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Specific energy consumption of a *Moringa oleifera* seed shelling machine

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Abstract: In this work, the Specific Energy Consumption (SEC) and machine capacity for a *Moringa oleifera* seed shelling machine were determined in relation to the cylinder speed and seed sizes. A *M. oleifera* seed shelling machine was tested and the SEC was appraised. The SEC and machine capacity of the *M. oleifera* seed shelling machine were determined at five speed levels, viz. 200, 240, 280, 320 and 360 rpm using three seed sizes (viz. small, medium and large seed sizes). The SEC and machine capacity increased with the seed sizes during the shelling process. The same trend was observed for the relationship between the SEC and cylinder speed. The minimum values obtained for the SEC using the small, medium and large *M. oleifera* seed sizes were 31.25, 40.07 and 54.22 Wh·kg^{-1}, respectively, at a cylinder speed of 200 rpm while the maximum values obtained for the small, medium and large seed sizes were 58.01, 74.37 and 100.63 Wh·kg^{-1}, respectively, at a cylinder speed of 360 rpm. The optimum values obtained for the machine capacity were 14.58, 11.38 and 8.41 kg·h^{-1} using the small, medium and large seed sizes, respectively. Conclusively, this study shows that the SEC and machine capacity were affected by the variation in the cylinder speed and seed sizes.

Keywords: power rating; cylinder speed; moringa seed; machine capacity; seed sizes

Energy remains one of the vital parameters in food processing industries. The optimal utilisation of energy is necessary to minimise the cost of production as well as improving the ease of operation. This has brought about studies on the Specific Energy Consumption (SEC) in food processing plants and industries. SEC is expressed as the energy expended per unit mass of a processed material. This can be computed from the integral of the area under the power against the time plot (Repellin et al. 2010; Liu et al. 2016). Ideally, it is necessary to reduce the energy expended in the processing line in order to maximise the usable net energy or the energy return on the investment (Gingerich, Hendrickson 1993). The worldwide energy consumption in the industrial sector was reported to be 42.8 E (Wh) in 2014, of which the Organization for Economic Co-operation and Development (OECD) countries accounted for 69% of the global industrial energy end-use (Lawrence et al. 2019). The efficient utilisation of energy in industries has contributed to a reduction in the emission of greenhouse gases which are detrimental to the environment. In agricultural materials, energy processing management is a key to effective production costs, which could be actualised by pre-treatment and primary processing methods.

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There are various factors affecting the SEC in processing of agricultural materials, among which are the moisture content, crop morphology, operating conditions, processing mechanisms, pre-treatment methods and so on. In comminution processes, some factors such as the moisture content, the size of the product and the operational parameters (including the shaft speed and feed rate) have been reported to have a significant effect on the SEC (Mani et al. 2004; Bitra et al. 2009; Opáth 2014). Similarly, Das and Gupta (2005) reported the influence of crop parameters, such as the seed sizes and machine design on the SEC. It has also been reported that the presence of shells or hulls increases the specific mechanical energy during the oil extraction from seeds (Zheng et al. 2005). Therefore, shelling is necessary to prevent chemical processes from occurring during the oil extraction. Based on the findings, the specific mechanical energy for most oil-bearing seeds during the oil extraction process is relatively high when they are unshelled. Presently, moringa seeds are shelled manually at the rate of 700 NGN ($1.52) per kilogram of the seed (Fakayode 2015; Fadele 2018), which is quite expensive. Gupta and Das (1999) showed the specific energy consumption for sunflower seed de-hulling to be 3.1 ± 3.8 $kJ \cdot kg^{-1}$ at a peripheral speed of 40.7 $m \cdot s^{-1}$ and a feed rate of 100 $kg \cdot h^{-1}$ using a medium seed size with a moisture content of 5.3%. Similarly, Kabutey et al. (2014) studied the energy requirement for the deformation of *Jatropha curcas* seeds in relation to their moisture content. Crop storage is another area where the SEC has been a concern as a result of the rising energy costs. The major challenge bedevilling the industrial sector of the Nigerian economy is the epileptic power supply and poor energy management. It is very important to identify some of the factors and process parameters that contribute to the energy management in the production line. This study aims to determine the effects of the cylinder speed and seed sizes on the specific energy consumption of a *Moringa oleifera* seed shelling machine.

