Effect of expeller press parameters on fish oil extraction

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Abstract: An investigation was carried out on the effect of expeller press parameters such as choke clearances (1, 2 and 3 mm), screw clearances (1, 2 and 3 mm) and screw (worm) shaft speeds (50, 60 and 70 rpm) on fish oil extraction. The oil extraction rate and extraction efficiency had a negative relationship with choke clearances and screw clearances but had a positive relationship with screw (worm) shaft speeds. The oil extraction rate and extraction efficiency were found to decrease with increase in choke clearances and also decreased with increase in screw clearances. Increase in screw (worm) shaft speeds from 50 to 70 rpm was observed to increase oil extraction rate and extraction efficiency. The extraction loss had a positive relationship with choke clearances and screw clearances but had a negative relationship with screw (worm) shaft speeds. The extraction loss was found to increase with increase in choke clearances and also increased with increase in screw clearances. Increase in screw (worm) shaft speeds from 50 to 70 rpm was observed to decrease extraction loss. The results obtained from the study of the effects of expeller press parameters on fish oil extraction showed that choke clearance, screw clearance and screw speed influenced oil extraction significantly at 95% confidence level. The best extraction condition was 1 mm choke clearance, 1 mm screw clearance and 70 rpm screw speed, which gave oil extraction rate of 18.91 kg h^{-1}, extraction efficiency of 83.96% and extraction loss of 5.76%. The results of this study are useful in optimising the design of presses for fish oil extraction.

Keywords: fish oil, extraction, expeller, parameters, optimize

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1 Introduction

Fish is generally considered as a useful component of diet and sometimes also known as ‘brain food’ besides its associated role for the treatment of various hyperlipidemia types. Many factors are found to be involved in causing plasma hyperlipidemia such as high fat diet, personality, trait and genetic background of individuals (Saify et al., 2004).

Fish oil is the lipid fraction extracted from fish and fish by products. Generally, fish oils are more complex than land-animal oils or vegetable oils due to long – chain unsaturated fatty acids. Fish oils are unique in the variety of fatty acids of which they composed and their degree of un-saturation (Gebauer et al., 2006).

Fish oil benefits can be obtained from eating fish or by taking fish/fish oil and its supplements. During the last two decades polyunsaturated fatty acids (PUFA) have attracted great interest among scientists for their medicinal and nutritional properties. Among the common sources of these PUFAs are fish/fish oils (Razak et al., 2001). PUFAs are also called “good fats” and are found mostly in marine derived (sea foods) and flax seed products.

Omega-3 and omega-6 fatty acids are essential fatty acids and are known for various physiological roles for humans which cannot synthesize and hence must be supplied by diet. Omega-3 fatty acids are long-chain carbon compounds that include alpha-linolenic acid (ALA, C18: 3n-3), eicosapentaenoic acid (EPA, C20: 5n-3) and docosahexaenoic acid (DHA, C22: 6n-3) (Gebauer et al., 2006).

The functions and potential beneficial effects of these omega-3 fatty acids have been recently reviewed as they are incorporated into phospholipids of cell membranes, influencing membrane fluidity, receptor-ligand interactions, cell-to-cell interactions, nutrient transport

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across membranes, neuronal transmission, modulator of gene expression and precursor for eicosanoids, preventive agent for cardiovascular disorders, autoimmune disease and cancers, modulator of inflammation and thrombosis and it is important for brain development and visual acuity. Intervention studies have demonstrated that intake of these omega-3 fatty acids in the form of fish/fish oil increases high-density lipoprotein (HDL) cholesterol concentrations, reduces triglyceride concentrations, as well as postprandial lipaemia and chilomicron remnant concentrations, thus decreasing the risk of atherosclerosis and cardiovascular disease (Saify et al., 2004; Gebauer et al., 2006). Some people use fish oil to lower blood pressure or triglyceride levels. The scientific evidence suggests that fish oil really does lower high triglycerides and it also seems to help prevent heart disease and stroke when taken in the recommended amounts (Saify et al., 2004; Robert, 2005; Gebauer et al., 2006; Nezhad et al., 2008).

Oil extraction is the process of recovering oil from oil-bearing agricultural products through physical, biological or chemical extraction. Physical extraction processes include homogenizing, heating, pressing and filtering, also regarded as wet rendering. Biological processes include enzymatic oil extractions and silage production through the use of enzymes from fish viscera residue (autolysis) or enzymes from other sources (hydrolysis). Chemical solvent extraction is another well-established process to extract fish oil using organic solvents, however, the use of toxic solvents results in protein denaturisation and loss of functional properties (Chantachum et al., 2000; Akinoso and Raji, 2011).

Historically, crude fish oil is produced from the antiquity by Nordic towns that used it as fuel in lamps. At the beginning of the nineteenth century, U.S. began to produce crude fish oil from menhaden, using a process with two steps: fish cooking and rock-weighted pressing (Khoddami et al., 2009; Khoddami et al., 2012). An improved form of mechanical device, which allowed considerably more pressure to be exerted, involves the use of hydraulically operated rams: a simple, hand-operated cylinder pump is used to press flat plates or hollow cages attached to the hydraulic ram against a fixed-position ram. This type of press develops into a motorized hydraulic pump system that presses the fish bag and then releases a press cake (Aloko et al., 2013; Maqsood et al., 2012).

