Parametric Optimization of Solvent Extraction of Soybean Oil

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Abstract

Edible oil extraction via favorable conditions is central to industrial growth and sustainability. This paper investigates the optimum conditions for the soybean oil extraction via solid-liquid or leaching mechanism. This was done by varying parameters viz. the solvent concentration, temperature, and time of extraction using a soxhlet apparatus in a water bath. The oil characterization was also carried out focusing on some physic-chemical properties. Statistical analysis was lastly carried out on different parameters of the oil extraction in view of correlation or statistical significance test using Analysis of Variance (ANOVA). Results showed the highest percentage yield of the oil as 19.25 Wt. % with the optimum conditions being 180 minutes of extraction, 70°C, and 300 ml n-hexane. The statistical significance evaluation showed F values of 6545.26, 63.07, 272.65, and 38.75 for soy cake weight loss with corresponding moisture content, variations in solvent extraction, temperature and time with their corresponding oil yields respectively, all greater than their critical F values. However, the F value determined for the sets of oil yield for the 3 parametric variations being 1.21, was found to be less than its critical F value. Hence, these conditions will be useful in maximizing soybean oil production at best possible cost. Also, Statistical significant evidence exist from the robust data analysis to show clear relationship on all the tested parametric variations for the oil extraction with their corresponding oil yields.

Keywords: Optimization; Solvent extraction; Soxhlet apparatus; Soybean; Statistical analysis

1. INTRODUCTION

"Soy vegetable oil" is one of the products of processing the soybean seed (*Glycine* Max), comprising of largely poly-unsaturated fatty acids and mono-unsaturated fatty acid in varying proportions [1]. It has been further clarified the presence of triacylglyerol, phosphatide, oxidation products, unsaponifiable matters and so on [2]. This makes it a soy-crude oil owing to the impurities present, hence, the refining process is very essential in view of eliminating the objectionable matters via different operations in stages viz.: short-mixing, bleaching, and deodorization in a refinery plant of edible oil processing factories. Another product of soybean seed is the soy residue, which is sometimes referred to as "de-oiled cake" (DOC) as a convention to most oil mill companies. It is the material remaining after solvent extraction of oil from the soy cake, with significant soy protein content. The meal is usually toasted in a desolventization toaster (DT). The DOC is an essential element for growing farm animals although, could be further processed into other protein-based soy products for human consumption [3].

The extraction process of the soy oil has been broadly divided into two methods, namely, the traditional methods and the improved methods as reported by Sheikh and Kazi (2016) [4]. To further clarify the narrative, the traditional method is the hand pressing method usually done at domestic level to cake samples such as the groundnut cake. The improved methods usually comprise of chemical method, which is sometimes called solid – liquid extraction (solvent extraction) or leaching, and the mechanical method, which is the pressing process with the aid of an oil expeller or expander. The former results in miscella generation, which is a mixture of the extracted oil and the extraction solvent, where solvent recovery requires distillation process. In this work, n-hexane is however chosen as the extraction solvent in a soxhlet apparatus set-up because of its availability, affordability, and low polarity leading to high yield compared with some other conventional solvents in use. It must be noted that the word soxhlet came-up from the system inventor, in person of Franz Von Soxhlet dated back to 1879 [5]. The mechanism of the extractor is in such a way that solid-liquid or leaching of the oil occurs using a polar solvent and a heating source, coupled with solvent recovery via distillation operation [6].

Different studies were conducted on oil extraction as obtained from the literature. Sheikh and Kazi (2016) [4] carried out a review task on different technologies for oil extraction, with focus on both traditional and improved methods. Chemical characterization of different soy oil samples of Bangladesh was conducted by Prodhan et al. (2015) [7]. The authors used different chemical parameters in view of the characterization and analyzed samples performance in terms of nutritional quality. Okunade and Fatoye (2024) [8] carried out extraction and characterization of different essential oil samples from synthesized food spice. The authors revealed the presence of different compounds in the oil samples while specifying the dominant ones amongst them. Solvent extraction and characterization of oil from date palm seed was conducted by Onoja et al. (2023) [9]. The authors considered the oil yield based on the particle sizes of the grinded sample as well as different chemical properties while comparing with other oil samples. Salikonova et al. (2024) [10] studied the properties of soy bean oil with purification practice. The authors compared the properties of unpurified oil sample with the purified one and offer reasonable conclusions. Lastly, Shafigullin et al. (2021) [11] investigated the fatty oil accumulation in soy bean seed and its thin layer chromatography. The thin layer chromatography looks into the lipophilic components of the soybean fatty oil, and the authors classified the oil sample based on the obtained properties.

It is evident from the sampled set of studies obtained from literature that optimization study was not well covered, which is critical in the industrial operations for food processing industries dealing with edible oils extraction and refinement. Hence, the need for clear and satisfactory equilibrium sets of data or conditions for optimum oil yield from laboratory scale to industrial level in view of economic concerns and sustainability. Besides the optimization concern, the issue of data treatment statistically for the parameters of extraction and optimization is understood to be very fundamental as well, which was thoroughly dealt with in the research paper for appropriate decision.