MATERIAL AND METHODS

Sample preparation. The moringa seeds for this research were purchased in Ibadan from the Moringa Farmers Association. The seeds were cleaned manually to get rid of all foreign materials such as the stone, pods, leaves and so on. The initial moisture content of the moringa seeds was found to be 10.75% (wet basis) using the recommended procedure by the ASABE (American Society of Agricultural and Biological Engineers) (2008). The seeds were graded into three size categories, namely small, medium and large seed sizes using two screens having apertures of 11.42 and 12.93 mm (Fadele, Aremu 2018).

Determination of machine capacity. This is also referred to as the shelling rate. The capacity of the machine was evaluated as the quantity of the moringa seeds the machine could process within a specific time. This was determined using three grades of the *Moringa oleifera* seeds, viz. small, medium and large seed sizes. This was calculated using Equation (1) as performed by Fadele and Aremu (2017):

$$C = \frac{Q}{t} \quad (1)$$

where: C – the capacity of the machine ($kg \cdot h^{-1}$); Q – the mass of the processed seed (kg); t – the time taken to process the seeds (h).

Measurement of power rating. The power consumption of the *Moringa oleifera* shelling machine was determined using a current-voltage data logger (Logit LCV), which is similar to that of Liu et al. (2016). The logger takes readings of the current and voltage during the shelling operation at the cylinder speed levels of 200, 240, 280, 320 and 360 rpm. The consumption was evaluated from the readings obtained for both the current and voltage applying Equation (2):

$$P = I \times V \quad (2)$$

where: P – the power consumption (W); I – the alternating current (A); V – the alternating voltage (V).

Determination of specific energy consumption. The specific energy consumption of the *M. oleifera* seed shelling machine was obtained from the power consumption and capacity of the machine using Equation (3) for the small, medium and large seed sizes:

$$SEC = \frac{P}{C} \quad (3)$$

where: SEC – the specific energy consumption ($Wh \cdot kg^{-1}$); P – the power consumption (W); C – the capacity of the machine ($kg \cdot h^{-1}$).

Statistical analysis. The data obtained were analysed using Microsoft Word Excel (version 2007) and Design Expert (version 10). The total numbers of observations carried out during the optimisation of the

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Moringa oleifera seed shelling machine as reported by Fadele and Aremu (2018) were 32 runs with each run being replicated 3 times. The average values of the response, i.e., the capacity, was obtained for each of the seed sizes as shown in experimental plan generated using Design Expert in Table 1. The SEC was determined sequel to the optimisation process. The power rating of the *M. oleifera* seed shelling machine was obtained at 20 replicates for each cylinder speed as shown in Table 2.

RESULTS AND DISCUSSION

Capacity of the *Moringa oleifera* seed shelling machine. The mean values obtained for the machine capacity were 10.98, 10.27 and 8.86 kg·h^{-1} while the optimum values were 14.58, 11.38 and 8.41 kg·h^{-1} using the small, medium and large seed sizes as shown in Table 3. The relationship between the cylinder speed and machine capacity of the moringa seed shelling machine using the small, medium

Table 1. Plans of the experimental design for the capacity

Runs	Cylinder speed (rpm)	Responses		
		small seed size C_S (kg·h^{-1})	medium seed size C_M (kg·h^{-1})	large seed size C_L (kg·h^{-1})
1	240	8.7	9.02	7.8
2	280	9.9	12.72	11.8
3	360	12.75	11.35	11.7
4	240	11.39	8.46	8.8
5	280	11.98	10.24	8.6
6	280	10	11	9.7
7	280	10.01	10.52	8.9
8	280	11.75	8.9	8.2
9	200	7.44	9.64	6.6
10	280	11.14	10.54	9.4
11	240	9.47	8.66	7.5
12	280	11.16	8.96	8.7
13	320	10.42	11.28	9.8
14	320	12.65	12.15	11.0
15	240	13.15	12.31	9.1
16	240	8.42	8.08	6.8
17	320	15.13	13.21	11.8
18	320	13.78	14.21	10.1
19	280	11.65	10.23	8.9
20	320	9.66	9.14	8.0
21	280	8.02	7.87	6.7
22	320	9.95	8.82	7.9
23	320	11.07	9.01	7.6
24	280	12	10.74	9.4
25	280	9.13	8.72	7.2
26	240	10.71	8.16	7.3
27	240	8.7	8.88	7.3
28	280	14.13	11.11	9.3
29	320	12.78	11.65	11.2
30	280	9.74	10.7	8.7
31	280	11.98	10.45	8.4
32	240	12.69	11.8	9.4