The next improvement in extracting oil is the screw press or expeller. Screw presses use an electric motor to rotate a heavy iron shaft, which has flights, or worms built into it to push the material through a narrow opening. The pressure of forcing the fish mass through this slot releases part of the oil, which comes out through tiny slits in a metal barrel fitted around the rotating shaft. Expellers have a continuous flow of material through the machine in contrast to the hydraulic system described above, which uses small, individual packages or batches of oil-bearing materials (Williams, 2005; Sayasoonthorn et al., 2012).

The processing techniques involved in commercial production of edible fats and oils vary according to the type of raw material. Fish reduction to produce oil and fishmeal, except for solvent extraction, generally employs the same principles, techniques and equipment common to the production of other edible fats and oils. In general, fish are processed by the wet reduction method in which the principal operations are cooking, pressing, separation of the oil and water with recovery of oil, and drying of the residual protein material. Continuous processing from the time the fish are landed optimizes efficiency and maximizes product quality (Maqsood et al., 2012).

The selection of equipment for extraction process depends on controlling and influencing factors, which are responsible for limiting the rate of extraction. A number of variables need to be taken into account to optimize oil production using screw presses. For quality preservation, temperature is an important parameter. The friction inside the barrel generates heat which is passed on to the oil. For oil recovery and energy consumption, pressure is more interesting to monitor. There are four important factors to be considered as follows:

i. Speed: Higher screw speed means more throughput and higher residual oil content in the press cake since less time is available for the oil to drain from the solids. At higher speed the viscosity thus remains lower resulting in less pressure build-up. This again causes the residual oil content to be relatively high (Williams, 2005).

ii. Restriction size: When the restriction size is reduced the pressure required to overcome the restriction increases. A resulting decrease in oil content causes increased viscosity of the paste and further pressure rise.

iii. Moisture content: An optimal moisture level for oil expression is expected to exist. In case of rapeseed it is a moisture level close to 7% (Bargale and Singh, 2000). For flaxseed the optimal moisture content is expected to be around 6% (Zheng et al., 2003).

iv. Cooking: Cooking causes increased cell wall rupturing thereby facilitating the outflow of oil. The oil point pressure decreases while pressure build-up increases due to increased viscosity in turn drastically increasing oil recovery.

1.1 Objectives of the study

1.1.1 Main objective

The main objective of the study is to evaluate the effect of expeller press parameters on fish oil extraction.

1.1.2 Specific objectives

The specific objectives of the study are:

i. To investigate the effect of expeller press parameters on oil extraction rate,

ii. To investigate the effect of expeller press parameters on extraction efficiency,

iii. To investigate the effect of expeller press parameters on extraction loss.

1.2 Justification of the study

Fish oil is usually obtained by various extraction techniques. Several studies on methods and conditions for fish oil extraction have been conducted in the past including solvent extraction, wet rendering, dry (steam) rendering and wet pressing methods. Extraction and purification of the lipids by conventional methods, such as hexane extraction, vacuum distillation, or conventional crystallization have the disadvantages of requiring high temperature processing which results in decomposition or degradation of the thermally labile compounds and/or employing toxic solvents having adverse health effects (Maqsood et al., 2012). Therefore, various research efforts are currently focusing on developments in the field of oil extraction and purification technologies. The demands on these processing technologies for extracting and purifying the fish oil are that they are eco-friendly and able to provide high oil yields and to minimize the loss of nutrients and provide a high-quality oil (Maqsood et al., 2012). With improved separation techniques and more gentle processing methods, these oils might play an even more important role in the pharmaceutical and food industry in the near future (Adeniyi, 2006). Many works have been done on fish oil production but literature has shown that little or no work has been done in terms of mechanical process of fish oil extraction.

2 Materials and methods

2.1 Determination of oil content

The fat extraction was carried out using soxhlet extraction method (AOAC, 2002; AOAC, 2005). The initial weight of the fish sample was taken then the sample was dried in an oven at about 105°C for about eight to ten hours until constant weight was reached and the sample was minced in an electric grinder. The homogenized fish sample was put into a labelled thimble. A dry boiling flask was correspondingly weighed and labelled, 300 cm^3 of petroleum ether (boiling point 40°C-60°C) was measured into the boiling flask and the extraction thimble was plugged lightly with cotton wool. The soxhlet apparatus was assembled and allowed to reflux for about six hours. The thimble was removed with care and the petroleum ether on the top of the container of the set-up was collected and drained into a container for reuse. The flask was removed and dried at (105°C-110°C) for one hour when it was almost free of petroleum ether. The flask and its content was finally transferred into a desiccator, allowed to cool and then weighed. The fat content was calculated from Equation (1) (AOAC, 2002; AOAC, 2005).

$$\text{Fat content (\%)} = \frac{W_2 - W_1}{W} \times 100 \qquad (1)$$

where, W_1 = Weight of empty flask (g); W_2 = Weight of flask and fat (g); W = Weight of fresh fish sample (g).

2.2 Instrumentation and test materials

A quartz stopwatch was used for measurement of time during the performance evaluation of the machine. A digital tachometer (DT 2235B) shown in Figure 1 was used to determine the peripheral speed of the worm shaft and electronic balance of sensitivity of 0.01 kg was used in weight measurements. The commonest available species of fish (Atlantic mackerel) in Nigerian market was used for the evaluation.

Figure 1 Digital tachometer

2.2.1 Determination of rotational speed of screw shaft

The shaft rotational speed of 50, 60 and 70 rpm; which correspond to peripheral speed of 7.3, 9.2 and 11.0 m s^{-1} respectively were considered for the experiment and were attained with help of set of driver (30 mm) and driven pulleys of different sizes (600, 700 and 840 mm). The shaft rotational speeds of the oil extractor during its evaluation were determined using a digital tachometer (DT 2235B) shown in Figure 1 which has a sensitivity of one revolution per second. Figure 2 shows the sets of driven pulleys used to vary the machine speed.

