Design and Evaluation of a Palm Fruit Thresher

ABSTRACT

Aims: The high demand for palm oil as food and industrial raw material is on the increase and the traditional method cannot sustain the demand for the crop. Therefore, there is need for design and fabrication of a locally and affordable palm oil processing machine, hence, this project.
Methodology: A palm fruit thresher was designed, fabricated and evaluated at the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The thresher. Comprises of hopper, threshing chamber, the drive mechanism, separation units and the discharge outlets. The machine was evaluated for effect of storage and sterilization time on the threshing efficiency. The storage time (1, 2, and 3 days) and sterilization time (30, 40, 50 and 60 minutes) were used to investigate the effect of these treatments on the machine threshing efficiency and throughput capacity.
Results: The palm thresher was designed, constructed and evaluated. The result of the experiment showed that the threshing efficiency and the throughput capacity increased from 87.0 to 93.0 % and 258.0 to 468.0 kg/hr. respectively, as the storage time increases from 1 to 3 days. The effect of sterilization time was also found to be significant on the throughput and shelling efficiency ($p < 0.05$). The shelling efficiency and the throughput capacity was found to increase from 58.3 to 92.2 % and 517.1 to 769.3 kg/hr. respectively, as the sterilization time increased from 10 to 30 minutes.
Conclusion: The results of these experiments showed that palm fruit threshing can be mechanized using a locally fabricated machine.
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Keywords: thresher; storage time; sterilization; fabrication; efficiency; throughput

1. INTRODUCTION

A palm tree (*Phoerix dactylifera*) belongs to the family (*Plamaceae*) originated in the tropical rain forest region of west Africa (Idio and Feyisitan, 2018). The crop has been reported to have high international demand beyond Africa (Balu *et al*., 2018). Though, China and EU do not produce palm oil but imported it because of its uses (EU, 2016). It is a popular tree crop in West Africa and it is described as the prince of the plant kingdom because virtually every part of it has economic value. It has been reported that about 338 billion pounds was generated from cultivation of oil palm worldwide, making oil palm by far the world's number one fruit crop (FAO, 2004). Malaysia produces the largest palm oil in the world (Zainal *et al*., 2016). Nigeria produce about 2% of the world palm oil production but over 50% of African oil palm production (Anyaoha *et al.,* 2018) to make it 5th largest producer in the world (FAOSTAT, 2017). Palm oil and palm kernel oil have a wide range of uses both as human consumption and as an industrial raw material (Sulaiman *et al*., 2011: Aljibouri and Alsharifi 2019: Hamzah *et al*., 2021)..

Though the technology of palm oil production has increasingly been mechanized but due to the cost and the technological no how the local farmer who are still in the majority in the rural area of Nigeria still depend on traditional manual methods. Threshing of palm fruits manually is tedious, time consuming and discourage mechanization (Fashina *et al* 2017). In the traditional method whole palm bunch are transported to the mill instead of only fruits which causes extra cost of transportation.

The first operation during the production of palm oil after harvesting is the separation of the palm fruits from the palm bunches. This necessitate a palm fruit thresher that will separate palm fruits from bunches easily using locally developed mechanical machine. It has been reported that the quality of palm oil produced depend on the method involve during the unit operations involved in its production (Shanti *et al*., 2019). The technical process of designing any agricultural machine requires testing its performance efficiency, to guarantee and ensures the highest practical productivity at the lowest cost (Aljibouri and Alsharifi, 2019: Hamzah *et al*., 2021). The present work is an attempt to separate the fresh fruit on the farm, so that only the fruits will be transported to the mill, while their stalks will be left in the field. This machine is designed to thresh both sterilized and unsterilized spikelet of palm bunch.

2. MATERIAL AND METHODS

The method used in the design and evaluation of the machine is described the sections below.

2.1 Machine Description and Operation

The palm fruit thresher was designed to have five units viz: The hopper, the threshing unit, the drive mechanism, separation units and the discharge outlets. The spikelet either sterilized or not will be introduced into the machine through the hopper. This spikelet will be thrown on the revolving beater which was lined with rubber to minimized mechanical damage to the fruits. The beaters use an impact force to separate the fruit from the spikelet. Thus, the palm fruits separated from the spikelet passes through the screen hole at the bottom of the threshing chamber and the spikelet without the fruit are pushed to the other end of the thresher.