C_S, C_M, C_L (kg·h^{-1}) – the capacities obtained for the small, medium and large sizes of the *Moringa oleifera* seeds

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Table 2. Power rating of the *Moringa oleifera* seed shelling machine at various speed levels

S.N.	Logged power rating at various cylinder speeds														
	200 rpm			240 rpm			280 rpm			320 rpm			360 rpm		
	C_1 (A)	V_1 (V)	P_1 (W)	C_2 (A)	V_2 (V)	P_2 (W)	C_3 (A)	V_3 (V)	P_3 (W)	C_4 (A)	V_4 (V)	P_4 (W)	C_5 (A)	V_5 (V)	P_5 (W)
1	2.5	199.1	497.75	3.9	213.6	833.04	3.8	202.8	770.64	3.4	213.1	724.54	3.8	216	820.8
2	2.7	199.1	537.57	3.8	214.3	814.34	3.9	201.7	786.63	3.7	213.9	791.43	3.7	216.3	800.31
3	2.5	198.1	495.25	3.9	210.4	820.56	3.2	202.9	649.28	3.6	214.6	772.56	3.6	216.7	780.12
4	2.5	197.3	493.25	3.6	210.3	757.08	3	201.7	605.1	3.7	214.3	792.91	3.8	215.4	818.52
5	2.9	197.7	573.33	3.5	211.7	740.95	2.8	200.8	562.24	3.9	214	834.6	3.8	215.1	817.38
6	2.4	190.4	456.96	3.6	211.2	760.32	2.7	201.6	544.32	3.8	213.5	811.3	3.8	215.5	818.9
7	2.6	191.2	497.12	3.6	210.3	757.08	2.7	200.1	540.27	3.7	213.6	790.32	3.7	215.9	798.83
8	2.4	190	456	3.6	211.9	762.84	3.7	201.9	747.03	3.6	214.2	771.12	3.7	214.6	794.02
9	2.5	190	475	3.7	213.5	789.95	3.4	201.1	683.74	3.5	213.8	748.3	3.6	215.8	776.88
10	2.5	192.2	480.5	3.2	213.4	682.88	3.6	202	727.2	3.7	213.6	790.32	3.6	214.7	772.92
11	2.4	199.2	478.08	3.6	214	770.4	2.7	201.9	545.13	3.9	214.2	835.38	3.6	214.7	772.92
12	3.1	201.6	624.96	3.9	213.1	831.09	2.6	200.5	521.3	3.8	213.9	812.82	3.9	215.4	840.06
13	2.6	202.4	526.24	3.5	214	749	2.6	200.9	522.34	3.5	213.2	746.2	3.6	216.3	778.68
14	3.1	201.9	625.89	3.6	213.1	767.16	3.6	200.9	723.24	3.5	213.5	747.25	3.9	214.8	837.72
15	2.5	202.9	507.25	4.1	212.3	870.43	3.7	201.3	744.81	3.4	212.8	723.52	3.8	214.3	814.34
16	2.8	202	565.6	3.7	212.3	785.51	3.6	200.8	722.88	3.5	214.2	749.7	3.8	215.6	819.28
17	2.5	201.1	502.75	3.7	212.7	786.99	3.6	202.7	729.72	3.4	213.2	724.88	3.6	215.6	776.16
18	3	201.3	603.9	3.8	213.2	810.16	2.5	201.9	504.75	3.7	213.4	789.58	3.6	217.1	781.56
19	2.7	201.1	542.97	3.9	213.8	833.82	3	202.8	608.4	3.6	212.4	764.64	3.9	217	846.3
20	2.7	201.2	543.24	3.4	213.1	724.54	2.5	204.3	510.75	3.6	212	763.2	3.6	216.2	778.32