Figure 2 Pulleys used to vary the machine speed

2.2.2 Screw shaft clearance

Three levels of screw shaft clearance (space between barrel wall and screw shaft) of 1, 2, and 3 mm were chosen for the experiment. Variation of clearance treatment was conducted by replacing screw shaft number (Figure 3) on barrel (cylinder) of 1-3 mm clearance (Harmanto et al., 2009).

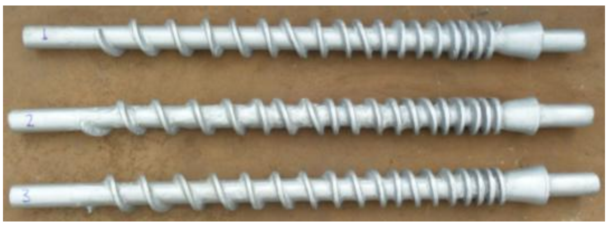

Figure 3 Worm shafts used to vary the screw shaft clearance

2.2.3 Choke clearance

The extractor was evaluated at three levels of choke clearance (space between barrel wall and conical choke) of 1, 2, and 3 mm. The adjustment of the choke was done with the aid of the choke regulator. Choke clearance was changeable from zero to 10 mm by the lever handle known as choke regulator.

2.3 Experimental Variables

The yield of oil extraction, efficiency of oil expression, expeller throughput and specific power consumption of a mechanical oil expeller largely depends on certain pre-treatment and machine parameters. The pre-treatment parameters like heating temperature and heating time as well as machine parameters like choke clearance, screw clearance and screw shaft speed are expected to influence oil expression through a mechanical oil expeller. Consequently, the following variables were selected for the study.

2.3.1 Independent variables

Choke clearances of 1, 2 and 3 mm (El-Nakib et al., 2012; Akerele and Ejiko, 2015; Ezeoha and Akubuo, 2017), screw clearances of 1, 2 and 3 mm (Harmanto et al., 2009) and screw shaft speeds of 50, 60 and 70 rpm (Ajao et al., 2010; Adebija, 2012; El-Nakib et al., 2012) were taken as major machine parameters for standardizing oil expelling condition for maximum oil expression.

2.3.2 Dependent variables

The performance of the oil expeller was evaluated under different treatments by observing the oil extraction rate, extraction efficiency and extraction loss.

2.3.2.1 Determination of the oil extraction rate

Extraction rate is the volume or weight of oil that the machine is capable of expelling per unit time (Olaniyan and Oje, 2007; Olaniyan and Oje, 2011).

$$E_R = \frac{W_0}{T} \quad (2)$$

where, E_R = Extraction rate (kg h^{-1}); W_0 = Weight of oil extract (kg); T = Operation time or duration (h).

2.3.2.2 Determination of extraction efficiency

The extraction efficiency of the machine was evaluated by expressing the oil extracted as a percentage of the total oil content of the fish samples. From the values obtained, extraction efficiency was determined according to Olaniyan and Oje (2007) and Olaniyan and Oje (2011) as:

$$O_E = \frac{W_{OE}}{XW_{FS}} \times 100 \quad (3)$$

where, O_E = Extraction efficiency (%); W_{OE} = Weight of oil extracted (kg); W_{FS} = Weight of fed sample (kg); X = Oil content of fish in decimal (determined).

2.3.2.3 Determination of extraction loss

Extraction loss is the ratio of the unrecovered sample to the fed sample. From the values obtained, extraction loss was calculated according to Olaniyan and Oje (2007) and Olaniyan and Oje (2011) as:

$$E_L = \frac{[W_{FS} - (W_{FE} + W_{RC})]}{W_{FS}} \times 100 \quad (4)$$

where, E_L = Extraction loss (%); W_{FS} = Weight of fed sample (kg); W_{FE} = Weight of fish extract (kg); W_{RC} = Weight of residual cake (kg).

2.4 Experimental procedure

2.4.1 Selection, preparation and pre-treatment of test material (fish)

Prior to analysis, the internal organs of the fish were removed and the fish was washed to remove the residual blood. The fish was cut into small pieces and was heated to 60°C-90°C for approximately 5-20 minutes (Chantachum et al., 2000). This process coagulates the proteins and disrupts the cell membranes thus allowing leakage out of bound water and oil.

2.4.2 Machine evaluation procedure

Materials required include weighing balance, measuring cylinder, water, minced fresh fish, cake receiving container and oil receiving container. The expeller (Figure 4) powered by an electric motor was set into operation and a known weight of each prepared sample was fed into the machine through the feeding hopper. The continuous helical screw shaft conveyed, crushed, squeezed and pressed the fishes in order to extract the oil. The oil and water phases (containing water-soluble proteins as well) were separated from the solid phase (press cake). The fluid extracted and the press cake were collected and weighed separately. Clarification was done to separate the oil from its entrapped impurities. The fish extract was left to settle and the oil was decanted. The decanted oil was heated to remove moisture and was allowed to cool and then filtered using sieves.

