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Influence of Moisture Content and Seed Dimensions on Mechanical Oil Expression from African Oil Bean (*Pentaclethra macrophylla* Benth) Seed

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Abstract

Purpose: New low-cost oilseeds are needed to meet an ever-increasing demand for oil for food, pharmaceutical, and industrial applications. African oil bean seed is a tropical crop that is underutilized and has high oil yields, but there have been no studies conducted on its mechanical oil expression up to now. The objective of this work was to investigate the effect of moisture content and seed dimensions on mechanical oil expression from the seeds. **Methods:** Fresh oil bean seeds were procured, de-hulled, and cleaned. Initial seed moisture content, obtained in accordance with the ASAE standard, was 12% dry basis (db). The seeds were further conditioned by dehydration and rehydration prior to oil expression to obtain four other moisture levels of 8, 10, 14, and 16% db. The major diameter of the seeds was measured using digital vernier calipers, and the seeds were classified into size dimensions (< 40, 41-45, 46-50, 51-55, and > 55 mm). The oil yield and expression efficiency were obtained in accordance with standard evaluation methods. **Results:** The highest oil yield and expression efficiency (47.74% and 78.96%, respectively) were obtained for a moisture content of 8% db and seed dimensions of < 40 mm, while the lowest oil yield and expression efficiency (41.35% and 68.28%, respectively) were obtained for a moisture content of 14% db and seed dimensions between 51-55 mm. A mathematical model was developed to predict oil yield for known moisture content and seed dimensions, with a coefficient of determination R^2 of 95% and the confidence level of the predictive model of 84.17%. The probability of prediction F ratio showed that moisture content influence was more significant than seed dimensions. **Conclusions:** The higher the moisture content and larger the seed dimensions, the lower the oil yield from African oil bean seeds.

Keywords: African oil bean seeds, Expression efficiency, Moisture content, Oil yield, Seed dimensions

Introduction

The African oil bean (*Penthaclethra macrophylla* Benth) is a leguminous tree of the family Leguminosae and sub-family Mimosoideae, and has been cultivated in Nigeria since 1937 (Ladipo, 1984; Ladipo and Boland, 1995). It is a multipurpose tree with the potential for agroforestry in the tropics, and is recognized by peasant farmers in the southeastern part of Nigeria for its soil improvement properties (Akindahunsi, 2004). The tree grows to about 21 m in height and about 6 m in girth. It flowers between March and April with smaller flushes in June and November, but the fruits are available at most periods of the year and consist of large woody pods. The fruit splits open when mature to expose the seeds (Agbogidi, 2010).

The seeds are rich in protein, oil, energy, and have an abundance of mineral salts, such as sodium, potassium, magnesium, calcium, phosphorus, as well as lower concentrations of iron, zinc, copper, and lead. They therefore have the potential for dietary improvement in the food industries (Oyeleke et al., 2014). Furthermore, the seeds have been found to cure numerable diseases, especially heart disease, diarrhea, epilepsy, malnutrition, stomach disorders, iron deficiency, eye problems, and insomnia. In addition, consumption of the seeds reduces the risk of cancer and

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tobacco-related diseases (Bonnie, 2010). The seed contains oil, which can be extracted to serve as an additional vegetable oil (Ramadan and Morsel, 2003). It contains over 52% oil in its cotyledon, and proper processing of the seeds has the possibility of increasing the oil content from 52% to over 60.1% (Enujiugha and Akanbi, 2005)

There exists a huge market and steady rise in demand for vegetable oil in most developing countries for nutritional, pharmaceutical, and industrial uses (Aremu and Ogunlade, 2016). The present vegetable oil production level in Nigeria is not able to supply the national demand (Obi, 2013; Aremu and Ogunlade, 2016). The vegetable oil market has thus been flooded with different adulterated types of oil, some posing health risks such as heart problems, obesity, hypertension, and cancer. Most people are not able to differentiate between the different vegetable oils as they all appear similar and have the same uses; thus, all types are considered suitable for consumption (Obi, 2013; Oluwole et al., 2015). New oilseeds are needed to produce inexpensive and readily available vegetable oils suitable for food, pharmaceutical, and industrial applications to bridge the gap between demand and supply.