2.2 Development of the Machine

The palm fruit threshing machine was design as discussed below.

2.2.1 The threshing chamber

To estimate the needed materials, the volume of each component was estimated.

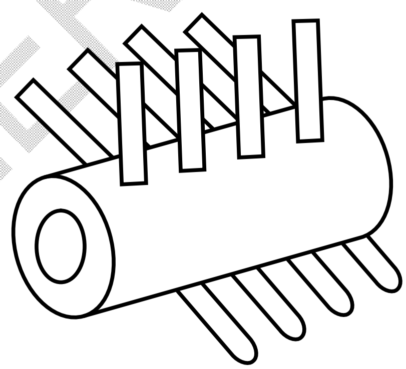
Determination of the total volume of the threshing drum

The threshing drum is the unit in which the threshing takes place. The component comprises of threshing drum with 18 spike tooth arranged alternatively on the drum (Fig. 1). The spikes are made of the same length at equidistance to one another. The following parameters were determined as a prerequisite for calculating the total volume of the threshing drum:

Volume of Cylinder = $\pi R^2 h$ (Stroud, 1995 : Alsharifi, 2018) (1)

For hollow Cylinder $\pi r_1^2 h - \pi r_2^2 h$ (2)

Fig. 1: Spike Tooth



The volume of the tooth was calculated using Equation 3.

Volume of each tooth = $\pi R^2 L$ (3)

The number of spikes was calculated using Equation 4.

$$z = m_p \left[\frac{Lp}{a} + 1 \right] \quad (4)$$

Where; a is the distance between the adjacent paths of teeth (a = 27 mm)

m_p is the number of pitch of the helix over which teeth are located (m_p = 3)

Total volume of spike = Volume of each tooth x Number of spike

Mass of the spikes tooth was calculated using Equation 5.

Density $(\ell) = \frac{Mass\ (m)}{Volume\ (v)}$ (Singh, 2005: Hamzah and Alsharifi ,2020) (5)

$\therefore m = \ell \ x \ v$

Weight of the spike tooth (w) = mg (N) (6)

Where, m is mass (kg) and g is acceleration due to gravity (m/s)

2.2.2 Analysis of the pulley on the stripping chamber shaft

The total mass of the pulley was calculated using Equation 7 and 8.

$$\text{Volume of the pulley (V)} = \pi\left(\frac{D^2}{4}\right) x\ t \qquad (7)$$

Where, D, is the diameter of the pulley and t is the thickness of the pulley.
Mass of the pulley was calculated using:

$$\text{Density } (\ell) = \frac{Mass\ (m)}{Volume\ (v)} \qquad (8)$$

$$m_p = \ell\ x\ v$$

2.2.3Determination of the length of stripping chamber drive belt

The length of the threshing pulley belt was determined using Equation 9 to determine the centre distance, C, of the two pulley and Equation 10 to determine the length of the belt.

$C = D + 1.5d$ (Hall *et al*., 1983) (9)

d is the diameter of the pulley of the shaft of prime mover
D is the diameter of the pulley on the threshing shaft
C is the centre distance between the shaft of the threshing shaft and the shaft of the prime mover.

The length of the belt was then calculated using Equation 10.

$$L = 2C + 1.57(D+d)\frac{(D-d)^2}{4C}$$ (Hall *et al*., 1983: Idio and Feyisira, 2018) (10)

and angle of contact was calculated using Equation 11.

$$\theta = \pi - \frac{D-d}{C} rad \qquad (11)$$

2.2.4Power requirement

The power requirement by the machine was determined using Equation 12.

$P = 2\pi nT / 60$ (Kurmi and Gupta, 2005) (12)

Where: P is the power required (watt),
n is the speed of the threshing shaft in (rpm) as used by Sharifi et al 2019 a and b and
T is the torque required to turn the threshing shaft (Nm).

2.2.5 Determination of the torsional moment of the threshing shaft

To determine the torsional moment Hannah and Stephens, 1984 equation was used.

$$m_t = \frac{P\,\text{x}\,60}{2\pi N} \qquad (13)$$

Tension in the belt was calculated using Equation 14.