Figure 4 Isometric drawing of the expeller press

2.5 Experimental design

The experimental design for the statistical analysis followed a three-treatment effect (choke clearance, screw clearance and screw speed) in a split-split-plot factorial design with completely randomized design (CRD) involving a three-way classification with three observations (replications) per experimental unit. The experimental unit comprised three factors: three choke clearances (1, 2 and 3 mm), three screw clearances (1, 2 and 3 mm) and three cylinder speeds (50, 60 and 70 rpm), giving a twenty seven (27) treatment combinations and eighty one (81) observations for the experiment. The choke clearance in the combination formed the levels of factor 'A', screw clearance formed the levels of factor 'B' and cylinder speed formed the levels of factor 'C'. All data collected were subjected to analysis of variance (ANOVA) to test for significant effects at 95% confidence limit using the procedure recommended by Steel and Torrie (1980). When significant difference is observed, treatment means were separated using the Fisher's least significant difference (F-LSD) test. The experimental design was shown in Table 1.

Table 1 Experimental design used in the study

Factors	Level		
Choke clearance, C (mm)	1	2	3
Screw shaft clearance, D (mm)	1	2	3
Screw shaft speed, N (rpm)	50	60	70

3 Results and discussions

Table 2 showed the results of the expeller press parameters effects on oil extraction rate (kg h^{-1}). The

ANOVA at $p≤0.05$ of the effect of expeller press parameters (choke clearance, screw shaft clearance and screw shaft speeds) on the oil extraction rate (kg h^{-1}) was presented in Table 3 and the means using F-LSD was presented in Table 4. The results of the expeller press parameters effects on extraction efficiency (%) were shown in Table 5. The ANOVA at $p≤0.05$ of the effect of expeller press parameters (choke clearance, screw shaft clearance and screw shaft speeds) on the extraction efficiency (%) was presented in Table 6 and the means using F-LSD was presented in Table 7. Table 8 was the results of the expeller press parameters effects on extraction loss (%). The ANOVA at $p≤0.05$ of the effect of expeller press parameters (choke clearance, screw shaft clearance and screw shaft speeds) on the extraction loss (%) was presented in Table 9 and the means using F-LSD was presented in Table 10.

Table 2 Results of the expeller press parameters effects on oil extraction rate (kg h^{-1})

S/N	Choke Size (mm)	Screw Clearance (mm)	Screw Speed (rpm)	Replications			Mean	SD
				1	2	3		
1			50	16.85	17.17	17.23	17.08	0.20
2		1	60	17.72	17.96	18.20	17.96	0.24
3			70	19.17	18.94	18.63	18.91	0.27
4			50	16.78	15.71	16.00	16.16	0.55
5	1	2	60	16.89	16.71	16.96	16.85	0.13
6			70	17.49	17.71	17.51	17.57	0.12
7			50	15.84	15.58	15.84	15.75	0.15
8		3	60	16.11	16.62	16.26	16.33	0.26
9			70	17.27	17.01	16.80	17.03	0.24
10			50	14.84	15.55	15.09	15.16	0.36
11		1	60	15.70	15.87	15.90	15.82	0.11
12			70	16.66	16.51	16.72	16.63	0.11
13			50	14.36	14.64	14.91	14.64	0.28
14	2	2	60	15.27	15.22	15.15	15.21	0.06
15			70	15.53	16.23	16.38	16.05	0.45
16			50	14.34	14.65	14.04	14.34	0.31
17		3	60	14.59	14.92	14.65	14.72	0.18
18			70	15.21	15.22	15.43	15.29	0.12
19			50	13.94	14.79	14.11	14.28	0.45
20		1	60	14.92	14.83	14.59	14.78	0.17
21			70	15.24	15.37	15.09	15.23	0.14
22			50	13.92	13.85	13.75	13.84	0.09
23	3	2	60	14.42	14.33	14.15	14.30	0.14
24			70	14.77	14.83	14.65	14.75	0.09
25			50	13.37	13.68	13.76	13.60	0.21
26		3	60	13.80	13.67	13.86	13.78	0.10
27			70	14.70	14.42	14.32	14.48	0.20

Table 3 ANOVA of the expeller press parameters effects on oil extraction rate (kg h^{-1})

Sources	DF	SS	MS	F-cal	F-tab
C	2	103.65	51.83	863.83*	3.18
D	2	18.86	9.43	157.17*	3.18
N	2	20.53	10.27	171.17*	3.18
C*D	4	1.80	0.45	7.50*	2.56
C*N	4	0.81	0.20	3.33*	2.56
D*N	4	0.38	0.10	1.67ns	2.56
C*D*N	8	0.24	0.03	0.50 ns	2.13
Error	54	3.22	0.06		
Total	80	149.48			

Note: C-choke clearance, D-screw clearance, N-screw speed, * Significant, ns Not significant.

Table 4 Effect of expeller press parameters on mean oil extraction rate (kg h^{-1})

Choke clearance (mm)	Screw clearance (mm)	Screw speed, rpm		
		50	60	70
	1	17.08	17.96	18.91
1	2	16.16	16.85	17.57
	3	15.75	16.33	17.03
	1	15.16	15.82	16.63
2	2	14.64	15.21	16.05
	3	14.34	14.72	15.29
	1	14.28	14.78	15.23
3	2	13.84	14.30	14.75
	3	13.60	13.78	14.48

Note: $F\text{-}LSD_{0.05}$ = 0.401.