The separation of oil from oilseeds is an important processing operation. The process employed has a direct effect on the quality and quantity of the oil obtained. There are two main methods employed: solvent extraction and mechanical oil expression. The solvent extraction method involves bringing the oilseed into contact with a solvent that dissolves the oil residing in the seed, and the separated mixture is later heated to evaporate the solvent and obtain the oil. This method is highly efficient, with over 98% oil recovery, but requires large infrastructure and high initial costs and a high level of technical expertise. In addition, large quantities of highly flammable solvents are used that pose a fire and pollution hazard. Mechanical oil expression, on the other hand, involves passing preconditioned oilseed through a screw press, where a combination of high temperature and shear is used to crush the oilseed to release the oil. The oil expression efficiency of the mechanical method depends on the oilseed and several pretreatment conditions. This method generally involves very low initial and operating costs compared to the solvent extraction method, and is relatively free of any polluting or fire hazardous substances.

Pretreatment conditioning consists of preliminary processing activities such as size reduction, moisture content adjustment, heat treatment, and pressure application (Ibrahim and Onwualu, 2005). The activities used depend on the nature of the oil-bearing material, as well as the methods and devices adopted in the oil extraction and expression. Previous studies on the African oil bean seed have focused on the medicinal and nutritional characteristics of the plant (Ladipo and Boland, 1995; Enujiugha, 2003; Enujiugha and Ayodele, 2003), with little information available on the solvent extraction method or mechanical oil expression methods. This study was therefore carried out to determine the effect of two independent variables (moisture content and seed dimensions) on the oil yield and expression efficiency of African oil bean seeds, and to generate mathematical models to determine the relationship between moisture content, seed dimensions, and oil yield.

Materials and Methods

The mechanical oil expression from African oil bean seeds was achieved using an oil expeller with a capacity ranging from 5-20 kg/h. It was powered by a 2.5 hp, three-phase electric motor with an inbuilt reduction gear, which was run at 45 rpm (Figure 1). The expressed oil and cakes were collected separately, and the barrel was cleaned after each expression. The experiment was replicated three times and average values were recorded.

Sample collection and preparation

Fresh and matured seeds of African Oil Bean were procured from Ojoo market in Akinyele Local Government Area of Ibadan, Oyo State, Nigeria. The seeds were visually inspected and cleaned so that the defective ones were discarded. The good seeds were decorticated by removing the hulls (as shown in Figure 2 a-c), and the beans were kept in airtight polythene bags.

Moisture content determination

The moisture content of the seeds was determined according to the ASAE (1998) standard method for oilseeds by oven drying the seeds at 105°C to a constant weight. Samples weighing 100 g were placed in the oven and allowed to cool, weighed, and the moisture content was calculated using Equation 1.

$$Mc = \frac{w_i - w_f}{w_f} \times 100 \tag{1}$$

Figure 1. Oil expeller.

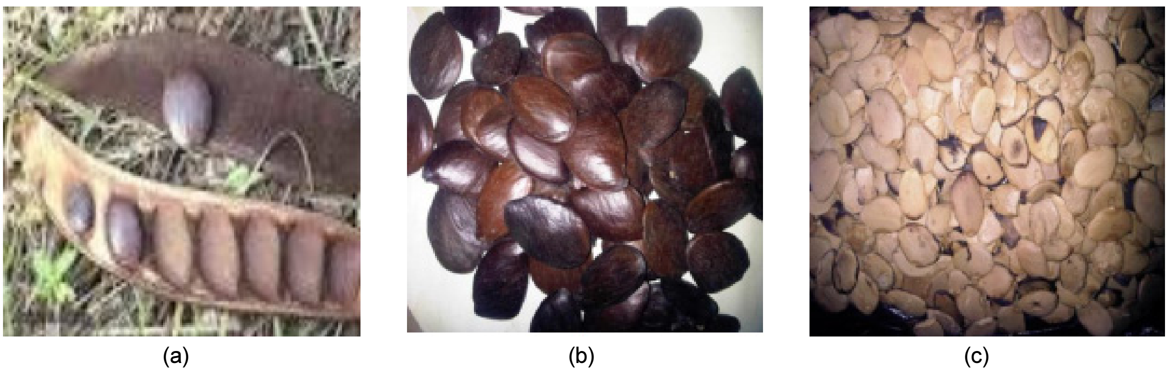

Figure 2. (a) Split open fruit, (b) Africal oil bean Seeds, (c) Dehulled seeds.

where Mc is the moisture content (% db), w_i is the initial weight of seeds before oven drying (g), and w_f is the final weight after oven drying (g).

