A Comparative Application of Latin Hypercube Design and Box-Behnken Design Methods in Extracting Sesameoil

[1]Aman Elmi Tufa*, [1]Youmin Hu, [1]Shuai Huang, [2]Wenwen Jin,[2]Fengcheng Li
[1]The School of Mechanical Science and Engineering, Huazhong University of Science and Technology Luoyu Road 1037, Hongshan District, Wuhan 430074, P.R.China.
[2]College of Life Science and Technology, Huazhong University of Science and Technology, Luoyu Road 1037, Hongshan District, Wuhan430074, P.R.China.
aman.elmi@yahoo.com*

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Summary: In the past decades, most researchers focus on process optimization and extraction methods to improve oil extraction from oilseeds. However, no information available on comparative analysis of different design methods to improve the process. The objective of this study was to evaluate the applicability of Latin hypercube design (LHD) and Box-Behnken Design (BBD) in oil extraction. Experimental oil yield, analysis of variance (ANOVA) of the model, and practical observation were used to compare the methods. The result shows both methods can supply adequate data for experiments. The range of oil yield is 26 – 41% for BBD and 31 – 41% for LHD. Analytically, the ANOVA result indicates that the model constructed of the LHD experiment has a better prediction of observed oil yield at a regression coefficient (R^2) of 0.98 and Root Mean Square Error (RMSE) of 0.4 while BBD has $R^2$0.87 and RMSE 1.4. From the experiment result, BBD is more suit to design, efficient, and easier to extract oil. LHD has better design options, more flexible but less efficient in the experiment. For the given process conditions, theresult comparison empirically analyzed suggests both methods can be applied for oil extraction.

Keywords: Oil extraction, Latin hypercube design, Mechanical press, Response surface methodology.

Introduction

The extraction method and factors affecting the extraction process are determinant factors to affect oil yield and oil quality.Oil extraction methods are critically influenced by the design of the experiment. Nowadays, the research and development section of oilseed processing industries have a focus to deal with special care to high-value and high oil content seeds. In this regard, sesame (Sesamum indicum L.) is the most important oilseed plant since it has high oil content, about 56 – 60% oil [1] also has a notable quality characteristic bearing high-value oil. The oil also hasessential health diets such as minerals, protein, fats, and carbohydrates [1, 2].The oil is well-known in baking, cooking, and flavoring food. As the volume, value, and demandrise, the seed was widely cultivated, proceed to a high interest for better extraction with betterexperiment design

Oilseeds pressing by a mechanical method is recommended for high-quality oil and high-value oils. Mechanical extraction is important because chemical contamination risk along with microbiological risk and an unbalanced diet are reported as the major public health problems [3].The potential risk prevalence is high. Because there is high annual oil production and consumption of sesame oil estimated at1.5x10^9 kg/year [4], in this regard, sesame pressed by a mechanical method issafer and healthier than the solvent method. It gives non-toxictype edible oil and cake for economic and environmentalben efits [5].

A study on 721 sesame samples from 10 countries indicates that oil content and property would vary with botanical characteristics [6]. During processing, oil yield reportedly varies with mechanical press factors such aspressure, seedmoisture, heat, and duration of pressing [7–12]. Though many types of researches were made, mostly solvent extraction, it seems no mathematical model is known for sesame seed with hydraulic mechanical press factors. According to [13], mathematical modeling is employed to simplify process design by reducing the waste of material, labor, and time. Modeling determines process efficiency and machine safety at optimum variables. Above all, these variables are inbuilt to new emerging technologies that make the study more practical and accessible.

Experiment design is a powerful statistical technique to improvethe processand optimization problems [14, 15]. LHD is an experiment method usually applied for structural analyses but not yet tried in oil extraction. Since 1975 of its first

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*To whom all correspondence should be addressed.

development, the Latin hypercube sampling design gain extensive use [16]. LHD has a certain optimality disadvantage. To solve this, [17] combines optimal design with LHD while [18] customize particle swarm optimization with LHD. However, many researchers, engineers, and statisticians use BBD to reduce the cost of the experiment. Initially, BBD was developed by George Box for a limited class of processing problems that are difficult to approach in any other manner. It is now recognized as one of the most efficient design methods and has been used for fitting quadratic surace andthe construction of second-order polynomial model [19]. Recently, BBD has a wide range of applications in science fields, including optimization of nanoparticle synthesis [20], optimization for edible oil extraction [21], optimization for operating conditions for CaCO3 crystallization [22], and so on.It is widely used to evaluate variables' effect on response, the characterization, and optimization of the end product. Eventhough both LHD and BBD experiments are very useful,still, their difference in oil extraction is not known, empirically or analytically.

