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Optimization of the Performance of a Vertical Screw Jack For Groundnut Oil Extraction

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Abstract

Groundnut (*Arachis hypogaea)* is one of the oil seeds in the category of the second most valuable commodity in the world trade. One of the methods of extracting groundnut oil is with the use of mechanical device which offsets some of the problems of traditional and chemical methods of extraction. Most local processors of groundnut oil do not use to or do not know how to put into consideration processing factors/inputs (temperature, heating time, pressure, moisture content and so on) that can lead to better (optimum) oil extraction outputs. This situation is causing low oil yield and low extraction efficiency, high extraction loss and poor quality of oil even when machines are used for extraction. Therefore, this study used a vertical screw jack to extract groundnut oil and also optimize the oil extraction process with the use of Design Expert (8.0.3 version) computer software package. Three levels of temperature (50, 60 and 70^{o}C) and two levels of heating time (5 and 10 min) were used to pretreat seeds in the extraction chamber of the vertical screw jack prior to oil extraction process. The extraction process were estimated for oil yield, extraction efficiency and extraction loss; and oil quality in terms of Free Fatty Acid (FFA), saponification value, acid value, refractive index and viscosity were analyzed. Results showed that, optimum oil yield (29.90%), extraction efficiency (48.12%) and extraction loss (4.23%) were achieved at temperatures and time of heating of 50, 50.21 and 70^{o}C; and 10, 5.02 and 10 min respectively. Temperature of 50^{o}C and time of heating of 10,

10, 10, 5 and 5 min gave optimum values of 3.38 mgKOH/g, 190.26 mgKOH/g, 6.74 mgKOH/g, 1.45 and 1.47 cm/s for FFA, saponification value, acid value, refractive index and viscosity respectively; whereas, optimum value of 5.06 was obtained for pH at temperature of 50.15^{o}C and 9.98 min time of heating.

Keywords: process conditions, optimization, vertical screw jack, groundnut oil extraction, Design Expert computer software package.

1. Introduction

Groundnut (*Arachis hypogaea)* crop is a legume and it has been ranked as one of the world's most important source of edible oil (Prasad *et al.*, 2009). Akubugwo *et al*., (2008) reported that groundnut is one of the oil seeds in the category of the second most valuable commodity in the world trade. The edible oil in groundnut seed (about 53%) contains up to 36% protein and 15% carbohydrate; and some essential nutrients such as vitamin E, vitamin B, sodium, calcium, potassium, phosphorus, magnesium, thiamine and zinc (Nkafamiya *et al.,* 2010 and Prasad *et al.*, 2009).

Some of the methods of extracting oil from groundnut seed and other oil bearing biological materials are mechanical, chemical and traditional methods. In mechanical and traditional methods, sufficient pressure would be applied either manually or with the use of specialized powered machine/equipment(screw press, hydraulic press, Ghani press and so on) in order to rupture the oil cells in the oil bearing materials, thus leading to liberation of needed oil. Chemical method involves the use of special solvents that are capable of dissolving the oil in oil cells when they come in contact with oil bearing materials. The process of oil extraction is usually preceded with some form of pretreatment operations (heat treatment, size reduction and moisture content adjustment); and variation of other process parameters like pressure, speed of machine, time of pretreatment, type of machine and type of feed stock. The essence is to be able to get maximum oil yield and extraction efficiency, and minimum extraction loss coupled with oil of acceptable qualities after extraction. Odewole *et al*., 2015 used solvent extraction method to extract oil from fluted pumpkin seed, Akinoso *et al*., (2006) and Orhevba *et al*., (2013) used mechanical oil expeller/press to get oil from sesame seed and neem seed respectively. Ibrahim and Onwualu (2005) reported that the yield and

quality of oil extracted from oil bearing materials would depend on moisture content adjustment, heating time, temperature and pressure application among other factors. Alonge and Olaniyan (2003) reported that prolonged pressure application on shea nut paste positively aided outflow of oil. Olaoye (1994) wrote that cooking of oil seeds would lead to desirable moisture content adjustment which would cause proper plasticity for efficient oil extraction and halting of enzyme action.