Loss in weight was assumed to be moisture loss (Orhevba et al., 2013b), and the initial moisture content was 12%. However, the seeds were divided into five equal parts; one part being left as it was; two parts being oven-dried to further reduce the moisture content to the desired levels (8 and 10% db); and the remaining two parts being further conditioned to moisture content levels of 14 and 16% db by addition of distilled water.

Equations 2 and 3 were used to obtain the required final drying weight for moisture content levels of 8 and 10%, while Equation 3 (Bisht, 1986; Akinoso, 2006; Orhevba et al., 2013a) was used to obtain the mass of water required to obtain moisture levels of 14 and 16%. Each sample was kept in sealed airtight polythene bags at 5°C in a refrigerator for over 24 h to ensure uniform moisture distribution throughout the samples.

$$W_f = w_i x \frac{100 - M_{ci}}{100 - M_{cf}} \tag{2}$$

$$Q = \frac{A(b-a)}{(100-b)} \tag{3}$$

where W_f is the final weight to which the seeds were dried (g), w_i is the initial weight of seeds before sun drying (g), M_{ci} is the initial seed moisture content (% db), M_{cf} is the final (desired) seed moisture content (% db), Q is the mass of water added (g), A is the initial mass of samples, a is the initial moisture content of samples, and b is the final (desired) moisture content of samples.

Determination of seed dimensions

The major diameter of the seeds was measured using digital vernier calipers. It ranged between 38.32-66.28 mm, and the seeds were classified into five different size divisions (< 40, 41-45, 46-50, 51-55, and > 55 mm) in order to determine the effect of size dimensions on the yield and expression efficiency.

Determination of oil yield and expression efficiency

The oil yield and expression efficiency were determined in accordance with Philippines Agricultural Engineering Standard (PAES 230 and 231) for oil expellers. A seed sample of 300 g was used for each experimental run. The weight of seeds and mass of oil expressed were obtained using a digital electronic weighing scale (Model, SF 400A). The following relationships were used to obtain the oil yield and expression efficiency.

$$Oy = \frac{Wo}{Wi} x100\% \tag{4}$$

$$E_e = \frac{Wo}{X.w_i} x100\% \tag{5}$$

where Oy is the oil yield (%), w_o is the weight of oil collected (g), w_i is the weight of seeds fed into the hopper (g), Ee is the extraction efficiency (%), X is the oil content of African oil bean seeds (0.604, as obtained from solvent extraction using n-hexane).

Modeling and statistical analysis

Factorial experiment was used in this study, which allows the effects between and within the parameters to be tested simultaneously. All experiments were carried out in triplicate and the data obtained were subjected to statistical analysis. The experimental design is presented in Table 1. A mathematical construct was developed based on the empirical data to predict the effects of moisture content and seed dimensions on oil yield by using the historical data plan of Design Expert Software Package (Version 6.0.6) to generate equations applying multiple linear regressions by using the Quadratic model at a 95% level of confidence (Equation 6). Adequacy of the model was authenticated by the coefficient of determination R^2 and probability of prediction F ratio test.

Table 1. Experimental design

Parameters	Levels				
	1	2	3	4	5
Moisture Content (% db)	8	10	12	14	16
Seed Dimensions (mm)	< 40	45	50	55	>60

$$y = a + b + a^2 + b^2 + a.b \tag{6}$$

where y is the percentage oil yield, a is the moisture content (% db), and b is the seed dimensions (mm).

Results and Discussion

The empirical data obtained from the studies on the effect of moisture content and seed dimensions on oil yield and equivalent expression efficiency are presented in Table 2.

The linear regression equations for the effect of moisture content and seed dimensions on the oil yield and expression efficiency are presented in Figures 3 and 4, respectively.

