate (hr)} \times 1\text{hr} \quad (9)$$

$$\text{Whole kernel recovery} = \frac{\text{Whole kernel recovered}}{\text{Total seeds fed}} \times 100\% \quad (10)$$

$$\text{Cracking efficiency} = \frac{\text{Completely cracked seed (average)}}{\text{Total seeds fed}} \times 100\% \quad (11)$$

Figure 9 Fully developed almond seed extractor

Table 2 Volume of feed variation with efficiency

Sample	Volume (mm^3)	Efficiency (%)
1	18794.91	68.6
2	29123.33	82.5
3	15581.93	62.5
4	12258.92	50.35
5	12397.00	53.4

Table 3 Number of seed variation with efficiency

Sample	Number of undamaged kernel	Number of completely cracked nuts	Cracking Efficiency (%)
1	26	30	75
2	30	34	85
3	28	32	80
4	30	35	88
5	27	33	83

The throughput capacity, whole kernel recovery, and cracking efficiency were estimated to be 42 kg hr^{-1}, 71%, and 82% respectively. Figure 10 shows the shelled almond fruits and the seeds obtained from from them.

Figure 10 Extracted almond seed and broken kernel

3.5 Discussion

The cracking efficiency was evaluated (Tables 2-3) based on the number of completely cracked seeds in a batch of 40 seeds, with an average of 33 seeds completely cracked at single feed to give a cracking efficiency of 82%. The throughput capacity was obtained to be approximately 42 kg hr^{-1} with 2 nuts sec^{-1} cracking rate.

The whole kernel recovery was also evaluated based on the number of unbroken seeds recovered per batch of the feed and stands at 71%. It was also observed that with a small sized almond seed (2.234×10^{-5} m^3) an efficiency of 55.5% is attained, however, for a medium sized seed (2.92×10^{-5} m^3) an improved efficiency was obtained.

Moreover, observations reveal that the feed rate was a major influence on the efficiency, with the best efficiency obtained when two seeds were fed into the machine and a far lower efficiency obtained when fifteen seeds was fed. However, a close observation shows that the lesser amount of seed per time gives a better efficiency and much larger throughput capacity.

No wet sample could be cracked due to high moisture content plus high fiber content of the seeds. Thus, for effective cracking the seeds must be dry for effective cracking since the performance evaluation of this machine is dependent on the physical state of the almond seeds.

4 Conclusions

The almond seed extractor performs satisfactorily with a throughput capacity, whole kernel recovery, and cracking efficiency of 42 kg hr^{-1}, 70%, and 82% respectively with 33 seeds of 40 seeds completely cracked at a rate of two seeds per seconds. This design is a major feat in the agricultural products processing and postharvest preservation for peasant farmers and processing industries. The material used in developing this machine were sourced locally thereby reducing cost of production hence making it affordable by peasant farmers and processing industries. The machine is safe, easy to operate with little maintenance required as all moving parts are well guarded.

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