In simple term, optimization is the process of finding value(s) or condition(s) of input variable(s) that will either maximize or minimize a particular output (response) (Odewole *et al*., 2016). In relation to the current study, the focus is to find the values of temperature and heating time that will either maximize or minimize each of the following output during groundnut oil extraction process: oil yield, extraction efficiency, extraction loss, Free Fatty Acid (FFA), saponification value, acid value, refractive index and viscosity. Optimization process can be done via differential calculus, linear programming and sequential technique, simultaneous technique and others. All the techniques of optimization are currently available in form of computer software packages for easy and speedy execution of tasks. One of such software package is Design Expert, and it was used for the optimization process of this study. The software uses desirability value (between 0 and 1), which is an index for selecting the best combinations of input factors that will either maximize or minimize outputs. The closer the desirability values to 1, the better the solution (Stat-Ease, 2000). In fact, more than one optimization combinations for a particular output could have the same desirability value; this cannot create any problem because the software has a way of selecting the best out of the pool of optimization combinations with an underline notation. The desirability values are usually considered independently for each output. This practice is important because, each output possesses different characteristics, and it would be a bias judgement to conclude that some outputs that may have low desirability values in comparison with others with higher values would not be considered as good optimization combinations. Akinoso *et al*., (2006) used linear programming optimization technique for optimizing oil expression process from sesame seed. Odewole and Olaniyan (2015) used Essential Regression (ESSREG) software package for process optimization of pretreatment and drying of red bell pepper. Sunmonu *et al*., (2015) used ESSREG for modeling the process of storage and packaging of spiced

African locust beans. Odewole *et al*., (2016a) used Design Expert software to optimize nutrients in dried mixture of fermented milled maize and sorghum (*ogi*). Odewole *et al*., (2016b) and Singh *et al*., (2010) used Response Surface Methodology to optimize some mineral nutrients in pretreated dried green bell pepper and carrots respectively. Ajala *et al*., (2016) got optimum yield of 66.90% for shea butter at sample weight of 30.04g, solvent volume of 364.04 ml and extraction time of 40 min.

Traditional method of extraction is full of drudgery, thus, the output is low and oil extracted may be of poor quality (Olaniyan and Oje 2007). Also, chemical method of extraction is faced with the problem of additional cost of removing chemical(solvent) from oil after extraction and the tendency of the presence of some the chemicals in the oil even after it is removed, which may adversely affect oil quality after some time. Some mechanical devices for groundnut oil extraction like hydraulic press can contaminate the oil if the hydraulic oil of the machine spills into the extraction medium; and most screw presses are bulky with high cost of maintenance. Most local processors of groundnut oil do not use to or do not know how to put into consideration processing factors/inputs (temperature, heating time, pressure, moisture content and so on) that can lead to better(optimum) oil extraction outputs. This situation is causing low oil yield and low extraction efficiency, high extraction loss and poor quality of oil even when machines are used for extraction. As a result of the aforementioned problems, this study considered the following objectives: the use of a mechanical device (vertical screw jack) to extract groundnut oil and optimization of the oil extraction process with the use of Design Expert computer software package.

2. Materials and Methods

The following equipment were used for the research: a vertical screw jack (Figures 1, 2 and 3), digital weighing balance (OHAUS CL Series, Model CL 201, China, accuracy: 0.1). Three levels of heating temperature (50, 60 and 70^{o}C) and two levels of heating time (5 and 10 min) were used for pre-treating the groundnut seeds before oil extraction. The moisture content of the groundnut seed was 8.4% (db). The experimental design was done with computer software (Design Expert 8.0.3 version under general factorial design). A uniform quantity (100 g per experimental run) of prepared groundnut seeds was used for the oil extraction operation.