In view of the preceding point, the aim of this research paper is therefore to investigate the optimum parameters for soybean oil extraction, as a criterion for best yield and quality of the oil.

The specific objectives are:

1. To study the effect of varying the temperature on the oil yield at constant solvent concentration and extraction time.
2. To study the effect of varying the solvent concentration on the oil yield at constant temperature and extraction time.
3. To study the effect of varying the extraction time on the oil yield at constant solvent concentration and temperature.
4. To determine the physic-chemical properties of the extracted oil samples.
5. To carry out statistical significance test on the oil extraction parameters.

Based on the outlined objectives, it is obvious that the last point relates to hypotheses tests, of which the hypotheses drawn in the paper were grouped below:

1. Statistical significant evidence exist for a relationship among the oil extraction drying and optimization parameters.
2. Statistical significant evidence exist for a relationship among the different sets of oil yield of the different varied optimization parameters.

Lastly, the paper has been structured into different sections viz.: section one – introduction; section two - materials and methods; section three – results and discussion; and section four – conclusion.

2. MATERIALS AND METHODS

2.1 Materials considered

Several materials have been considered during the conduct of the experiment from the extraction to characterization process as specified in table 1.

Table 1. List of the materials used in the course of experiment

S/No	Materials
1	Soybean Cake Sample
2	Distilled Water
3	N-hexane (C_6H_{14})
4	98% Ethanol (C_2H_5OH)
5	Phenolphthalein indicator
6	1% starch indicator
7	0.099 N Sodium hydroxide(NaOH)
8	0.1 N Sodium thiosulphate ($Na_2S_2O_3$)
9	10% aqueous Potassium iodine (KI)
10	Dam's reagent
11	Buffer 7.0 solution
12	Di-ethyl ether
13	Carbon tetrachloride (CCl_4)

2.2 Equipment

In view of utilizing the materials specified in table 1, the following equipment were also considered in the whole experiment as clearly presented in table 2. The experimental set up and process for the oil extraction in view of the parametric study was presented in figure 2.

Table 2. List of Equipment / Instruments Used

S/N	Equipment	Model	Specifications	Manufacturers
1	Temperature Control Water Bath	QSEDS01	0 – 100°C Temp. range	England
2	Electric Drying Oven		0 – 240°C Temp. range	Zoetermeter-Holland
3	Analytical Weighing Balance	PW184	Max. 180 g, d = 0.0001	Adam
4	pH meter with electrode	EIC7053	pH/mV (0-14); p/conc (0-2.0); Isopotential (0-20); Slope % (-20-120)	England
5	Hot Plate		0-100°C Range	
6	Stop Watch		Seconds, minutes and hours	England
7	Thermometer		0 - 360° C Range	
8	Pipette		25 mL Capacity	
9	Desicator	PYREX		England
10	Beaker	SIMAX	25 mL and 250 mL Capacity	Czech Republic
11	Conical Flask	GG-17	250 mL Capacity	Pec
12	Round Bottom Flask	GG-17	500 mL Capacity	Pec
13	Measuring Cylinder	PYREX	100 mL Capacity	England
14	Spatula			
15	Retord Stand With Clamp			

16	Extraction Thimble			
17	Burette	BS846	50 mL Capacity	England
18	Reflux Condenser	50/42CX7/08		England
19	Evaporating/ Petri Dish	PYREX		England
20	Soxhlet Extractor	911418		England
21	Grinder			