Table 5 Results of the expeller press parameters effects on extraction efficiency (%)

S/N	Choke Size (mm)	Screw Clearance (mm)	Screw Speed (rpm)	Replications			Mean	SD
				1	2	3		
1			50	77.61	79.10	79.48	78.73	0.99
2		1	60	80.22	80.97	82.46	81.22	1.14
3			70	84.70	83.96	83.21	83.96	0.75
4			50	79.48	74.25	75.75	76.49	2.69
5	1	2	60	79.48	78.73	79.85	79.35	0.57
6			70	82.09	83.21	82.09	82.46	0.65
7			50	75.00	73.88	75.00	74.63	0.65
8		3	60	76.12	78.36	76.87	77.12	1.14
9			70	81.34	80.22	79.10	80.22	1.12
10			50	71.27	74.63	72.39	72.76	1.71
11		1	60	74.63	75.75	75.75	75.38	0.65
12			70	78.36	77.99	78.73	78.36	0.37
13			50	70.15	70.90	72.39	71.15	1.14
14	2	2	60	73.88	73.51	73.13	73.51	0.38
15			70	74.25	77.61	78.36	76.74	2.19
16			50	70.15	71.64	68.66	70.15	1.49
17		3	60	71.27	72.76	71.27	71.77	0.86
18			70	73.51	73.88	74.63	74.01	0.57
19			50	67.16	69.78	67.91	68.28	1.35
20		1	60	71.27	70.90	69.78	70.65	0.78
21			70	72.39	73.13	71.64	72.39	0.75
22			50	67.91	67.16	66.79	67.29	0.57
23	3	2	60	69.78	69.40	68.66	69.28	0.57
24			70	70.90	71.64	70.52	71.02	0.57
25			50	65.30	66.79	67.16	66.42	0.98
26		3	60	67.16	66.42	67.54	67.04	0.57
27			70	70.90	69.78	69.03	69.90	0.94

Table 6 ANOVA of the expeller press parameters effects on extraction efficiency (%)

Sources	DF	SS	MS	F-cal	F-tab
C	2	1412.22	706.11	578.78*	3.18
D	2	154.95	77.48	63.51*	3.18
N	2	311.51	155.76	127.67*	3.18
C*D	4	4.10	1.03	0.84 ns	2.56
C*N	4	7.85	1.96	1.61 ns	2.56
D*N	4	2.71	0.68	0.56 ns	2.56
C*D*N	8	3.56	0.45	0.37 ns	2.13
Error	54	65.86	1.22		
Total	80	1962.76			

Note: C-choke clearance, D-screw clearance, N-screw speed, * Significant, ns Not significant.

Table 7 Effect of expeller press parameters on mean extraction efficiency (%)

Choke clearance (mm)	Screw clearance (mm)	Screw speed, rpm		
		50	60	70
1	1	78.73	81.22	83.96
	2	76.49	79.35	82.46
	3	74.63	77.12	80.22
2	1	72.76	75.38	78.36
	2	71.15	73.51	76.74
	3	70.15	71.77	74.01
3	1	68.28	70.65	72.39
	2	67.29	69.28	71.02
	3	66.42	67.04	69.90

Note: F-LSD$_{0.05}$ = 1.811.

Table 8 Results of the expeller press parameters effects on extraction loss (%)

S/N	Choke Size (mm)	Screw Clearance (mm)	Screw Speed (rpm)	Replications			Mean	SD
				1	2	3		
1	1	1	50	9.17	9.17	9.32	9.22	0.09
2			60	7.58	7.25	7.67	7.50	0.22
3			70	5.33	5.62	6.33	5.76	0.51
4		2	50	11.75	11.58	11.67	11.67	0.09
5			60	11.18	11.27	11.20	11.22	0.05
6			70	11.00	11.03	10.85	10.96	0.10
7		3	50	11.80	11.87	11.75	11.81	0.06
8			60	11.57	11.45	11.62	11.55	0.09
9			70	11.33	11.50	11.30	11.38	0.11
10	2	1	50	13.07	12.98	12.93	12.99	0.07
11			60	12.20	12.53	12.42	12.38	0.17
12			70	11.25	11.63	11.35	11.41	0.20
13		2	50	14.62	13.87	14.12	14.20	0.38
14			60	13.83	13.62	13.58	13.68	0.13
15			70	12.85	12.82	12.88	12.85	0.03
16		3	50	14.80	14.78	14.78	14.79	0.01
17			60	14.62	14.50	14.33	14.48	0.15
18			70	13.78	14.12	13.85	13.92	0.18
19	3	1	50	13.48	11.67	13.47	12.87	1.04
20			60	12.82	12.87	12.90	12.86	0.04
21			70	12.38	12.52	12.32	12.41	0.10
22		2	50	14.67	14.20	14.35	14.41	0.24
23			60	14.03	14.05	14.22	14.10	0.10
24			70	13.37	13.85	13.62	13.61	0.24
25		3	50	14.85	14.80	14.82	14.82	0.03
26			60	14.53	14.45	14.65	14.54	0.10
27			70	13.73	14.07	13.82	13.87	0.18

Table 9 ANOVA of the expeller press parameters effects on extraction loss (%)

Sources	DF	SS	MS	F-cal	F-tab
C	2	215.55	107.78	1539.71*	3.18
D	2	106.19	53.10	758.57*	3.18
N	2	18.93	9.47	135.29*	3.18
C*D	4	22.34	5.59	79.86*	2.56
C*N	4	1.65	0.41	5.86*	2.56
D*N	4	3.03	0.76	10.86*	2.56
C*D*N	8	6.00	0.75	10.71*	2.13
Error	54	3.84	0.07		
Total	80	377.52			

Note: C-choke clearance, D-screw clearance, N-screw speed, * Significant.