After the extraction operation, the performance indices of the vertical screw jack in terms of oil yield, extraction efficiency and extraction loss were estimated with equations reported in Odewole *et al*., 2015. Also, the performance of the machine in terms of quality of oil extracted (Free Fatty Acid (FFA), saponification value, acid value, refractive index and viscosity) was analyzed in accordance to AOAC (2002) standard procedures. All the performance data obtained with respect to combined effect of temperature and time of heating were substituted into the output section of the experimental design layout of the computer software for optimization process according to the procedures in Stat-Ease (2000). The oil extraction operation was carried out at the Department of Agricultural and Biosystems Engineering workshop, University of Ilorin, Ilorin, Nigeria, and quality analysis in terms of Free Fatty Acid (FFA), saponification value, acid value, refractive index and viscosity of extracted groundnut oil was done at the Chemistry Department, University of Ilorin, Ilorin, Nigeria.

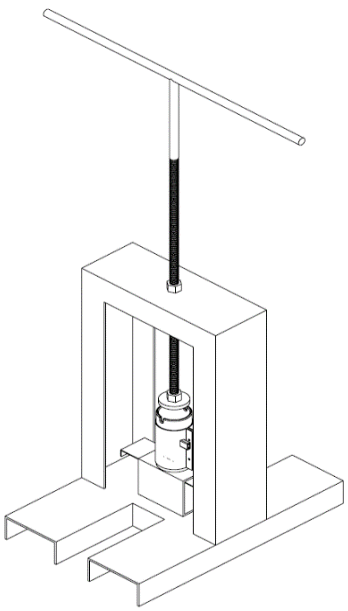

Figure 1: Isometric view of the vertical screw jack

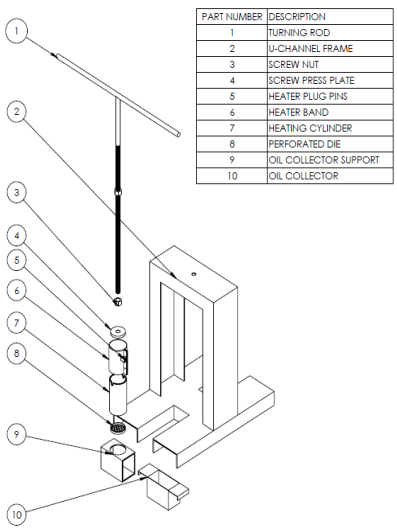

Figure 2: Exploded view of the vertical screw jack.