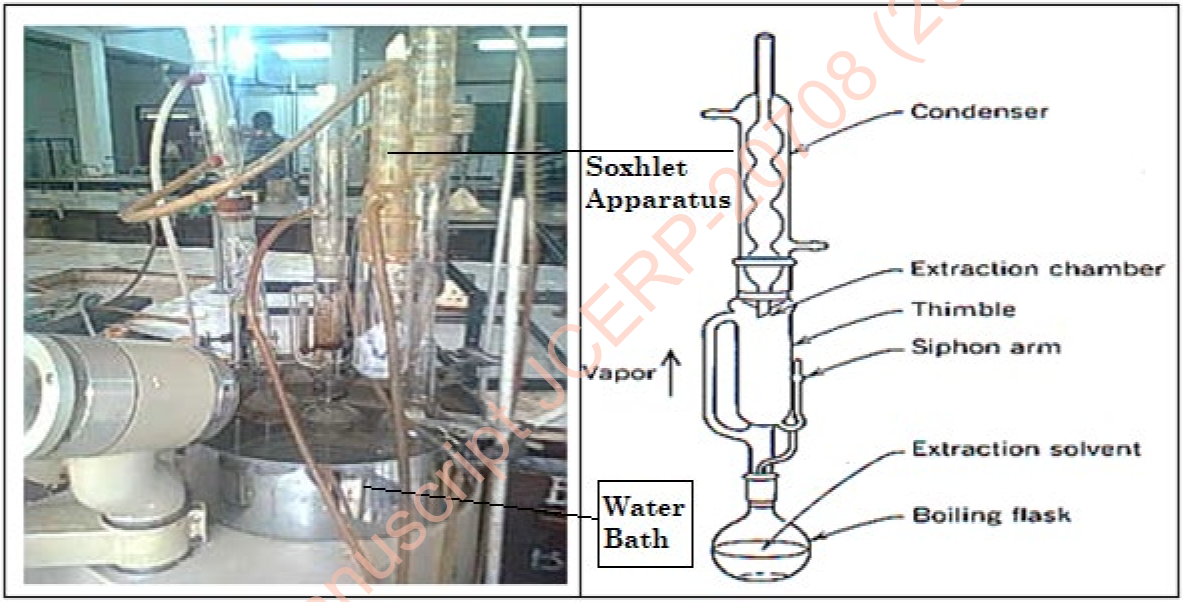

Figure 1. Experimental Set-Up for the Oil Extraction and the Soxhlet Set-up Description

2.3 Research Methods

2.3.1 Raw Materials Collection and Moisture Content Determination

The basic raw material i.e. the **Expander Soybean Seed-Cake** was procured from the press milling plant of **“Sunseed Nigeria PLC Oil Mill Division, Dakace, Zaria, Nigeria.”**, and was further grinded to fine particle sizes using a grinder. The cake samples were placed in clean and dried evaporating dishes and weighed. The evaporating dishes were placed in an oven working at a temperature of 80˚C to further dry the cake samples. After every one hour, the samples were removed and cooled in a desiccator and weighed with analytical balance. The moisture contents of the cake samples were evaluated using the following relationship:

$$\%\, Moisture\ Content = \frac{W_1 - W_2}{W_1 - W_2} ------(1)$$

Where:

W_e = weight of dish alone

W_1 = weight of dish + sample before drying

W_2 = weight of dish + sample after drying

2.3.2 Solvent Extraction of the Oil

i. Variation of Concentration of the Solvent for Oil Extraction

About 20 g of soybean cake sample was weighed into a porous thimble, and then inserted into a soxhlet apparatus. About 200 mL of n-hexane was poured into a 500 mL round bottom flask. The apparatus was heated in a temperature control water bath at 70˚C for 180 minutes and the procedure was repeated for different concentrations viz. 250 mL, 300 mL, and 350 mL.

ii. Variation of Temperature for Oil Extraction

About 20g of soybean cake sample was weighed into a porous thimble, which was then inserted into a soxhlet apparatus. About 300 mL of n-hexane was poured into a 500 mL round bottom flask. The apparatus was heated in a temperature control water bath at a temperature of 65˚C for 180 minutes and the procedures was repeated for different temperatures viz. 70˚C, 75˚C, and 80^{o}C

iii. Variation of Time for Oil Extraction

About 20 g of soybean cake sample was weighed into a porous thimble, which was then inserted into a soxhlet apparatus. About 300 mL of n-hexane was poured into a 500 mL round bottom flask. The apparatus was heated in a temperature control water bath at 70˚C for 90 minutes and the procedure was repeated for different minutes viz. 120,150,180 and 210 minutes.

Note: To ensure steadiness of the manipulated variable i.e. 'temperature' for the water bath, a thermometer was used after the device was set to the desired temperature for like 10 minutes.

iv. The % Oil Yield Determination

The percentage oil yield for the several runs above was calculated as follows:

- Weight of cake sample per run =W_o
- Also, Weight of empty boiling flask = W_1
- And the weight of flask plus oil after extraction and recovery = W_2

$$\% \, Oil \, Yield = \frac{W_2 - W_1}{W_0} - - - - (2)$$

v. Characterization of the Extracted Oils

Characterization of the extracted oil sample was carried out via the following tests:

1. F.F.A Test of the Oil Samples

The American Oil Chemistry Society (AOCS) Da 14-48 method was used. About 1 g of the oil sample obtained for each of the runs was poured into a conical flask, with few drops of ethanol added. The resulting solution was swirled vigorously and placed on hot plate to warm up, after which phenolphthalein indicator was added and swirled again for proper mixing. It was titrated with 0.099 N NaOH until the appearance of bright pink coloration. The % FFA was determined using the model equation 3 as obtained from Wazed et al. (2023) [12]:

$$\% \, FFA = \frac{Titre * N * 10\% \, of \, 282}{W_s} - - (3)$$

Where molecular weight of the fatty acid as oleic in the oil = 282g/mol

Titre = ($v_1 - v_0$) cm

Where V_1 = final volume of NaOH used

V_0 = initial volume of NaOH used

W_s = weight of the sample taken

N = Normality of the NaOH used

2. pH Test of the Oil

About 2 g of the oil sample obtained for each of the runs was poured into a clean dry 25 mL beaker with 15 mL of hot distilled water added and stirred slowly. It was then cooled in a water bath to 25°C. The pH electrode was standardized with buffer solution of pH 7.0, after which was rinsed with water. The electrode was then immersed into the oil sample and the meter reading taken.