Table 10 Effect of expeller press parameters on mean extraction loss (%)

Choke clearance (mm)	Screw clearance (mm)	Screw speed, rpm		
		50	60	70
1	1	9.22	7.50	5.76
	2	11.67	11.22	10.96
	3	11.81	11.55	11.38
2	1	12.99	12.38	11.41
	2	14.20	13.68	12.85
	3	14.79	14.48	13.92
3	1	12.87	12.86	12.41
	2	14.41	14.10	13.61
	3	14.82	14.54	13.87

Note: F-LSD$_{0.05}$ = 0.437.

3.1 Effect of expeller press parameters on oil extraction rate

ANOVA at 5% significant level was conducted for the study of effects of machine parameters on oil extraction rate as presented in Table 3. There was a significant difference in the choke clearances, screw shaft clearances, screw shaft speeds and the two-way interactions of choke clearance and screw clearance, choke clearance and screw speed but no significant difference in the two-way interaction of screw clearance and screw speed and their three-way interaction on the fish oil extraction rate. The separation of means at 5% level of significance showed that the differences between the choke clearances, screw shaft clearances and screw shaft speeds treatment combinations means were statistically significant except few treatment combinations means which were not statistically significant (Table 4). It was observed from Table 4 that the rate of oil extraction decreased with increasing choke clearance and screw shaft clearance but increased with increasing screw shaft speeds. The choke clearance of 1 mm had the highest oil extraction rate of 18.91 kg h^{-1} at the screw shaft clearance of 1 mm and screw shaft speed of 70 rpm. The least oil extraction rate of 13.60 kg h^{-1} was obtained at the choke clearance of 3 mm, screw shaft clearance of 3 mm and screw shaft speed of 50 rpm.

This was contrary to the work of El-Nakib et al. (2012) which stated that reducing the opening discharge area decreased the expressed oil productivity. This may be explained by decreased seed material flow. When the choke discharge opening increased from 0.5 to 1.4 mm, oil productivity increased from 11.94, 11.78, 12.29, 11.86 and 10.68 to 13.17, 13.49, 13.75, 13.57 and 13.2 kg h^{-1} for single stage machine, and double stage machine with 1.2, 1.0, 0.8 and 0.6 mm intermediate choke gap at 30 rpm screw rotational speed and 8% seed moisture content. El-Nakib et al. (2012) observed similar trends when considering the effect of machine speed on rate of oil extraction. The authors stated that increasing screw rotational speed tended to increase the oil productivity. Increasing screw rotational speed from 30 to 90 rpm, oil productivity increased from 12.56, 12.99, 13.29, 13.68 and 13.13 to 13.58, 13.88, 15.07, 15.45 and 15.1 kg h^{-1} for single stage machine, and double stage machine with 1.2, 1.0, 0.8 and 0.6 mm intermediate choke gap respectively at 6% moisture content and 0.5 mm choke gap (El-Nakib et al., 2012).

3.2 Effect of expeller press parameters on extraction efficiency

From the ANOVA (Table 6) there was a significant difference in the choke clearances, screw shaft clearances and screw shaft speeds but no significant difference in their interactions on the extraction efficiency. A 2-tailed F-LSD test at 5% level of significance showed that the differences between the choke clearances, screw shaft clearances and screw shaft speeds treatment combinations means were statistically significant for most of the treatment combinations (Table 7). For the studied range, extraction efficiency increased with decreasing choke clearances and screw shaft clearances but extraction efficiency increased with increasing screw shaft speeds (Table 7). A maximum efficiency of 83.96% was obtained at 1 mm choke clearance, 1 mm screw shaft clearance and 70 rpm screw shaft speed. A minimum expression efficiency of 66.42% was obtained at 3 mm choke clearance, 3 mm screw shaft clearance and 50 rpm screw shaft speed. However, the choke clearance of 1 mm, screw clearance of 1 mm and screw speed of 70 rpm were considered to be the optimum pressing condition for fish oil extraction. This implied that these process parameters must be controlled to effectively extract oil from fish.

This was in agreement with the statement of Bamgboye and Adejumo (2007) who reported that a reduction in speed of rotation of the shaft, for example, could reduce the oil yield, increasing the oil content in the cake and solids in the oil. Akinoso et al. (2009), while evaluating the effects of compressive stress, feeding rate and speed of shaft screw press on palm kernel oil yield, observed same trend of increase in oil yield with increased speed. Ezeoha and Akubuo (2017), while investigating the effects of speed of shaft screw press and choke gap on palm kernel oil yield, observed same trend of increase in oil yield with decreased choke gap.

The effects of different shaft speeds (21, 54, 65, and 98 rpm), nozzle sizes (6, 10, and 12 mm), and diameters of the shaft (8, and 11 mm) on *Nigella sativa L* seeds were examined by Deli et al. (2011) using a cylinder press. In this type of press the press cake was extruded through a nozzle attached to the end of the cylinder. Nozzle diameter was one of the factors affecting the pressure level in the expeller. Pressure increased with decreasing nozzle size. The highest oil yield was obtained under the following conditions: 21 rpm shaft speed, shaft diameter of 8 mm, and nozzle size of 6 mm.

