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A Study of Yield Characteristics During Mechanical Oil Extraction of Preheated and Ground Soybeans

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Abstract: Soybeans were extracted for oil by compressing a ground sample at various operating pressures, pressing durations and product bulk temperatures. The oil yield from the various operations was measured and expressed as a percentage of the original mass of crushed seeds. It was found that the oil yields increased linearly with increase in pressure as the compression pressure was increased from 40 to 80 kgf/m^2 and that oil yield also increased linearly with increase in the duration of pressing within the range of 6 to 12 minutes. Oil yield also increased with the bulk temperature of the preheated oilseeds but reached a peak yield at about 75°C and then decreased with further increase in temperature of oilseeds. It was also found beneficial to dry the seeds to a moisture content slightly below the ambient moisture content of 9.3% (d.b.) although reducing moisture to a value lower that 5% (d.b.) resulted in a reduction in oil yield. A single empirical model for estimating the oil yield for varied conditions of pressure, duration of pressing and the bulk temperature of oil bearing material was developed which could estimated the yield with good accuracy within the experimental range.

Keywords: Oil yield, soybean, temperature, pressure, duration of pressing, moisture content

INTRODUCTION

Soybean is the most widely produced oilseed in the world today and the crop is also grown in many countries with varied geographical and climatic condition [1]. The crop is grown by both large scale and small scale farmers and for a majority of the peasant farmers in the developing countries it is or has the capacity to become the sole means of income. However, unlike in the developed countries where large scale processing facilities are available, the extraction of edible oils in developing countries can be problematic due to social-economic constraints evident in many farming communities[2,4].

The practice in developing countries is to introduce some cheap and simple technology in the rural areas that can quickly be adopted and which will therefore have an immediate impact on the livelihoods of the communities while at the same time impacting positively on the national and regional economic growth[2,5]. In so doing it is sometimes necessary to introduced technology that might otherwise not be considered the most efficient but which under the circumstances will be the most convenient or appropriate [6].

In the case of oil extraction from oil-crops, a number of mechanical devices are in use in developing countries. Some of these devices are traditional and have been in use for centuries while others have been introduced in recent years specifically for use in the small scale sector of developing economies[4,7,12]. The principle of operation of these machines include the application of direct hydraulic pressure where the product is placed under high pressure for a considerable amount of time and the oil allowed to slowly permeate from the mass of compressed kernels or ground product. Another popular type, the screw oil expeller, works by compressing the product in a tube. A screw which is rotates inside the tube forces oil out of the compressed mass to escape through an enclosing screen that runs parallel to the screw and along the tube-wall while the spent cake is extruded through the end of the tube.

There are many variations in design of the two types of mechanical extractors in use throughout the developing world. However, although the principle of operation remains the same, there is a major and significant difference when it comes to source of power required to drive these oil extractors. While a majority of the small scale equipment is designed for either

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hand or foot operation there are some that are animal driven [7, 13]. Also, a few much lager units that require mechanized emotive power can be found in areas where there are organized crop processing group operations.

The yield from an oil-bearing material is dependent on the quality of the oilseeds and no method of extraction however efficient can compensate for this. At the same time, the extraction process needs to be well managed in order to extract as much oil from the seed as it is technically possible. Also, apart from the limitations that may be due to shortcoming in the equipment design, there are a number of other factors or conditions that can be manipulated during extraction in order to maximize yield. These factors include the moisture content of material, size of particles and the temperature of particles. The pressure applied during extraction and the duration of application of the pressure also has a direct effect on the yield although the control of these two factors might be limited due to design and operation requirements in some types of extractors.

The effect of these factors has been studied by a number of researchers[14,17]. In all these studies the authors have established that there exists an optimum value of moisture content for each product at which oil yield is highest when other variables are held constant. The oil yield has also been found to increase with the extracting pressure and duration of extraction within a limited rage of either factor but to level out on exceeding a certain range. Baryeh[14] while working with palm oil established that a preheated product yielded higher quantities of oil and that the longer the duration of heating at a preset heating medium temperature yielded higher oil quantities for heating medium temperatures below 100°C above which temperature yields started falling. Fasina and Ajibobola [15] however found the oil yield to decrease with post-heating medium temperature within the range of 65-100 °C for Conophor. This work also found a relationship between yield and both preheating moisture content and post-heating moisture content.