Influence of moisture content and seed dimensions on oil yield

As presented in Table 2, it was observed that oil yield varies significantly with moisture content and slightly with seed dimensions. The observed variation in the oil yield for these parameters may be due to the optimum

Table 2. Empirical data for effect of moisture content and seed dimensions on oil yield

		Trial 1	Trial 2	Trial 3	Average	S. D.
Moisture Content (% db)	8	47.5	47.92	47.81	47.74	0.22
	10	46.62	47.65	47.09	47.12	0.52
	12	36.89	36.88	37.94	37.24	0.61
	14	34.95	34.85	35.39	35.06	0.29
	16	36.1	35.42	36.12	35.88	0.4
Seed Dimensions (mm)	40	41.7	39.73	39.49	41.31	1.21
	45	40.03	41.55	40.33	40.64	0.81
	50	42.13	39.79	39.15	40.36	1.57
	55	38.79	42.35	39.21	40.12	1.95
	60	41.15	39.81	40.71	40.56	0.68

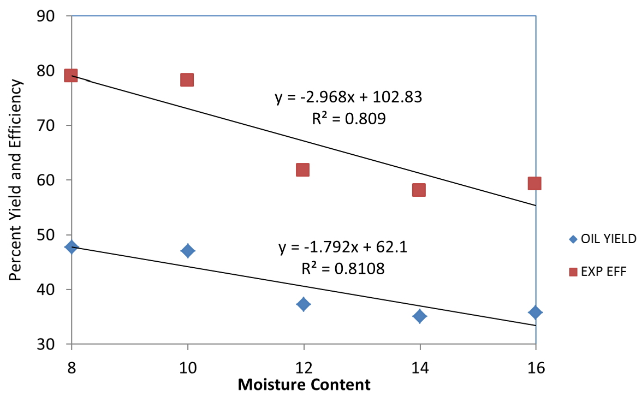

Figure 3. Effect of moisture content on oil yield and expression efficiency.

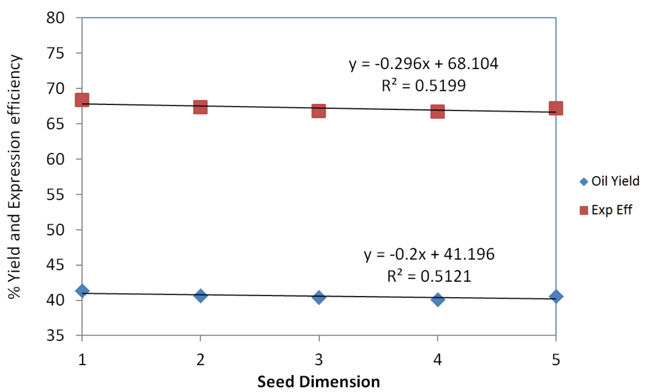

Figure 4. Effect of seed dimensions on oil yield and expression efficiency.

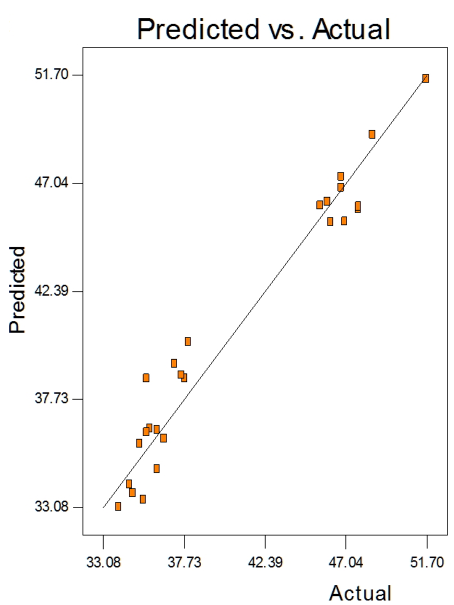

Figure 5. Predicted vs. actual oil yield.

level for the appropriate physicochemical changes in the oilseed. The model equation for predicting African oil bean seed oil yield is presented in Equation 7:

$$\begin{array}{lccccc} y = 38.76 - 7.17a & -\,0.4b & +\,3.04a^2 & +\,0.64b^2 & +\,1.22a.b & \quad (7) \\ F\ ratio \quad 93.26 & 0.29 & 5.87 & 0.26 & 1.34 & \end{array}$$

(Standard Dev. = 2.62, R^2 = 0.8417, Mean = 40.6, Adjusted R^2 = 0.8, predicted R^2 = 0.7334)

The plot of predicted vs. actual oil yield is presented in Figure 5.