El-Nakib et al. (2012), while evaluating the effects of machine setting of one stage and double stage expression, screw speeds of 30, 50, 70 and 90 rpm, cake output clearance 0.5, 0.8, 1.1 and 1.4 mm, for double stage expression setting intermediate choke gap of 0.6, 0.8, 1.0 and 1.2 mm and moisture content of oilseed 6, 8 and 10% on sunflower seeds oil extraction, observed that the outlet clearance was the most important parameter that controls the other variables of oil expression process as well as the output material characteristics. Decreasing the choke opening, decreased cake oil content and increased oil recovery. The narrow choke gap may reduce the flow of the material inside the expression cage that may increase the duration of extraction and also include more seed breakage and fine size of the seed material that may contribute to higher expression efficiency. When the choke discharge opening increased from 0.5 to 1.4 mm it tended to decrease oil expression efficiency from 75.1, 77.5, 82.9, 85.7 and 85.7 to 61.3, 65.9, 69.2, 71.0 and 72.3% for single stage machine, and double stage machine with 1.2, 1.0, 0.8 and 0.6 mm intermediate choke gap at 30 rpm screw rotational speed and 8% seed moisture content (El-Nakib et al., 2012).

The observed different trends considering the effects of machine speed on extraction efficiency showed a reduction in oil expression efficiency by increasing rotational speed. This behavior may be explained from increasing the throughput. Increased throughput meaned reduced expression duration and thus less chance for the oil to flow from between the solid material. Increasing screw rotational speed from 30 to 90 rpm led to decrease in oil expression efficiency from 72.1, 75.9, 81.7, 86.0 and 86.3 to 67.0, 69.9, 76.5, 78.5 and 79.7% for single stage machine, and double stage machine with 1.2, 1.0, 0.8 and 0.6 mm intermediate choke gap respectively at 6% moisture content and 0.5 mm choke gap (El-Nakib et al., 2012).

Because of the wear of the flight in operation, flight clearance increased with the use, therefore the effect of it was of interest. The pressure decreased with increasing radial flight clearance, the cause of which was the leakage of the material across the flight. In normal operations a lower discharge pressure represented a lower pressure drop across the die and directly led to a reduction in the production rate (Deli et al., 2011). To compensate for this loss the rate of the screw rotation had to be increased.

3.3 Effect of expeller press parameters on extraction loss

ANOVA at 5% significant level was conducted for the study of effects of machine parameters on extraction loss as presented in Table 9. There was a significant difference in the choke clearances, screw shaft clearances, screw shaft speeds and their interactions on the extraction loss. A 2-tailed F-LSD test at 5% level of significance showed that the differences between the choke clearances, screw shaft clearances and screw shaft speeds treatment combinations means were statistically significant except few of the treatment combinations which were not statistically significant (Table 10). For the studied range, extraction loss increased with increasing choke clearances and screw shaft clearances but extraction loss decreased with increasing screw shaft speeds (Table 10). The lowest extraction loss of 5.76% was obtained for the condition of 1 mm choke clearance, 1 mm screw shaft clearance and 70 rpm screw shaft speed. The highest extraction loss of 14.82% was obtained for the condition of 3 mm choke clearance, 3 mm screw shaft clearance and 50 rpm screw shaft speed.

4 Conclusions

The results obtained from this study showed that fish oil being an essential source of rich healthy oil, can be efficiently extracted by the use of screw press expeller machine. The results obtained showed that this process (mechanical extraction) is a suitable method for extracting fish oil because of its high yield and high oil purity, both in large or small quantity. This process also generated little or no waste since the fish cake will be used as animal feeds thereby reducing cost of waste disposal.

The functional parameters evaluated in the study included choke clearances of 1, 2 and 3 mm; screw shaft clearances of 1, 2 and 3 mm and screw shaft speeds of 50, 60 and 70 rpm. The results obtained showed that oil extraction rate and extraction efficiency had a negative relationship with choke clearances and screw clearances but had a positive relationship with screw (worm) shaft speeds. The oil extraction rate and extraction efficiency were found to decrease with increase in choke clearances and also decreased with increase in screw clearances. Increase in screw (worm) shaft speeds from 50 to 70 rpm was observed to increase oil extraction rate and extraction efficiency. The extraction loss had a positive relationship with choke clearances and screw clearances but had a negative relationship with screw (worm) shaft speeds. The extraction loss was found to increase with increase in choke clearances and also increased with increase in screw clearances. Increase in screw (worm) shaft speeds from 50 to 70 rpm was observed to decrease extraction loss.

The results obtained from the study of the effects of expeller press parameters on fish oil extraction showed that choke clearance, screw clearance and screw speed influenced oil extraction significantly at 95% confidence level. The best extraction condition was 1 mm choke clearance, 1mm screw clearance and 70 rpm screw speed, which gave oil extraction rate of 18.91 kg h^{-1}, extraction efficiency of 83.96% and extraction loss of 5.76%. The results of this study are useful in optimising the design of presses for oil extraction. The study hence provides data toward optimal design of an expeller press.

References

Adeniyi, O.D. 2006. Herring fish (Clupea harengus) oil production and evaluation for industrial uses. *Journal of Dispersion Science and Technology*, 27(4): 537–541.

Ajao, K.R., H.A. Ajimitokan, J. Olaomi, and H.F. Akande. 2010. Design and development of a groundnut oil expelling machine. *Journal of Agricultural Technology*, 6(4): 643–648.

Akerele, O.V., and S.O. Ejiko. 2015. Design and construction of groundnut oil expeller. *International Journal of Engineering and Computer Science*, 4(6): 12529–12538.

Akinoso, R., and A.O. Raji. 2011. Optimization of oil extraction from locust bean using response methodology. *European Journal of Lipid Science and Technology*, 113(2): 245–252.

Akinoso, R., A.O. Raji, and J.C. Igbeka. 2009. Effects of compressive stress, feeding rate and speed of rotation on palm kernel oil yield. *Journal of Food Engineering*, 93(4): 427–430.