S.N. – serial number; C_1– C_5 (A) – the logged current; V_1 – V_5 (V) – voltage; P_1 – P_5 (W) – power rating at the cylinder speed of 200, 240, 280, 320 and 360 rpm, respectively

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Table 3. Capacity of the *Moringa oleifera* seed shelling machine for the small, medium and large seed sizes

Seed sizes	No. of observations	Machine capacity (kg·h^{-1})					
		minimum	maximum	mean	optimum value	SD	ratio
Small	32	7.44	15.13	10.98	14.58	1.484	2.03
Medium	32	7.87	14.21	10.27	11.38	1.625	1.81
Large	32	6.6	11.8	8.86	8.41	1.484	1.78

and large seed sizes is depicted by Figure 1. The machine capacity using all the seed sizes followed an increasing trend with the cylinder speed, which is in agreement with that of Dalha (2013) in the decortications of the groundnut and cowpea. Sobowale et al. (2016) obtained 9.56 kg·h^{-1} as the capacity of a melon seed shelling machine while Ojolo et al. (2010) reported 15.57 kg·h^{-1} as the machine capacity of a cashew nut shelling machine. Singh et al. (2013) also reported a machine capacity of 5 kg·h^{-1} for a musk melon shelling machine. The capacity of a groundnut decorticator was reported to range from 10–20 kg·h^{-1} (FAO 2002). The optimum capacity agrees with the values obtained by other researchers. Figure 2 shows the relationship between *M. oleifera* seed sizes and the machine capacity. The machine capacity tends to reduce with an increase in the seed sizes. This could be as a result of the void spaces between the kernel of the seed and its shell. The size of the seed does not commensurate with that of the kernel; the seed might appear to be large while the enclosed kernel is small. The capacity of the *M. oleifera* seed shelling machine was observed to be significantly affected by the variation in the *M. oleifera* seed sizes as indicated by the statistical analysis presented in Table 4. The mathematical relationship between the capacity and the cylinder speed can be expressed by the following regression equations (Equations 4–6):

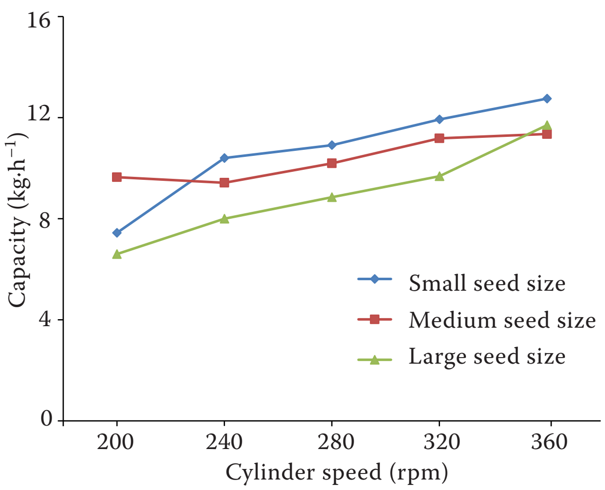

Figure 1. Relationship between the cylinder speed and the capacity of the seed shelling machine using the small, medium and large *Moringa oleifera* seed sizes

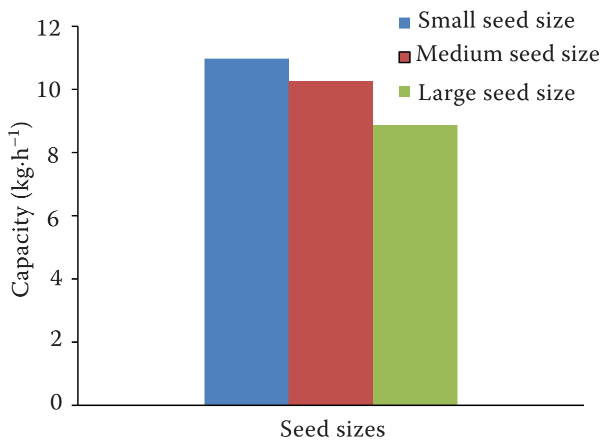

Figure 2. Relationship between the *Moringa oleifera* seed sizes and the capacity