The premise of the current work is that there exist a relationship between the actual moisture content of the oil bearing material at the exact moment of extraction and the oil that it yields. In addition, if we control and monitor the actual bulk temperature of the oil bearing material instead of controlling the temperature of the heating medium, we should be able to develop a model that more reliably relates the oil yield to temperature. This is so because it is the temperature of the oil bearing cells that influence the yield rather than the temperature of the heating medium since the heating medium only serves as a medium for heat transfer. As a result of this heat transfer the temperature of the cells in the oil bearing material rises. In addition, although oil yield is also affected by the moisture content of the product, the moisture content of the product was allowed to change during the heating process in the models so far developed [16].

This study examines the relationship between bulk temperature of oil bearing material, the magnitude of pressure, duration of application of pressure and moisture content on the oil yield for soybean samples within reasonable operating limits of small expeller equipments.

MATERIALS AND METHODS

Sample Preparation: Dry soybeans were obtained from the local retail market in Nairobi and packaged in sealed plastic bags after cleaning and sorting. The material was then stored in a refrigerator at 5°C until required. Samples for the determination of the effect of moisture content on oil yield were dried to the predetermined moisture content using a hot air oven maintained at a set air temperature of 40°C before being stored in the fridge. Prior to any oil extraction runs all the soybeans samples were withdrawn from the fridge and ground using a hammer mill to an average particle size of approximately 1mm in diameter.

The test sample of approximately 100g was then heated to the required temperature by wrapping the material in a cloths bag (sachet) made of muslin cloth and placing it in a hot air oven in which the heating medium (air) was maintained at approximately 10 degrees above the required sample bulk temperature. The cloths bag ensured that there was a negligible loss of moisture from the sample during heating and also allowed a thermocouple to be placed inside the bag and in contact with the ground material. This way the bulk temperature of the material could be monitored using a data logger (Thermodac, model no. 5001A, Eto Denki Company, Japan). The sample was removed from the oven when temperature was 2 to 3 degrees above set value. To ensure a completely uniform bulk temperature the material was transferred to a sealed vacuum flask and held for another 10 minutes before oil extraction.

Oil Extraction: Each sample was removed from the thermos flask while still enclosed in the compression sachet made of muslin cloth and inserted into in a prefabricated oil extraction cell (perforate metal cylinder). A dallchi keiki compression hardness tester (Model no. 198 Tanifuji Machine co. ltd., Tokyo, Japan) was then used to compress the ground material at a constant force and for a specified duration. The oil extracted was captured using glassware and recorded as yield in grams. The percentage oil yield was later computed from the ratio of mass of oil to the mass of sample before oil extraction.

Table1: Oil extraction conditions during experiments

No of runs	Extraction pressure, kgf/m^2	Temperature of ground product, °C	Duration of pressing, minutes	Moisture content, % (.b)
25	40, 50, 60, 70, 80	50, 60, 75, 90, 120	6	9.3
20	40, 50, 60, 70, 80	25	6, 8, 10, 12	9.3
15	40, 50, 60, 70, 80	25	6	2.7, 5.0, 7.2

Experimental Setup: A total of 25 experimental runs were carried out in order to determine oil yields at five extraction pressures (40, 50, 60, 70 and 80 kgf/m^2) and product temperatures (50, 60, 75, 90, 120 °C). During these runs the product was at its equilibrium moisture content of 9.3% (db) and pressing duration was fixed at 6 minutes. Another 20 extraction runs were carried out for varied extraction pressure and duration as shown in Table one while maintaining both product temperature and moisture content constant fixed at 25 °C and 9.3 (db) respectively. The last batch of 15 experimental runs was done at varied pressure and moisture content but for fixed product temperature and duration of pressing as shown in Table 1.

RESULTS AND DISCUSSIONS

The change in oil yield with increase in the bulk temperature of the product is presented in Fig.1. It can be seen that the yield increased with increase in bulk temperature and reached the highest values under the experimental conditions in the neighbourhood of 75°C for all extraction pressure settings. Further increase in bulk product temperature for any given extraction pressure however resulted in a rapid decrease in oil yield. The cause of the increase in yield with heating is not definitely known but is often attributed to reduced viscosity of the oil in the capillaries of the vegetable matter[15]. Reduced yield at higher temperatures could be due to oil degradations and the likely increase in the brittleness of the product. However knowledge of the optimal bulk temperature is important because equipment such as screw expellers can be manipulated so as to operate under conditions that optimize oil yield[18].