In this study, LHD and BBD based experiment study has been performed by using mechanical pressing variables to extract sesame oil. A comparative research approach [23] was conducted to determine a more suitable and accurate method for designing and modeling oil extraction. The research investigated the nature of physical data, the empirical result, efficiency, and practical applicability between these methods.

Materials and methods

Materials

A 1 kg of 20pieces of the seed was purchased from Jurong Valley Love Square Agr. Products Co., Ltd.Heilongjiang province (Harbin) through TAOBAO. The seed is a standardized type, edible as oil, soy milk, and shelf-stained powder.The seeds were stored under room temperature for a week before processing. The weight percentage ofmoisture content (MC) was determined to be 5.69% g on wet basis (w.b).

The analytical method for moisture determination

The oven-drying method (forced-air) of capacity (10 – 300 ±1 °C) was used for drying seeds. First, MC was determined after drying three samples of 100 g for 6 hrs at a constant temperature of 105 °C until no more moisture loss is available. Secondly, the MC level was determined from triple seed samples dried at a constant temperature of 60 °C at an interval heating time of 1 hr. The moisture loss variation between samples is checked to be below 0.02. The tendency was drawn between heating time and moisture loss to determine three distinct moisture levellocations. Accordingly, 2.84% MC is obtained at 60 °C heating for 45 min, and 0% MC is obtained at 105 °C heating for 6 hrs (5.69% initial MC). The MC level was determined for pressing purposes to evaluate the MC level effect on the oil yield. In that case, moisture migrates at a higher rate at the beginning of the drying phase, where the product equilibrates to the logarithmic model [24]. During heating, the stable temperature reading of the oven was used to control the temperature and the time of heating was managed to reduce experiment variations and errors among the samples. Seed MCwas determined by the analytical method given in AOAC [25] using equation (Eq. 1).

$$MC\,(\%\,\mathrm{w.b}) = \left(\frac{W_1 - W_2}{W_1}\right) \times 100 \qquad \text{Eq. 1}$$

where W_1 and W_2 represents the weights (g) of the sample before drying and after drying, respectively

Experiment design

The experiment was done using a single factor experiment using the high-low method. Usually, if one knows little about the particular process being studied, one might start by constructing a simply high-low type of design about some reasonable starting point and build a first-order model. This would be used to determine a direction in which one might move to improve the desired dependent variable response. Then experiments are conducted, changing the independent variables along the indicated direction until no further improvement in the response is found. Then another small high-low type of design is constructed and the process is repeated until it does not appear that any improvement is possible, suggesting that we are near a locally optimal point. Then a fuller second-order model is constructed with more data to describe the local region.

Primarily the single-factor experiment was conducted at 5 sample levels for each variable to determine how variables individually affect oil yield and to assign the range of variables for the experiment. The test performed by varying pressure, MPa (10, 18, 25, 36, 40) at constant (67.5 °C, 1.85%w.b, 17.5 min), by varying temperature, °C (35, 51, 67.5, 84, 100) at constant(25 MPa, 1.85% w.b, 17.5 min), by varying MC % w.b (0, 1.4, 2.85,4.2 5.69) at constant (67.5 °C, 25 MPa, 17.5 min), and by varying press time, min (5, 11, 17.5, 24, 30) at constant (67.5 °C, 25 MPa, 1.85%w.b). Secondly, the multiple factor experiments with BBD and LHD are conducted to have a complete picture of the variable's interaction effect on the oil yield for the ranges of pressure (10 – 40 MPa), temperature (35 – 100°C), time (5 – 30 min), and MC (0 – 569% w.b) ata different number of runs forthe advantage of observing differences.