3. Iodine Value Test of the Oil

The method specified by ISO 3961 (1989) was used. About 0.4g of oil sample obtained for each of the different runs was weighed into a conical flask and 20 mL of carbon tetrachloride was added to dissolve the oil. The 25 mL of dam's reagent was added using a safety pipette in fume chamber. Stopper was inserted and the mixture vigorously swirled. The flask was then placed in the dark for 2 hrs. 30 minutes. At the end of this period, 20 mL of 10% aqueous potassium iodide and 125 mL of water were added using a measuring cylinder. The content was titrated with 0.1 N sodium thiosulphate solution until the yellow color almost disappeared. Few drops of 1% starch indicator was added and the titration continued by adding thiosulphate drop wise until blue coloration disappeared after vigorous shaking. The Iodine value determination was done using the model equation 4 in accordance with Wazed et al. (2023) [12] computations:

$$I.V = \frac{10\%\ of\ 126.9 * N * Titre}{W_s}\left(\frac{gI_2}{100gOil}\right) - - - - - (4)$$

Where the molar mass of the iodine = 126.9g/mol

N = Normality of the sodium thiosulphate used

Titre = $V_1 - V_0$

Where: V_1 = Final volume of thiosulphate used

V_0 = Initial volume of Thiosulphate used

W_s = weight of the sample taken

2.4. Statistical Significance Tests

Data analysis was rigorously performed on different parameters of the oil extraction through inferential statistics. This was in view of observing possible correlations among the linked parameters of the optimization study. Analysis of Variance (ANOVA) was employed to test the following expanded hypotheses of the introductory part viz.:

1. Correlation between weight losses for cake samples after drying with the corresponding percentage of moisture contents.
2. Correlation between varied temperature of extraction with the oil yield, at constant solvent concentration and time.
3. Correlation between varied solvent concentration with the oil yield, at constant temperature and time of extraction.
4. Correlation between varied extraction time with the oil yield, at constant temperature and solvent concentration.
5. Correlation among the different sets of oil yield corresponding to the different varied optimization parameters.

The models with the assumption employed were:

$$SSB = \sum n_j(\bar{X}_j - \bar{X})^2 - - - - - - (5)$$

$$SSE = \Sigma \sum \left(X - \bar{X}_j\right)^2 - - - - - - (6)$$

$$MSB = \frac{SSB}{k-1} - - - - - - - (7)$$

$$MSE = \frac{SSE}{N-k} - - - - - - (8)$$

$$F = \frac{MSB}{MSE} - - - - - - - (9)$$

$$df_1 = k - 1 - - - - - - (10)$$

$$df_2 = N - k - - - - -(11)$$

Note: Assumed Confidence Level (α) = 0.05

Where: SSB = Sum of Squares between Treatments; SSE = Error or Residual Sum of Squares; MSB = Mean Square between Treatments; MSE = Error or Residual Mean Square; X = Individual Observation; $\bar{X}$ = Overall Sample Mean; n_j = number of observed data in a given group; $\bar{X}_j$ = Sample Mean for a given group; N = Total observed data for all groups; k = Number of Treatments or Groups. df_1= Degrees of Freedom between Treatments; df_2 = Residual Degrees of Freedom; F = Statistical Significance Comparison Parameter

Note that the Critical F value ($F_{Critical}$) is determined from the ANOVA table for the assumed confidence level (α) of 0.05 based on datum intersection point for df_1 anddf_2.

Conclusion to be drawn depends on the F value determined as well as the Critical F value as follows:

i. If F value > $F_{Critical}$ – Reject Null Hypothesis, hence, there is a statistical significant evidence to show strong relationship between or among treatments or groups at the assumed and specified confidence level (α).

ii. If F value < $F_{Critical}$ – Accept Null Hypothesis, hence, there is no statistical significant evidence to show clear relationship between or among treatments or groups at the assumed and specified confidence level (α).

3. RESULTS AND DISCUSSION

3.1 Moisture Content Results

The results of the moisture content for the different runs specified in the methods section has been presented in table 3.

Table 3. Moisture content of the cake sample

Weight of sample before drying (g)	Weight of sample after drying (g)	Weight lost (g)	Moisture content (Wt. %)
50.1245	45.4629	4.6616	9.30
50.1326	45.4703	4.6623	9.30
50.3528	45.5693	4.7835	9.50
50.2708	45.5051	4.7657	9.48
50.0516	45.4118	4.6398	9.27

$$\text{Average Moisture Content of the Cake} = \frac{9.3+9.3+9.5+9.48+9.27}{5}$$

Hence, Moisture Content on Average = 9.37%

Obviously, the moisture content of the Soybean oil-cake on average was 9.37% which is in conformity with the literature standard moisture of range 9 – 12% for there to be efficient extraction [13]. It was however noted that high moisture in the cake that deviates from literature standard value results in poor oil yield or reduced efficiency of extraction due to reduced penetration potentials of the solvent in the cake sample for the leaching operation, ultimately leading to increased residual oil content in the de-oiled cake (DOC) sample.