$m_t = (T_1 - T_2)\ R$ (Hannah and Stephens, 1984) (14)

Using a prime mover of 3kW, equivalent to 4 h.p and Speed (N) = 1400rpm.
Where m_t = Torsional moment of the shaft (Nm)
T_1 = Tension in the tight side of the belt, (N)
T_2 = Tension in the slack side of the belt, (N)
R = Radius of the pulley on the shaft (m)

2.2.6 Determination of the diameter of the shaft of the threshing Chamber

The ASME CODE Equation 15 was used to determine the diameter of solid shaft.

$$d^3 = \left(\frac{16}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \right) \quad \text{(Kurmi and Gupta, 2005: Idio and Feyisira, 2018)} \tag{15}$$

Where;

d is diameter of the shaft of the stripping chamber (mm)

K_b is Combined shock and fatique factor applied to bending moment = 2.0

K_t is Combine shock and fatique factor applied to torsional moment = 2.0

M_b is Bending moment (Resultant)

M_t is Torsional moment

S_s is Allowable shear stress = 60MN/m^2 for shaft that has no key way

2.2,7 The separating chamber

The separating chamber consists of a blower which is made of 4 vanes, each with thickness of 2.0 mm and also drives by the same prime mover.

2.2.8 The prime mover

The whole system is driven by the prime mover. The power of the prime mover is 3kW with speed of 1400 rpm.The orthographic drawing of the machine is as presented in Fig. 2 while the isometric view of the machine is as presented in Fig.3