Discussions

It was observed that oil yield and expression efficiency decreased with an increase in moisture content. A significant variation was obtained in the oil yield and expression efficiency for different moisture content levels. The highest oil yield (47.74%) and expression efficiency (78.96%) were obtained at a moisture content of 8% db, while the minimum oil yield (35.06%) and expression efficiency (57.94%) were obtained at a moisture content of 14% db. This implies that, for the African oil bean, a higher moisture content results in lower oil yield and expression efficiency. This phenomenon may be attributed to the fact that for a low moisture content, the shear and compression of the seeds is more easily achieved than for a high moisture content. Furthermore, the decrease in oil yield with increase in moisture content level may be attributable to the explanation provided by Vaughan (1970) that the effect of moisture level may be related to the development of mucilage (a sticky substance) on the outer walls of the seed particles. The further addition of water results in swelling of the mucilage, which produces a cushioning effect that may prevent the rupturing of the oil cell walls and hence hinder oil expression. Similar findings were reported by Ajibola (1983).

Ibrahim and Onwualu (2005) also reported that the moisture content of seeds is an important factor that affects the yield and quality of the oil extracted, and that cloudy oil is obtained from seeds with high moisture level. The decrease in oil yield with an increase in moisture content also corresponds to the findings of Singh et al. (1984) in the development of a mathematical model to predict sunflower oil expression; Akinoso (2006) on the effect of moisture content, roasting duration, and temperature on the yield and quality of palm kernel; and Ogunsina et al. (2008) on the oil point pressure of cashew kernels. Other studies with similar findings include Ajibola et al.

(1993), Akinoso et al. (2006), Lawson et al. (2010), Bamgboye and Adejumo (2011), Abidakun et al. (2012), Adejumo et al. (2013a), Adejumo et al. (2013b), Arisanu (2013), Ejikeme et al. (2013), Orhevba et al. (2013a), Orhevba et al. (2013b), Santos et al. (2013), Wilfred et al. (2013), Ogunsina et al. (2014), Yusuf et al. (2014), Adejumo et al. (2015), and Bamgboye and Adejumo (2015).

The seed dimensions had a slight effect ($p > 0.05$) on the oil yield and expression efficiency from African oil bean seeds (Table 2). A maximum oil yield (41.3%) and expression efficiency (68.28%) were obtained from seed sizes of < 40 mm, while minimum oil yield (40.12%) and expression efficiency (66.64%) were obtained for seed dimensions between 51-55 mm. Therefore, the reduction of the size of the seeds in order to expose a greater area of the seed cells to rupture prior to mechanical oil expression can improve the oil yield and expression efficiency, as found by Ward (1976), Ajibola et al. (1993), Adeeko and Ajibola (1994), Olajide (2000), Sayyar et al. (2009), and Adesina and Bankole (2013).

The R^2 value was high (84.17%) at a 95% confidence level, while the probability of prediction (F ratio) was 20.2%, and an estimated error of ±2.62 was predicted. Moisture content and seed dimensions were negative, indicating that oil yield increases with a reduction in each factor. The second order of moisture content, the second order of seed dimensions, and the interaction between moisture content and seed dimensions were positive, which implies that an increase in any of these improves the oil yield (Akinoso et al., 2006). From Equation 7, it can be seen that any variation in moisture content has a more significant impact on oil yield (F ratio = 93.26) than the seed dimensions (F ratio = 0.29).

Conclusions

The effect of moisture content and seed dimensions on the oil yield and expression efficiency of the African oil bean seed by using an oil expeller was investigated. The moisture content had a significant influence on the percentage oil yield and expression efficiency of the seeds, while the seed dimensions had a slight influence. The results showed that seeds with a higher moisture content yielded less oil compared to seeds with lower moisture contents, and the smaller the seed dimensions, the higher the oil yield from African oil bean seeds

Conflict of Interest

The authors have no conflicting financial or other interests.

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