3.2. Optimization and Characterization Results

For the different parametric variations for the oil extraction having specified in the methods section, the different optimization results with the conditions obvious for the highest oil yield have been presented in table 4, 5 and 6. The follow-up characterization results have been presented in table 7 in range values for the different samples taken and evaluated. Follow-up graphical depiction of the moisture content evaluation as well as the optimization results have been shown in figure 3, 4, 5, and 6.

Table 4. Effect of Solvent Concentration on oil yield at 70℃ and 180min.

Solvent Concentration (mL)	Weight of Sample (g)	Weight of Oil extracted (g)	Oil yield (Wt. %)
200	20.0429	3.4352	17.14
250	20.0418	3.8015	18.98
300	20.0425	3.8582	19.25
350	20.0399	3.8577	19.25

Table 5. Effect of Temperature on Oil yield at 300ml n-hexane and 180min

Temperature (℃)	Weight of Sample (g)	Weight of Oil extracted (g)	Oil yield (Wt. %)
65	20.0398	3.8216	19.07
70	20.0425	3.8582	19.25
75	20.0389	3.8555	19.24
80	20.0392	3.8575	19.25

Table 6. Effect of Extraction time on oil yield at 300ml n-hexane and 70℃

Extraction time (min.)	Weight of Sample (g)	Weight of oil extracted (g)	Oil yield (Wt. %)
90	20.0468	3.1173	15.55
120	20.0399	3.2204	16.07
150	20.0377	3.8392	19.16
180	20.0425	3.8582	19.25
210	20.0386	3.8554	19.24

Table 7. Characterization of the Extracted Oil

Physic-chemical Properties	Specifications / Range Values	Literature Standard / Source
F.F.A (Chemical Property) (%)	0.67 - 1.05	1.26 ± 0.23 [14]
Iodine Value (Chemical Property) $gI_2/100g$ Oil	122.08 - 145.84	122.0 – 142.0 - ES-PTO-002 Standard [15]
pH (Physical Property)	6.8 - 6.92	N/A