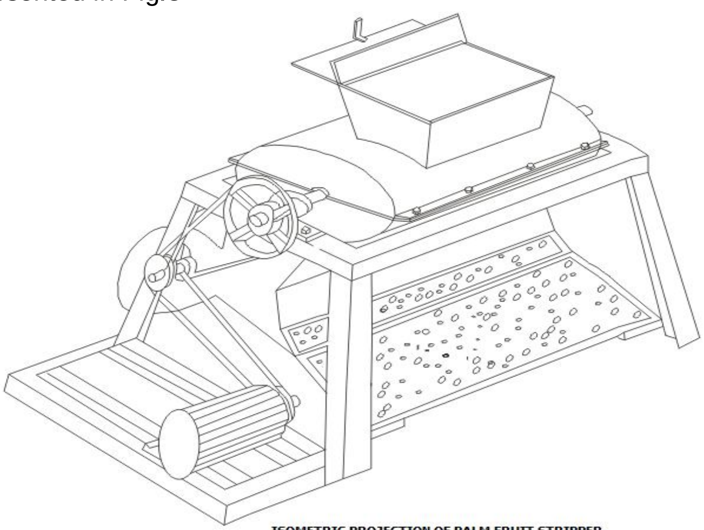


Fig. 2: Machine Assembly

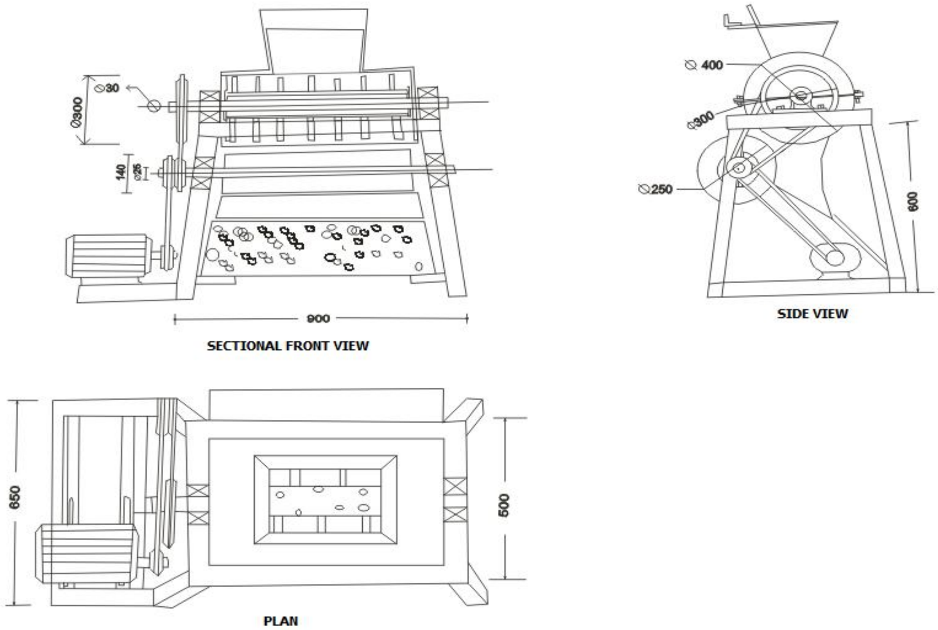


Fig. 3: Isometric Views

2.3 Experimental procedure

Ripped palm bunches are bought from some local farmers in Ogbomoso area of Nigeria. The spikelet was removed from the palm bunches to make further processes easy. The spikelet was weighed and weight recorded before feeding it into the machine through the hopper. After the threshing operation, the fruit threshed, the unthreshed fruits and the time taking for threshing operations were also recorded.

2.4 Evaluation of the machine

Evaluation of the machine was done using two major treatments which may accelerate the loosening processes of the fruit from the bunch. The effect of storage time and sterilization time on threshing efficiency and throughput of the machine was examined. It has been reported from literature that sterilization improve palm oil production (Hassan *et al.*, 2012). For every test, 5kg sample of spikelet were sterilized for 30, 40, 50, and 60 minutes and another sample were stored for one, two and five days. For every threshing operation the threshing time was recorded using stop watch.

The machine evaluation was done under the headings below:

2.4.1 Threshing efficiency of the machine

The threshing efficiency was calculated using Equation16.

Efficiency $\left(\int\right) = \frac{W_{st}}{W_{uf}} \times 100\%$ (Alwan, 2016)

(16)

Where: Weight of threshed fruits is W_{st},

Weight of unthreshed fruits is W_{uf}

2.4.2 Throughput capacity of the machine

This is the total weight of the palm fruits threshed per hour.

Throughput Capacity (Kg/hr) = $\frac{W_{ch}}{th(hr)}(kg)$ (Idio and Feyisira, 2018) (17)

W_{ch} = Weight of threshed fruits (kg)

th = time taking for the threshing operation

3. RESULTS AND DISCUSSION

Palm Fruit Threshing Machine

The developed palm fruit thresher is as presented in Plate in its working condition. The result of the evaluation of the machine is as presented below.

Plate 1: Palm fruit thresher

Effect of storage time on the shelling efficiency of the machine

Table 1 shows the effect of storage time on the machine threshing efficiency. From the results, it can be observed that the longer the storage time the higher the threshing efficiency. Shelling efficiency increased from 87.0 to 93.0 % as the storage time increased from 1 to 5 days.

Table 1: **Effect of storage time on the shelling efficiency of the machine**

Days	Weight of the Unstripped Fruit W_{uF} (kg)	Weight of the Stripped Fruit W_{st} (kg)	Weight of ChaffW_{ch} (kg)	Time (s)	Efficiency %
1st	35.7±3.0	31.2±4.80	2.1±0.56	319	87
3rd	32.4±0.3	28.7±0.56	1.4±0.20	230	89
5th	30.0±2.7	27.9±1.36	1.1±0.44	152	93

The gradual increase in the efficiency of the thresher as a result of storage time was as a result of gradual reduction in strength of attachment of the seed to the spikelet which resulted in reduction in force required by the machine to remove the fruit. The variation of the machine threshing efficiency with the increase in storage time is shown in Fig.4.