It can be observed in Fig.1 that the oil yield increases with increase in extraction pressure for any given pre-heat product bulk temperature. The effect of extraction pressure on yield is however better captured in Fig.2 for samples that were at an ambient bulk temperature of 25°C before extraction took place. The oil yields first increases slowly with increase in pressure before it reaches a region (50-70 kgf/m^2) during which there is rapid increase in yield probably because this is the pressure at which the material structure crumbles. As can be seen in Fig.2., however, there is a reduced rate of rise in yield with further increase in extraction pressure beyond 70 kgf/m^2.

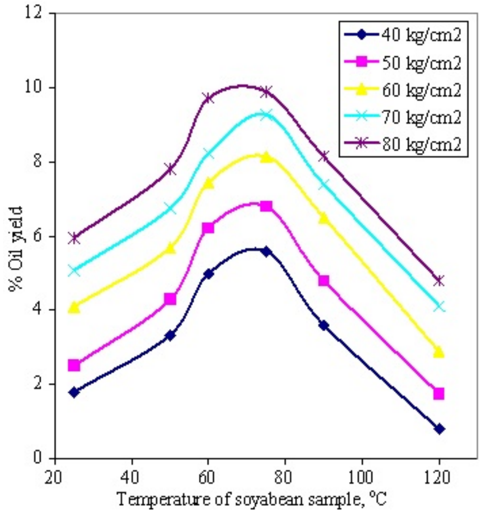

Fig. 1: Variation of oil yield with increase in temprature of soybean sample at five different extraction pressures.

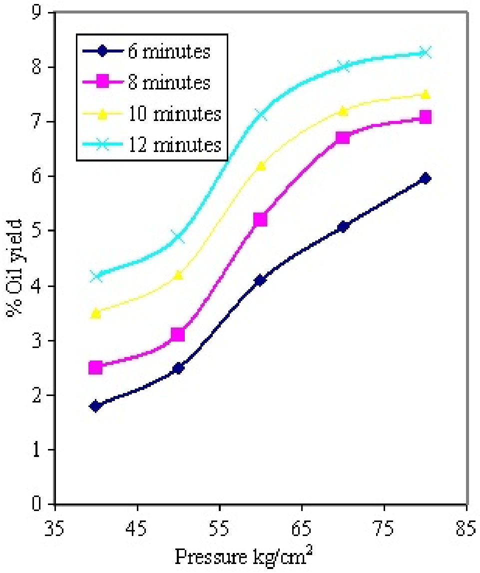

Fig. 2: Oil yield arunction of extration pressure at four different duration of pressing.

The effect of the duration of application of extraction pressure on the yield for soybean meal that has had no preheat treatment can also be observed in Fig.2. It can be seen that the percentage yield increases with the duration of extraction at all extraction pressures. Also it is evident that there is a rapid

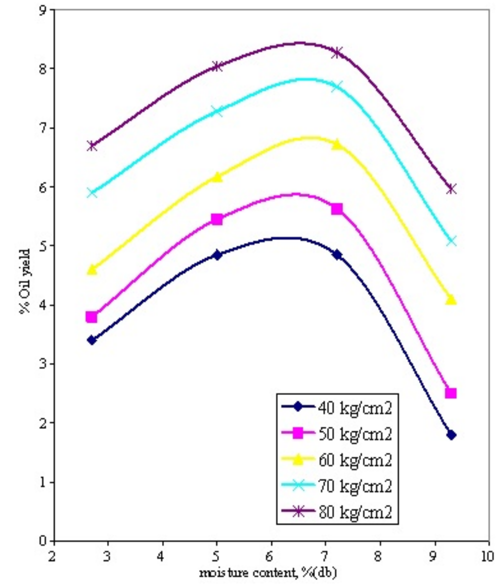

Fig. 3: Oil yield as a functionof soybean moisture content at five fixed extraction pressure during mechanical extraction.

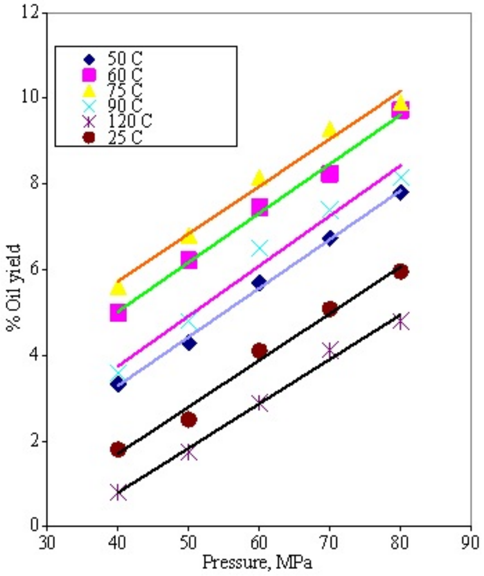

Fig. 4: Variation of oil yield from soyabean with extraction pressure at six preheat temprature of soyabean are set at 9.3% (db) and six minutes respectively.

increase in oil yield as the extraction pressure is increased from 50 to 70 kgf/m^2 signifying a critical stage in pressure extraction since the increase in yield between 70 and 80 kgf/m^2 is much lower. However the fact that the yield at 80 kgf/m^2 is nearly 4 time and two times that at 40 for the 6 minute and twelve minutes durations, respectively, is worth noting.