Figure 2. Effect of Weight Lost on Moisture Content

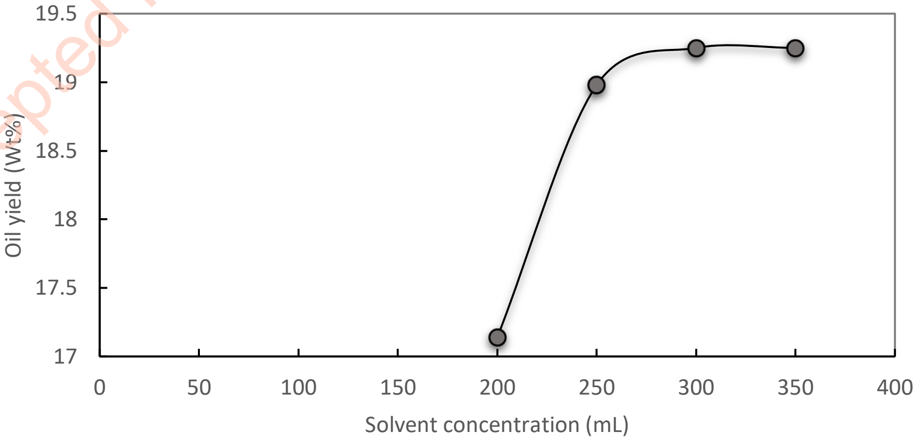

Figure 3. Effect of Solvent Concentration on Oil Yield

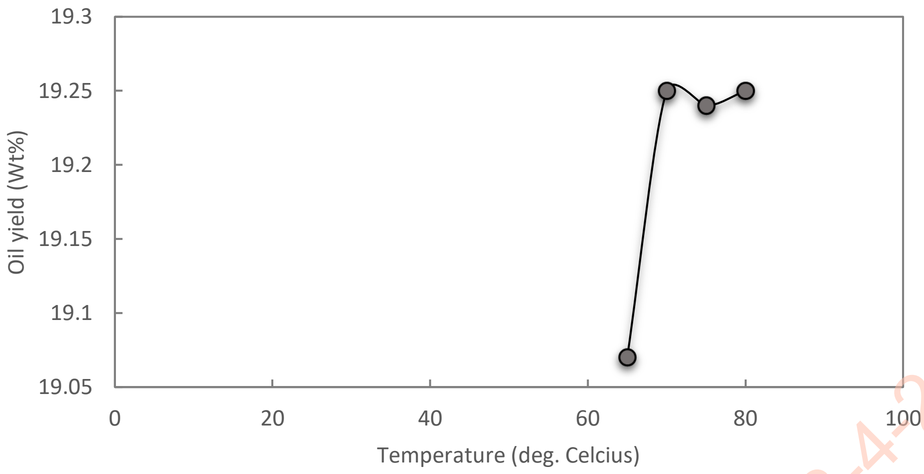

Figure 4. Effect of Temperature on Oil Yield

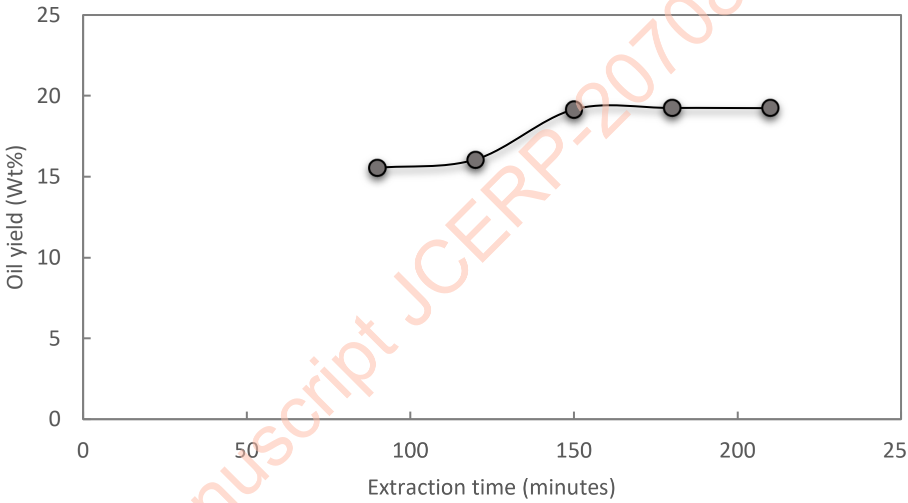

Figure 5. Effect of Extraction Time on Oil Yield

On a general note, it is clearly noted that the oil yield range is 15.55 - 19.25% in the parametric variations done, with the lowest yield under the condition of 90 minutes extraction time, 300 mL n-hexane, and 70^0C extraction temperature. Obviously, the highest or optimum yield is traced to 180 minutes of extraction, 300 mL n-hexane, and 70^0C extraction temperature. The range of oil yield observed is interestingly in line with the literature standard range of 15-25% [14], for an effective and efficient extraction process. Therefore, possibilities exist in exceeding the optimum yield of 19.25% if other measures can be put in place. For example, further size reduction of the cake sample prior to the leaching operation might enhance the diffusion and penetration potential of the solvent, ultimately increasing the oil yield due to the enhanced fineness of the particles and higher surface area. However, this was not taken into considerations as an optimization parameter. To compare briefly with other edible seeds, research conducted by Onoja et al. [9] for a date palm seed oil extraction showed a relatively lower yield of around 11% from the seed. Another research on oil extraction from *Calophyllum inophyllum* L. kernel via optimization conducted by Mohd Shamsuddin et al [5] showed oil yield in the range 23.04-45.85%, being of better yield than the soybean seed.

On moving to the specific parametric variations, Table 4 in view of addressing the first objective shows that on keeping the temperature constant at70℃ with constant time of 180min, and varying the solvent concentration, the yield of oil increased up to solvent concentration of 300ml. But on increasing to 350ml, no appreciable change was observed, showing 300ml of n-hexane already optimum for the extraction. Looking at table 5 in view of addressing the second objective, switching to the optimum 300ml n-hexane and a constant time of 180min with varying temperature resulted in increased oil yield up to the boiling point of the solvent which is around 70℃. Further increase in temperature shows slight yield reduction effect, which confirms 70℃ as the optimum temperature for the extraction. Table 6 for the third research objective shows the effect of time variation on oil yield at constant temperature of 70℃ and constant solvent concentration of 300ml. 180min was equally observed to be the optimum time for the oil extraction of the 20 g cake sample used.

Based on the descriptive discussions on the parametric variations for the oil yield, it could be further clarified that the engineering principle of the optimization process is linked to mass transfer phenomenon, being an adsorption process, as well as chemical stability for the solvent utilization to the leaching activity. Thermodynamics in view of solubility measures and temperature impact applies. Time for the extraction obviously played a crucial role in ensuring the maximum extraction of the oil from the cake as an indicator of efficiency, but has got its limit in fear of diminishing return. So, applies to the temperature being another crucial parameter when increased to a considerable range values closed to the boiling point of the solvent for enhanced diffusion rate. Further temperature increment far from the solvent boiling point as obviously observed from the results is uneconomical and energy inefficient, and might even hinder the quality of the oil to be extracted as well as the de-oiled cake as a residue for further processing. The issue of solvent is obvious on high concentration for positive impact from the results but with also a limit. More utilization of solvent is uneconomical due to intense solvent recovery energy, high cost, and may even result in high recovery losses.