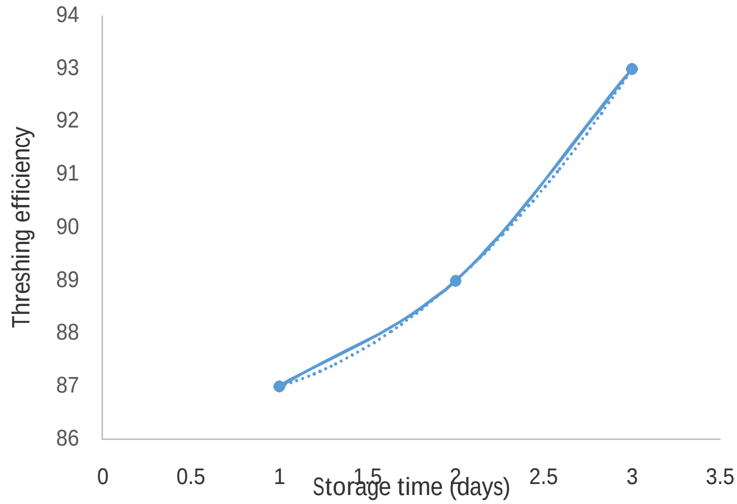


Fig.4: Effect storage time on threshing efficiency of the machine

The regression equation representing the effect of storage time on the machine threshing efficiency was observed to be polynomial as presented in Equation 18.

$$Th_{ref} = 1S_t^2 – 1S_t^2 + 87 \qquad (R^2 = 1) \qquad (18)$$

Where; Th_{ref} is threshing efficiency and S_t is the storage time

Effect of storage time on throughput capacity of the machine

The result of the experiment showed that the throughput capacity of the machine increased from 258.0 to 468 kg/hr. as the storage time increased from 1 to 5 days. This showed that the longer the storage time the higher the throughput capacity of the machine (Fig.5). This may be as a result of decrease in the force that attaches the fruit to the spikelet as storage time increased. It was observed that the quality of the palm fruit decreases as the storage time increases.

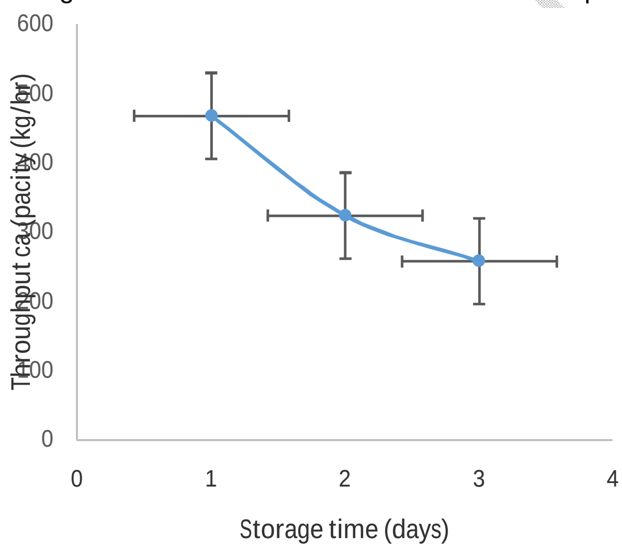


Fig. 5: Effect of storage time on throughput of the machine

The relationship between the storage time and the throughput was observed to be polynomial as presented by Equation 19.

$T_{RH} = 39\ S_t^2 - 261S_t + 690 \qquad (R^2 = 1) \qquad (19)$

Where T_{RHS} is the throughput of the machine and S_t is the storage time

Effect of sterilization time on the threshing efficiency of the machine

Fig. 6 shows the effect of sterilization time on the machine efficiency. From the results, it can be observed that the longer the sterilization time the higher the threshing efficiency. It was observed that as the sterilization time increased from 30 to 60 minutes the threshing efficiency also increased from 58.3 to 92.2%. The increase in threshing efficiency as the sterilization time increased may be due to the weakening of the binding force between the fruit and the spikelet as the time of sterilization increases. The result was in agreement with the report of Ojomo *et al*. 2010 that reported a higher threshing efficiency with increase in sterilization time for a palm fruit stripper. Fig. 6 shows the variation between the machine efficiency and the sterilization time. The regression equation for the effect of sterilization time on the threshing efficiency of the machine was observed to be linear as presented in Equation 20.