Aloko, D.F., S.M. Haske, and O.O. Aluko. 2013. Development of model equation for oil extraction from maize seed by factorial analysis. *Journal of Research in Environmental Science and Toxicology*, 2(8): 154–160.

AOAC. 2002. *Official Methods of Analysis of Association of Official Analytical Chemist (AOAC)*, 14th ed. Maryland, Gaithersburg, USA: AOAC International.

AOAC. 2005. *Official Methods of Analysis of Association of Official Analytical Chemists (AOAC)*, 18th ed. Gaithersburg, MD, USA: AOAC International.

Bamgboye, A.I., and A.O.D. Adejumo. 2007. Development of a sunflower oil expeller. *Agricultural Engineering International: CIGR Journal*, Vol IX, Manuscript EE 06 015.

Bargale, P.C., and J. Singh. 2000. Oil expression characteristics of rapeseed for a small-capacity screw press. *Journal of Food Science and Technology*, 37(2): 130–134.

Chantachum, S., S. Benjaku, and N. Sriwirat. 2000. Separation and quality of fish oil from pre-cooked and non-precooked tuna heads. *Food Chemistry*, 69(3): 289–294.

Deli, S., M. Farah-Masturah, Y. Tajul-Aris, and W.A. Wan-Nadiah. 2011. The effects of physical parameters of the screw press oil expeller on oil yield from Nigella sativa L. seeds. *International Food Research Journal*, 18(4): 1367–1373.

El-Nakib, A.A., M.H.A. Abdel, A.M. Rasmy, and M.M. Geasa. 2012. Evaluation of developed oilseed expression machine. *Misr Journal of Agricultural Engineering*, 29(4): 1357–1376.

Ezeoha, S.L., and C.O. Akubuo. 2017. Investigating the effect of choke gap and speed of a screw press on palm kernel oil yield. *In 2017 Annual International Meeting Presentation for American Society of Agricultural and Biological Engineers (ASABE), Spokane, Washington, 16-19 July*.

Gebauer, S.K., T.L. Psota, W.S. Harris, and P.M. Kris-Etherton. 2006. n-3 Fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. *American Journal of Clinical Nutrition*, 83(6): 1526–1535.

Harmanto, A., E. Hendriadi, M. Rahmarestia, and J. Wiyono. 2009. Performance test of a screw-press machine for extracting Jatropha curcas seed into crude oil as an alternative energy source. *Indonesian Journal of Agriculture*, 2(1): 35–40.

Khoddami, A., A.A. Ariffin, J. Bakar, and H.M. Ghazali. 2009. Fatty acid profile of the oil extracted from fish waste (head, intestine and liver) (Sardinella lemuru). *World Applied Science Journal*, 7(1): 127–131.

Khoddami, A., A.A. Ariffin, J. Bakar, and H.M. Ghazali. 2012. Quality and fatty acid profile of the oil extracted from fish waste (head, intestine and liver) (Euthynnus affinis). *African Journal of Biotechnology*, 11(7): 1683–1689.

Maqsood, S, S. Benjakul, and A. Kamal-Eldin. 2012. Extraction, processing and stabilization of health-promoting fish oils. *Recent Patents on Food, Nutrition and Agriculture*, 4(2): 141–147.

Nezhad, Z., M. Khosravi, N. Baniasadi, and Z. Daneshvar. 2008. Omega-3 fatty acid content in various tissues of different Persian Gulf fish. *Iranian Cardiovascular Research Journal*, 2(1): 24–31.

Olaniyan, A.M., and K. Oje. 2007. Development of mechanical expression rig for dry extraction of shea butter from shea kernel. *Journal of Food Science and Technology*, 44(5): 465–470.

Olaniyan, A.M., and K. Oje. 2011. Development of model equations for selecting optimum parameters for dry process of shea butter extraction. *Journal of Cereals and Oilseeds*, 5(2): 47–56.

Razak, Z.K.A., M. Basri, K. Dzulkefly, C.N.A. Razak, and A.B. Salleh. 2001. Extraction and characterization of fish oil from Monopterus albus. *Malaysian Journal of Analytical Sciences*, 7(1): 217–220.

Robert, O. 2005. Practical applications of fish oil (Ω-3 fatty acids) in primary care. *The Journal of the American Board of Family*

Practice, 18(1): 28–36.

Saify, Z.S., F. Ahmad, S. Akhtar, N. Mushtaq, M. Arif, and S. Siddiqui. 2004. Effects of fish oil and lipid lowering drugs on serum triglycerides alone and in combination. *Pakistan Journal of Pharmacology*, 21(2): 31–37.

Sayasoonthorn, S., S. Kaewrueng, and P. Patharasathapornkul. 2012. Rice bran oil extraction by screw press method: optimum operating settings, oil extraction level and press cake appearance. *Rice Science*, 19(1): 75–78.

Steel, R.G. and J.H. Torrie. 1980. Principles and Procedures of Statistics. NewYork: McGraw-Hill Book Company.

Williams, M.A. 2005. Recovery of oils and fats from oilseeds and fatty materials. In *Bailey´s Industrial Oil and Fat Products*, ed. F. Shahidi, Vol. 5, ch. 3, 99–189. New Jersey: John Wiley and Sons, Inc.

Zheng, Y., D.P. Wiesenborn, K. Tostenson, and N. Kangas. 2003. Screw pressing of whole and dehulled flaxseed for organic oil. *Journal of American Oil Chemists Society*, 80(10): 1039–1045.