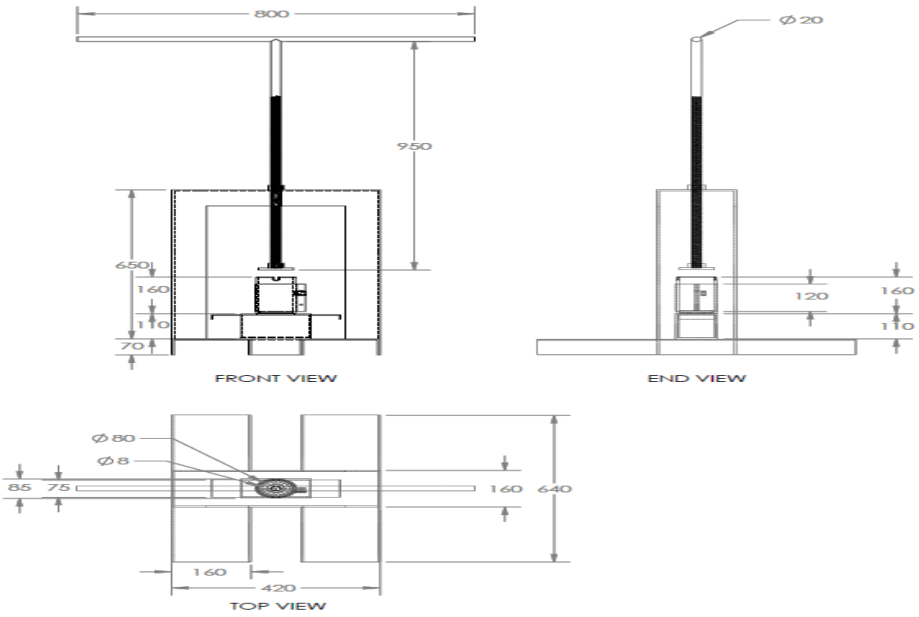

Figure 3: Orthographic view of the vertical screw jack

Note: all dimensions are in mm

3. Results and Discussion

Results of optimization analyses are shown in Table 1. The goal of optimization was either to maximize or minimize each of the output; all the outputs served as the performance indices of the vertical screw jack. Upon completion of the optimization task, the software selected one best combination of input factors (temperature and time of heating) from not less than 10 different optimization results for each output that best fulfilled the goal of the optimization (maximized or minimized). The nine (9) optimization combinations for each output were ranked according to desirability (0-1).

From Table 1, to maximize oil yield and extraction efficiency to 29.90 % and 48.12 % respectively, temperatures of 50 ^{o}C and 50.21^{o}C and times of heating of 10 min and 5 min should be used respectively. In order to minimize extraction loss to 4.23 %, temperature of 70 ^{o}C and heating time of 10 min should be used. Adeeko and Ajibola (1990) reported that prolonged heating time of groundnut above 25 min at greater than 90^{o}C

did not improve oil yield. Similarly, minimum pH (5.06) and maximum viscosity (1.47) of extracted groundnut oil can be achieved with the use of the vertical screw jack at temperatures 50.15 ^{o}C and 50 ^{o}C; and heating time of 9.98 min and 5 min respectively. Akinoso *et al.*, 2006 reported optimum oil yield, equivalent extraction efficiency of 50.4%, 90.1% respectively at roasting temperature of 124.2 ^{o}C and roasting time of 13 min for mechanical expression of sesame seed. Tunde-Akintunde *et al*. (2001) reported increase in oil yield for mechanically expressed soybeans oil at heating temperature in the range of 70 to 80^{o}C and heating time in the range of 15 to 30 min. Olaniyan (2010) wrote that maximum oil yield of 39.6% (extraction efficiency of 66%) was obtained when milled conophor nut was heated at 65^{o}C for 28 min.

Furthermore, in order to minimize other outputs (FFA, saponification value, acid value and refractive index) to their respective optimized values (as shown in Table 1), their corresponding temperatures and times of heating should be used during the oil extraction process. Akinoso *et al.*, 2006 reported optimum FFA of 1.1% at roasting temperature of 124.2 ^{o}C and roasting time of 13 min for mechanical expression of sesame seed.

Table 1: Results of Optimization Analysis

SN	Outputs	Temperature (^{o}C)	Time (min)	Optimized Value	Optimization Goal	Desirability Value
1	Oil Yield (%)	50	10	29.90	Maximized	0.95
2	Extraction Efficiency (%)	50.21	5.02	48.12	Maximized	1.00
3	Extraction Loss (%)	70	10	4.23	Minimized	0.89
4	pH	50.15	9.98	5.06	Minimized	1.00
5	FFA (mgKOH/g)	50	10	3.38	Minimized	0.71
6	Saponification Value (mgKOH/g)	50	10	190.26	Minimized	0.75
7	Acid Value (mgKOH/g)	50	10	6.74	Minimized	0.71
8	Refractive Index	50	5	1.45	Minimized	0.92
9	Viscosity(cm/s)	50	5	1.47	Maximized	1.00

4. Conclusions

Groundnut oil was extracted with a vertical screw jack. Optimum oil yield (29.90%), extraction efficiency (48.12%) and extraction loss (4.23%) were achieved at temperatures and time of heating of 50, 50.21 and 70^{o}C; and 10, 5.02 and 10 min respectively. Temperature of 50^{o}C and time of heating of 10, 10, 10, 5 and 5 min gave optimum values of 3.38 mgKOH/g, 190.26 mgKOH/g, 6.74 mgKOH/g, 1.45 and 1.47 cm/s for FFA, saponification value, acid value, refractive index and viscosity respectively; whereas, optimum value of 5.06 was obtained for pH at temperature of 50.15 ^{o}C and 9.98 min time of heating.

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