$T_{RH} = 11.62\ S_{RT} + 51.5 \qquad (R^2 = 0.9863) \qquad (20)$

Where T_{RH} is the threshing efficiency (%) and S_{RT} is the steralisation time (minutes)

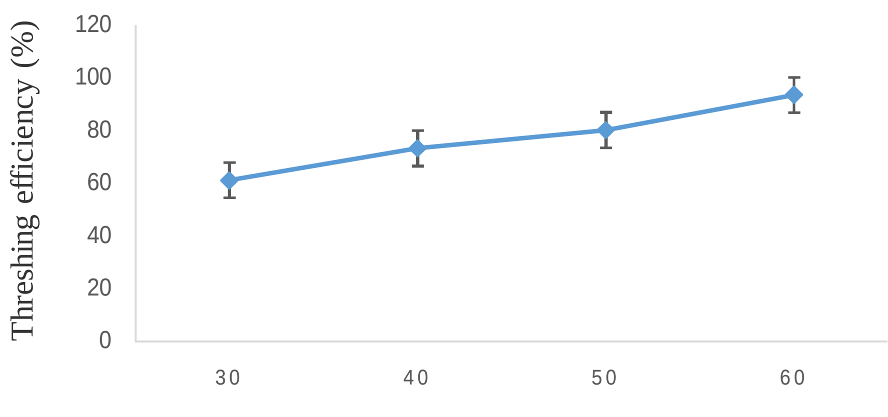


Fig.6: Effect of sterilisation on threshing efficiency of the machine

Effect of sterilization time on the throughput of the machine

The result of the experiments showed that as the sterilization time increased from 30 to 60 minutes the throughput capacity increased from 517.06 to 769.25 kg/hr. The increase in throughput capacity as the sterilization time increased may be due to the reduction in the energy required for the threshing as the time of sterilization increased. The results of this experiment were in agreement with the report of Ologunagba *et al*. 2010 that reported a higher throughput with increase in sterilization time for a palm fruit stripper. Fig. 7 shows the variation between the machine throughput and the sterilization time. The regression equation for the effect of sterilization time on the throughput of the machine is as presented in Equation 21.

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$T_{RH} = -12.34St^2 + 141.59St + 394.07 \qquad (R^2 = 0.9765) \qquad (21)$

Where T_{RH} is the threshing efficiency (%) and S_t is the steralisation time (minutes)

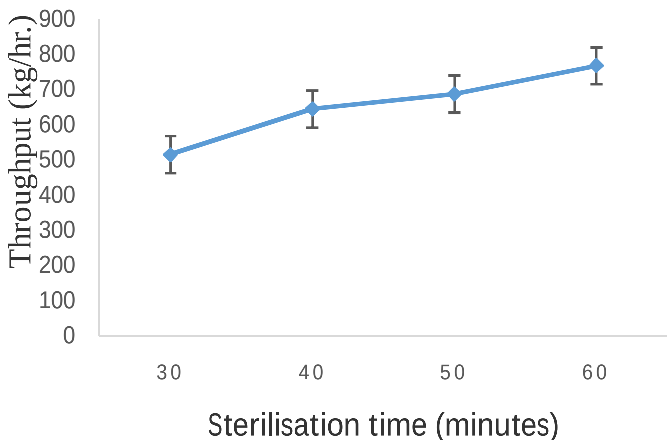

Fig.7: Effect of sterilisation on the throughput of the machine

4. CONCLUSION

The results of the experiment showed that efficiency and the throughput capacity of the thresher increased as the storage time and sterilization time increases. The results of this experiment has giving hope to small and medium scale palm fruit farmer who usually find palm fruit threshing as a tedious work.