Regarding the characterization done in view of addressing the fourth objective for the extracted oil samples, it was obvious from Table 7 the summary of the different physic-chemical properties considered in rage values. Slight variations exist in the iodine value determination as a chemical property. These variations are still in conformity with the suggested range from literature i.e. (122 – 142) $gI_2/100gOil$ [15], although some have deviated slightly. The obtained iodine value makes the oil a drying type which signifies its high degree of unsaturation, hence, making it suitable for use in paints production. There is however greater potential for the oil to polymerize as a reactivity indicator owing to the high level of unsaturation linked to the fatty acid component of the oil. For the FFA tests carried out, being another chemical property considered, it was also observed from the characterization table 7 that there are little variations with the conditions embarked for the extraction. The highest FFA value observed was 1.05%, but most values were in conformity with the standard literature value of 1.26 ± 0.23 [14]. It is however noted that high free fatty acid in oil is attributed to presence of rotten seeds in the cake sample considered for extraction process of the oil. The high free fatty acid in an extracted soy crude oil could ultimately result in high refining losses and making the system uneconomical.

On extension, in view of the possible applications of the oil based on the need for improved yield and sustainable operations, domestic applications has been considered as most fundamental being an edible oil. However, beside the domestic application, the idea of paints production having specified in the previous brief discussion could be expanded further. The paint synthesis involves a primary raw material known as a binder, which is a polymer and the heart for the paints production. Examples of the binder are alkyd resin, polyvinyl acetate (PVA) as the most conventionally used and so on. The binder synthesis requires oil as one of the raw materials that is very fundamental as well. Furthermore, on venturing into renewable and alternative energy services, the area of biofuels has cut significant attentions as alternative to transport sector and beyond. Hence, biodiesel production being one of the biofuels is achieved fundamentally via transesterification of oils with an organic base in the presence of a strong base catalyst. However, gradual transition has occurred in the area biofuel from the first generation to the use of non-edible oil raw material and other non-edible feed-stocks in what is referred to as higher generation and advanced biofuels [16]. This is in view of addressing possible clash or conflict with food and the need for better energy security in energy operations with ultimate goal of service sustainability [17]. Hence, oil extraction is very crucial due to its diverse applications and hence, judicious measures are necessary in their extraction, especially at the industrial or large scale level, coupled with extensive quality measures. Beside the oil, the de-oiled cake sample (DOC) being high in protein content while containing residual oil is also a crucial material applied for animal feed processing in the animal feed industry.

3.3 Hypotheses Test Results

The analysis of variance (ANOVA) results linked to the fifth and last objective for the statistical significance tests based on the different models utilized with the assumption used were presented in table 8, 9, 10, 11, and 12.

Table 8. ANOVA Data Summary for Hypothesis 1 (Weight Lost vs. Moisture Content)

<table>
<tr><td colspan="5">H_0 = Null Hypothesis: $\mu_1 = \mu_2$ (Equal Means)
H_1 = Alternative Hypothesis = Unequal Means</td></tr>
<tr><td>Variation</td><td>Sum of Square (SS)</td><td>Degrees of Freedom (df)</td><td>Mean Square (MS)</td><td>F</td></tr>
<tr><td>Between Treatment (B)</td><td>54.4692</td><td>$df_1 = 2-1 = 1$</td><td>54.4692</td><td>$F_{critical}$ = 5.3177</td></tr>
<tr><td>Error / Residual (E)</td><td>0.0666</td><td>$df_2 = 10 - 2 = 8$</td><td>0.0083</td><td>F value = 6545.26</td></tr>
<tr><td colspan="5">∴ **F value > $F_{critical}$**</td></tr>
</table>

From the statistical evaluations of table 8, based on the different models utilized and assumption with ANOVA table considerations, it is obvious that the F value was greater than the critical F. Hence, we reject the null hypothesis, and confidently specify that statistical significant evidence exist to show clear relation between the soy cake weight loss and its moisture content at the confidence level of 0.05.

Table 9. ANOVA Data Summary for Hypothesis 2 (Solvent Concentration vs. Oil Yield

<table>
<tr><td colspan="5">H_0 = Null Hypothesis: $\mu_1 = \mu_2$ (Equal Means)
H_1 = Alternative Hypothesis = Unequal Means</td></tr>
<tr><td>Variation</td><td>Sum of Square (SS)</td><td>Degrees of Freedom (df)</td><td>Mean Square (MS)</td><td>F</td></tr>
<tr><td>Between Treatment (B)</td><td>131425.5181</td><td>$df_1 = 2-1 = 1$</td><td>131425.5181</td><td>$F_{critical}$ = 5.9874</td></tr>
<tr><td>Error / Residual (E)</td><td>12503.1089</td><td>$df_2 = 8 - 2 = 6$</td><td>2083.8515</td><td>F value = 63.07</td></tr>
<tr><td colspan="5">∴ **F value > $F_{critical}$**</td></tr>
</table>

Similarly, table 9 showed the statistical analysis results based on the different models utilization with the critical F value traced from the ANOVA table at the assumed confidence level. It is also obvious on the fact that the determined F value was greater than the critical F. Hence, we reject the null hypothesis, and specify equally that statistical significant evidence exist to show clear relation between the solvent concentration and its oil yield at the assumed confidence level of 0.05.