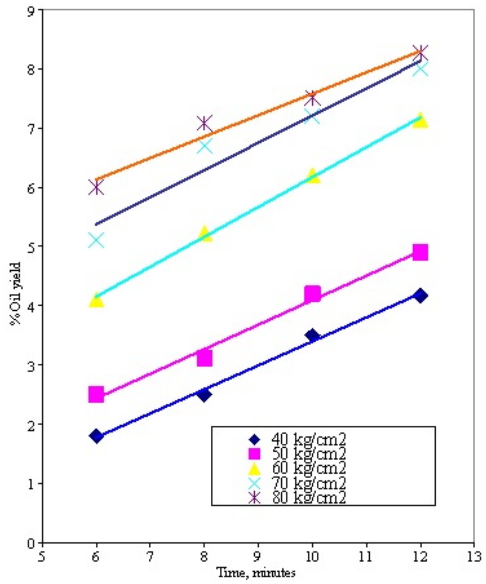

Fig. 5: Variation of oil yield from soybean with duration of pressing at five extration pressure for product whose moisture content and preheat bulk temprature if 9.3% (db) and 25^{o}C respectively.

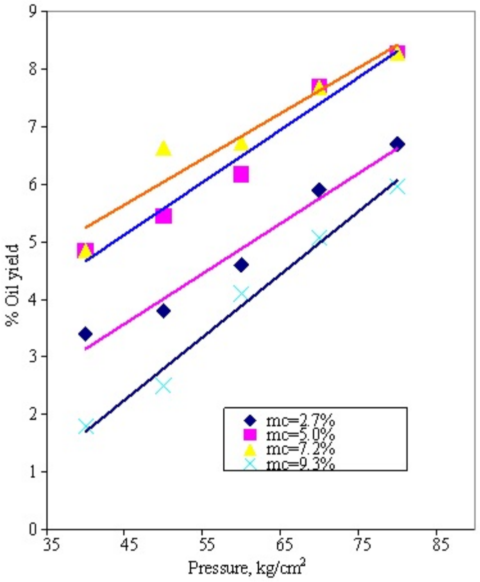

Fig. 6: Variation of oil yield with extraction pressure at at four moisture contents of soyabean samples preheated to 25oC and pressed for a duration of six mintes.

Clearly it is worthwhile to employ higher pressures especially pressures above 70 kgf/m^2.

The variation of oil yield with the moisture content and extraction pressure is graphically presented in Fig.3. The yield rises from a low value at the moisture

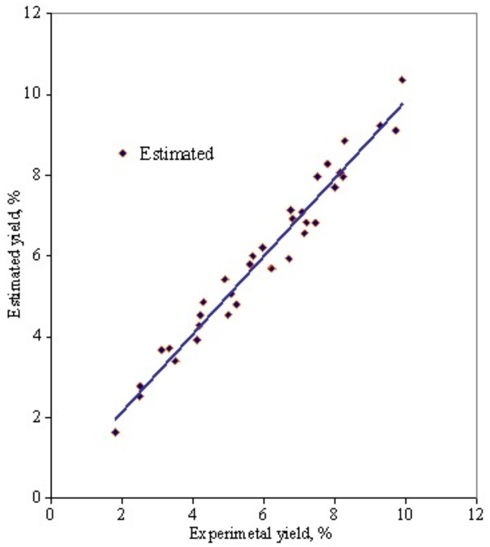

Fig. 7: Comparison of experimental oil yield and estimates of Eq.2 represent multiple leaner regression analysis of yield against extraction pressure, duration of pressing and prdheat bulk temperatures of sample.

contents of 2.7% (db) to reach a maximum value at moisture contents of between 5 and 7% (db) for all extraction pressures. Thereafter the yield decreases with increase in moisture content for all extraction pressures. Evidently therefore it would be preferable to extract oil at moisture contents close to 6% (db) in order to get higher yields.