$$C_s = -10.48 + 0.125CS - 0.000168\left(CS\right)^2 \quad (4)$$
$$R^2 = 0.96$$

$$C_m = 6.73 + 0.013CS \quad (5)$$
$$R^2 = 0.87$$

$$C_l = 0.65 + 0.030CS \quad (6)$$
$$R^2 = 0.97$$

where: C_s – the capacity of the machine using a small seed size (kg·h^{-1}); C_m – the capacity of the machine using a medium seed size (kg·h^{-1}); C_l – the capacity of the machine using a large seed size (kg·h^{-1}); CS – the cylinder speed (rpm).

The coefficient of determination (R^2) obtained for the three different seed sizes were found to be 0.96, 0.87 and 0.97 for relationship between the capacity and the cylinder speed using the small, medium and large *M. oleifera* seed sizes, respectively. This shows that the variation in the cylinder speed accounts for 96, 87 and 97% of the total responses in the capacity for small, medium and large seed sizes, respectively.

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Table 4. The ANOVA for the capacity (kg·h^{-1}) using the small, medium and large sizes of *Moringa oleifera* seeds

Source	SS	*df*	MS	*F*–value	*P*–value
Between groups	74.93	2	37.46	13.50	< 0.0001
Within groups	257.98	93	2.77		
Total	332.91	95			

df – degree of freedom; SS – sum of squares; MS – mean square

Specific energy consumption. The SEC of the *M. oleifera* seed shelling machine was recorded to have maximum values of 58.01, 74.37 and 100.63 Wh·kg^{-1} using the small, medium and large moringa seed sizes at cylinder speed of 360 rpm, respectively, while the minimum values were 31.25, 40.07 and 54.22 Wh·kg^{-1} using the small, medium and large moringa seed sizes at cylinder speed of 200 rpm, respectively, as shown in Table 5. The outcome of the greatest value of the specific energy consumption that was obtained for the large seed size could be as a result of the morphology and anisotropic properties of the seed which makes it require a larger compressive force during the shelling process. The SEC followed an increasing trend with the cylinder speed for all the seed sizes as shown in Figure 3, which could be as a result of interference between the air generated by the cylinder and the feathery nature of moringa seed shell. This implies that, as the cylinder speed increased, most of the seeds are blown away, thus delaying the shelling process. This fact results in a greater energy consumption with a lower output. These findings are similar to observations of Liu et al (2016) for comminution of Douglas fir chips into finer particles. It is very obvious that the SEC increased with an increase in the seed sizes which is in agreement with Ghorbani et al. (2010, 2011) for the size reduction of alfalfa chops. However, the reverse is the case for the dehulling of sunflower seeds using a centrifugal shelling device

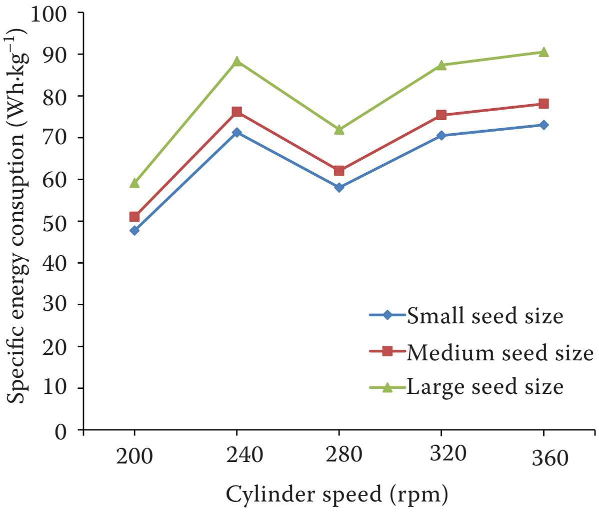

Figure 3. Plot of the cylinder speed against the specific energy consumption using the small, medium and large *Moringa oleifera* seed sizes

Table 5. Specific energy consumption at the various cylinder speeds and seed sizes