Table 10. ANOVA Data Summary for Hypothesis 3 (Temperature vs. Oil Yield)

H_0 = Null Hypothesis: $\mu_1 = \mu_2$ (Equal Means) H_1 = Alternative Hypothesis = Unequal Means				
Variation	Sum of Square (SS)	Degrees of Freedom (df)	Mean Square (MS)	F
Between Treatment (B)	5681.2470	$df_1 = 2\text{-}1 = 1$	5681.2470	$F_{critical} = 5.9874$
Error / Residual (E)	125.0235	$df_2 = 8 - 2 = 6$	20.8372	F value = 272.65
$\therefore$ **F value > $F_{critical}$**				

Table 10 also followed same calculation approach for the correlation purpose. It was also obvious from the table 10 that the F value calculated was greater than the critical F, leading to the rejection of the null hypothesis, and deducing that statistical significant evidence exist to show clear relation between the extraction temperature and its oil yield at the assumed confidence level of 0.05.

Table 11. ANOVA Data Summary for Hypothesis 4 (Extraction Time vs. Oil Yield)

H_0 = Null Hypothesis: $\mu_1 = \mu_2$ (Equal Means) H_1 = Alternative Hypothesis: Unequal Means

Variation	Sum of Square (SS)	Degrees of Freedom (df)	Mean Square (MS)	F
Between Treatment (B)	43656.4133	$df_1 = 2-1 = 1$	43656.4133	$F_{critical}$ = 5.3177
Error / Residual (E)	9014.0665	$df_2 = 10 – 2 = 8$	1126.7583	F value = 38.75
∴ F value > $F_{critical}$				

The summary data of table 11 for the correlation purpose has also been presented. It obviously showed the F value as greater than the critical F, hence, the null hypothesis is rejected as well, deducing that statistical significant evidence exist to show clear relation between the extraction time and its oil yield at the confidence level of 0.05.

Table 12. ANOVA Data Summary for Hypothesis 5 (Oil Yields for the 3 Variations)

H_0 = Null Hypothesis: $\mu_1 = \mu_2 = \mu_3$ (Equal Means) H_1 = Alternative Hypothesis: Unequal Means				
Variation	Sum of Square (SS)	Degrees of Freedom (df)	Mean Square (MS)	F
Between Treatment (B)	4.1536	$df_1 = 3-1 = 2$	2.0768	$F_{critical}$ = 4.1028
Error / Residual (E)	17.1989	$df_2 = 13 – 3 = 10$	1.7199	F value = 1.2075
∴ F value < $F_{critical}$				

Contrary to be previously described table 8, 9, 10, and 11, table 12 revealed a different scenario based on the end point F values. In this case, the F value was obviously less than the critical F, leading us to confidently accept the null hypothesis. In view of that, it therefore means that we do not have statistical significant evidence to show clear relation among the 3 data sets for oil yield corresponding to the different variations done of the optimization parameters at the assumed confidence level of 0.05.

4. CONCLUSION

Optimum parametric investigation for soy bean oil extraction was successful, coupled with oil characterization and robust statistical analysis for correlation purpose amongst the oil extraction parameters. This was in view of improved and more satisfactory equilibrium set of conditions for oil extraction on industrial scale extension as linked to mass transfer efficiency, thermodynamic effectivity, energy efficiency, economic and environmental favors. Obviously, the cake sample considered has been analyzed with a moisture content on average at 9.37 wt. %, conforming to the literature value range, and hence the effectiveness of the sample for oil extraction on any scale. The best oil yield was 19.25% with the corresponding optimum conditions for the oil extraction using the soxhlet set-up being temperature of 70^{o}C, solvent concentration of 300 mL, and extraction time of 180 minutes. This is practically relevant on extrapolation to industrial scale for socio-economic favors and ultimately in view of sustainable operations. The inferential statistics considered for correlation purpose amongst cake sample drying parameters and optimization parameters for the oil extraction showed strong relationship. This was from the statistical significant evidence existing in most of the parameters and data sets when compared, focusing on their F values with the corresponding critical F values. It is certain that this research work has significantly advanced the present state of knowledge from the robust statistical analysis conducted in view of the extraction parametric statistical relation updates as a strong and valid decision tool in data science advancement linked to process engineering. The possible applications of the extracted oil spans from domestic to industrial activities being cooking, paints and biofuels production and so on.

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