The oil yield could also be linearly related to an extracting condition using a model based on Eq.1 below. In each case all other variables were held constant while comparing the oil yields at various values of variable X in the Eq.1.

- $Y = k + m (X)$ (1)

Where:

- Y= Oil yield, ratio of mass of oil to mass of sample expressed as %
- k=regression constant for intercept
- m= regression constant for slope

The coefficients of Eq.1 relating yield to extraction pressure are given in Table 2. These values show the linear relationship between yield and pressure as the moisture content and the duration of pressing are each held constant at 9.3% (db) and six minutes respectively, and for the indicated pre-heat temperature of soybeans. The relationship is also graphically presented in Fig.4 and it is evident from the figure as well as from the high coefficients of determination (Table 2) that the yield increases linearly with extraction pressure if the other variables are held constant within the preheat temperature range of 25 to 120 °C.

Table.2: Regression constants of Eq.1 for the linear variation of yield with pressure (x in kgf/cm^2) at a fixed extraction duration of six minutes and product moisture content of 9.3% (db).

Temperature of product (°C)	intercept	slope	R Square
25	4.868	0.1501	0.9698
50	1.298	0.1108	0.9970
60	0.440	0.1147	0.9926
75	1.298	0.1108	0.9856
90	0.930	0.1170	0.9783
120	3.350	0.1037	0.9932

Table.3: Regression constants of Eq.1 for the linear variation of yield with duration of extraction period (x in minutes) at the fixed moisture content of 9.3% (db) and preheat product temperature of 25°C.

Pressure (kgf/m^2)	slope	intercept	R Square
40	0.4655	-1.297	0.9888
50	0.4895	-0.853	0.9899
60	0.4600	0.160	0.9987
70	0.3295	4.002	0.9930
80	0.2240	5.429	0.9175

Table 4: Regression constants of Eq.1 for the linear variation of yield with pressure (x in kgf/cm^2) at four moisture contents and fixed duration of pressing and preheat temperature of six minutes and 25°C respectively.

moisture content (% d.b.)	Slope	intercept	R Square
2.7	0.0870	0.340	0.9719
5.0	0.0910	1.028	0.9722
7.2	0.0792	2.082	0.9205
9.3	0.0690	0.518	0.9898

Similarly, the linear relationship between oil yield and duration of pressing as the sample moisture content and preheat temperature are held constant at 9.3% (db) and 25 °C are presented in Fig.5 and Table 3. Clearly there exists a linear increase in yield with increase in duration of pressing for the extraction pressures of 40-80 kgf/ cm^2. Fig.6 and Table 4 also present the linear relationship between oil yield and pressure for fixed preheat bulk temperature of sample and duration of pressing of 25 °C and six minutes respectively. Here also the oil yield was found to be linearly related to the extraction pressure even as the moisture content varied as can be seen in Fig 6 and Table 4.

In light of the good linear relationships between yield and different extraction variables an attempt was made to relate yield to several variables using multiple linear regression analysis. Due to the fact that oil yield at high preheated bean temperatures tended to decrease with increase in temperature (Fig. 1) the oil yield data at preheat temperatures of 90 and 120 °C was not used in this regression analysis. Also only data for oil yields at moisture contents of 9.3% wet basis were used since there fewer data points at other moisture content and this would have had the effect of distorting the regression results. The multiple regression for the three variables (pressure, pressing duration and preheat temperature) can be presented mathematically inform of Eq.2. The coefficients y0, y1, y2 and y3 were found to be -7.65852, 0.11415, 0.441074 and 0.083199 respectively and there was a high R^2 value of 0.9636. A plot of the relationship of experimental values and those estimated using coefficients of Eq.2 is presented in Fig.7 and indeed show that this equation can conveniently estimate oil yield from soybean within the experiment range for which it was developed.

- $Y = y0 + y1\ (X1) + y2(X2) + y3(X3)$ (2)

Where: y0, y1, y2 and y3 are regression coefficients, and

- X1= Pressing force, kgf/m^2
- X2= Duration of pressing, minutes
- X3= Preheat temperature of sample, ^{O}C

Conclusion: This work shows that initial heating of material before mechanical expression is very important and that there exist an optimum bulk temperature which should not be exceeded if oil yield is to be maximized. Furthermore the study shows that there is a linear relationship between oil yield and both the magnitude of expressing force and the duration of it application. Also, the bulk preheated temperature of the soybeans is linearly related to the oil yield for temperatures falling below 75 ^{O}C.

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