Seed sizes	Cylinder speed (rpm)	No. of observations	Specific energy consumption (Wh·kg^{-1})				
			minimum	maximum	mean	SE	SD
Small	200	20	31.25	42.90	35.93	0.798	3.568
	240	20	46.80	59.66	53.63	0.679	3.036
	280	20	34.60	53.92	43.69	1.539	6.883
	320	20	49.59	57.26	53.07	0.523	2.339
	360	20	52.98	58.01	54.98	0.375	1.675
Medium	200	20	40.07	55.00	46.06	1.022	4.574
	240	20	60.01	76.49	68.75	0.870	3.892
	280	20	44.35	69.12	56.02	1.973	8.825
	320	20	63.58	73.41	68.03	0.671	2.999
	360	20	67.92	74.37	70.49	0.480	2.148
Large	200	20	54.22	74.42	62.33	1.384	6.189
	240	20	81.20	103.50	93.03	1.178	5.267
	280	20	60.02	93.54	75.80	2.670	11.941
	320	20	86.03	99.33	92.06	0.908	4.059
	360	20	91.90	100.63	95.39	0.650	2.907

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Table 6. The ANOVA for the SEC (Wh·kg^{-1}) using the small, medium and large seed sizes

Seed Sizes	Source	SS	*df*	MS	*F*–value	*P*–value
Small seed size	between groups	5 400.27	4	1 350.07	86.98	< 0.0001
	within groups	1 474.59	95	15.52		
	total	6 874.86	99			
Medium seed size	between groups	8 878.82	4	2 219.71	87.01	< 0.0001
	within groups	2 423.58	95	25.51		
	total	11 302.4	99			
Large seed size	between groups	1 6215.24	4	4 053.81	87	< 0.0001
	within groups	4 426.39	95	46.59		
	total	2 0641.63	99			

df – degree of freedom; SS – sum of squares; MS – mean square

(Das, Gupta 2005). The reverse data obtained could be due to the different types of the shelling devices in the machines. The type of shelling device in the *M. oleifera* seed shelling machine is a tangential impact shelling device, which is quite different from that of sunflower sheller. Moreover, it was observed that the cylinder speed had a significant effect on the SEC for all the seed sizes as confirmed by the statistical analysis presented in Table 6. The mathematical relationship between the SEC and the cylinder speed can be expressed by the following regression equations (Equation 7 – SEC using a small seed size; Equation 8 – SEC using a medium seed size; Equation 9 – SEC using a large seed size):

$$SEC_S = -25.49 + 0.532CS - 0.00072\left(CS\right)^2 \quad (7)$$
$$R^2 = 0.56$$

$$SEC_M = -27.25 + 0.569CS - 0.00078\left(CS\right)^2 \quad (8)$$
$$R^2 = 0.56$$

$$SEC_L = -31.58 + 0.659CS - 0.0009\left(CS\right)^2 \quad (9)$$
$$R^2 = 0.56$$

The coefficient of determination (R^2) obtained was found to be 0.56 for the relationship between the SEC and the cylinder speed using the small, medium and large *M. oleifera* seed sizes. This shows that the variation in the cylinder speed accounts for 56% of the total responses in the SEC for all the seed sizes.

CONCLUSION

The study on the Specific Energy Consumption of a *M. oleifera* seed shelling machine showed that the SEC increased with the *M. oleifera* seed sizes. The variation in the cylinder speed with the SEC follows an increasing trend, i.e., the cylinder speed tends to increase with the SEC. The minimum values obtained for the SEC using the small, medium and large *M. oleifera* seed sizes were 31.25, 40.07 and 54.22 Wh·kg^{-1}, respectively, at a cylinder speed of 200 rpm, while the maximum SEC value obtained for the small, medium and large moringa seed sizes were 58.01, 74.37 and 100.63 Wh·kg^{-1}, respectively, at a cylinder speed of 360 rpm. The optimum values for the machine capacity were 14.58, 11.38 and 8.41 kg·h^{-1} using the small, medium and large seed sizes, respectively. The machine capacity increased with an increase in the cylinder speed using all the seed sizes. The machine capacity and the SEC were found to be significantly affected by the variation in the cylinder speed and seed sizes.

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