Reference

1. Idio M.A. and Feyisitan K.O. The design and Fabrication of a batch palm kernel digester and pressing machine. International journal ogf scientific and engineering research. 2018; 9 (11):1-7.
2. Balu, N.,Azman, I, Norfadilah, H., Nazlin, I., Dayang.,N.S., Nik Abdullah, N.I., Noraida o.,Kamalrudin, M.S., NurAin, M.H.and Kushair.Malayia:100 Years of resilent palm oil economic performance Journal of oilPalm " Research. 2018; 30:13-25
3. EU.2016. palmoil alliance balance and fact based. The palm oil story, fact and figures. www.palmoilandfood.eu
4. FAO Small scale palm oil processing in Africa. FAO. 2004. Agricultural science bulleting.
5. Zainal N.H, Azizi A,A, Idris J, Mamat R, HassanM.A, Bahrin E.K and Abd-Azizi S Microwave-assistedpre-carbonisationof palm kernel shell produced charcoal with high heatingvalue and low gaseous emission. Journal of cleanerproduction. 2016; 2945-2949. http://doi.org/10.1016/j.jclepro.2016.10.176
6. Anyaoha Kelechi, Ruben Sakrabani, Abdul Mouazen: Evaluating oil palm fresh fruit bunch processing in Nigeria. Waste Management and Research. 2018, 36(3): 236-246. DOI:10.1177/073424x17751848.
7. FAOSTAT FAO Crops statisticsDatabase. (2017). From http://faostat3.fao.org/browse/Q/QC/E(acssed
8. Aljibouri, M.A.and Alsharifi, S.K. 2019. Evaluation of Local Design Machine for Corn Threshing, Indian Journal of Ecology. 2019;46(4):913-920.
9. Sulaiman, F., Abdullah, N., Gerhauser, H., and Shariff, A.. An outlook of Malaysian energy, oil pal industry and its utilization of wastes as useful resources. Biomass and Bioenergy, 2011; 35 (9):3775-3786.
10. Hamzah.I.J., Alsharifi, S.K., Aleawi. G. Requirements of maize mechanical shelling, .CIGR Journal. 2021; 23(1);252-256.
11. Fashina A.B. Durodola O.S. and Hammed, I.A. Development and Performance Evaluation of Oil Palm Digester. Bioprocess Engineering Journal. 2017; (2):49-53. 2017
12. Shanti F.S., Shareena, S.Khairuddin, S., Afrasyab, K., RobiahY.,Marini, S,Nordiana,R.,Norzafirah, A.M.F. and Muhammed H.A.. Mathematical Modelling and simulation of thresher operation in palm oil mill. *Journal of Sustainable Science and Management,* 2019;*14(5:43-54).*
13. Hamzah, I. J., and Alsharifi, S. K. A.. Innovative harvesting methods about the harvest losses for two machines. Bulgarian Journal of Agricultural Science. 2020; 26(4), 913-918.

14. Stroud, K.A.: Engineering Mathematics, Fourth Edition. Palgrave Macmillian Publisher, Basing Stocks, Ham Pshire, New York.1995.
15. AlSharifi, S. K.. Affecting on threshing machine types, grain moisture content and cylinder speeds for maize, Cadiz variety. CIGR Journal, 2018 ;20(3): 233-
16. AlSharifi, S. K., A. Mousa, and A. T. Manhil. Effect of sheller rotational speed on some maize cultivars quality. CIGR Journal. 2019a; 21(2): 196- 203.
17. AlSharifi, S. K.,. Mousa, A and Manhil, A.T. Effect of threshing machines, rotational speed and grain moisture on maize shelling. Bulgarian Journal of Agricultural Science. 2019b; 25(2): 243– 255
18. Singh, S. A Dictionary of Physics. A.P.H. Publishing Corporation, New Delhi; 110002.; 2005, Pg – 140. Stripper
19. Hall, A.S., Holowenko, A.R., and H.G. Laugh lin"Theory and Problem of Machine" McGraw Hill, New York. 1983; P. 113 – 123.
20. Khurmi, R.S. and Gupta, J.K.. A textbook of machine Design. 15th Edition Schand and company Ltd. New Delhi, India. (2005)
22. Hannah, J. and Stephens, R.C. Mechanics of Machines. Elementary Theory and Examples Fourth Edition. 1984.
23. Alwan. S. K, Alsharifi, A. Arabhosseini, M.H. Kianmeher ,Ali M. Kermani. Effect of husking and whitening machines on rice Daillman cultivar Agricultural Engineering International: CIGR Journal. 2016;18, (4): 232-243
24. Ojomo, A.O., Ologunagba, F.O and Alagha, S.A. Performance Evaluation of a palm fruit Bunch. ARPN journal of Engineering and Applied Sciences. 2010; 5(9): 29-33.
25. Ologunagba, F. O., Ojomo, A. O. and Lawson, O. S. Development of a dual powered palm fruit stripper. *ARPN Journal of Enjineering and Applied Sciences*. 2010; 5(11): 1-5.