BBD experiment design:4 factors* 3 levels that provide 29 experiment runs with five center points. Three levels of each variable are: pressure, MPa (10, 25, 40), temperature, °C (35, 67.5, 100), MC% w.b (0, 2.85, 5.69) and press time, min (5, 17.5, 30). The response surface method was used to build the regression model from experimental data. The useful part of the seed, such as oil[21] and protein contents [27] are successfully extracted and optimized by BBD package.

LHD experiment design: There are a total of 20 different sample points (runs) generated by using Matlab R2017 alhs design command (LHD) for this study. The techniques of sampling represented in design for point (p) and dimension (d) written as pxd matrix $X = \left[x_1 x_2 \dots x_p\right]^T$, each column and row represent the factor $x_i = [{x_i}^1 {x_i}^2 \dots {x_i}^d]$ [28]. The nature of data has no replicates since the dimension (d) is divided into p equal level. Therefore data collection performed strictly with attention for replicates could not appear in the design. Sample points selected from the given ranges by LHD are viewed in the scatter matrix plot for optimum location.

Oil yield determination

The practical oil extraction experiment was done by using a machine that can press up to 60 ±1 MPa and heat up to 200 ±1 °C. The machine has the system part and the pressing part. The system part contains electromechanical and fluid mechanics systems controllers such as temperature gauge, pressure gauges, and the timer. The press part has a cylinder of size Φ140 * 165mm for seeds pressing. A 100 g of seed was rolled between screeners of cloth of fine mesh and placed between the bottom and upper pressing plates. When the pressure isapplied, the plunger moves up to squeeze the seed between plates. Simultaneously the perforated inner wall of thecylinder sieve with fine mesh allow oil passage and filtration. The oil was collected in test tubes for analysis work. The weight of extracted oil (Y) in percentage was determined by using Eq. 2

$$Y\,(\%) = \frac{W_b - W_a}{W_b} x100\%. \qquad \text{Eq. 2}$$

where W_b is the weight of seed and cloth before pressing in (g), W_a is the weight of seed and cloth after pressing in (g). The gap between seed drying and seed pressing was kept uniform to reduce errors during the process, and the stable pressing temperature was used throughout experiments.

After extraction, the oil is kept out of oxidation, and important physicochemical properties are measured at the optimum conditions where oil is susceptible to cause a major change in the property. The iodine and acid values are tested by [29] methods, peroxide value by IUPAC [30] methods, fatty acid composition by Chromatography [31] method.Oil taste and odor are measured based on 10 groups of panels [32].

Comparisonmethods

The comparison research approach was applied between LHD and BBD methods and empirical and analytical results were compared. The methods were compared bydata suitabilityfor the experiment, model suitability to measure statistical significance using (F-value) and significance probability value at $p < 0.05$ from ANOVA. The range of oil yield obtained during the experimentwas used to evaluate the performance range for empirical results. The model suitability for predictingobserved oil yield was checked by using R^2 value and RMSE. Design suitability is checked by the interval of oil output and observation from the practical work. Design-expert 8.0.6 software and Matlab R2017a were used to experiment with data.

Results and Discussion

Single-factor experimental analysis

Efforts were made to measure how oil yield was affected by process variables. The temperature effect was investigated between 35 – 100°C and the result shows that oil yield increased between 35 – 84°C contribute to 34.3 – 38% oil yield without degradation. The taste and odor is similar to conventional market oil when extracted between 70 – 100 °C, based on 10 groups of panels [32]. According to [33], temperature also improves sesame oil qualities. The effect of 10 – 40 MPa pressure produces 30.7 – 38.3% oilreaches optimum atabout 37 MPa, which tends to stable or decline similar to the effect observed with cocoaseeds [12].The MC 5.69 – 0% w.b was investigated, the oil yield of 33.8 – 37.7% obtained where the maximum belongs to 2.85%MC. Oil yield improved as the moisture inside the seed gets smaller and smaller [7]. It is observed that cake is baked on long pressing, excessive pressure, and high temperatureto decrease oil yield due tothe blocking effect of oil extraction.

BBD and LHD result analysis

The experimental oil yield of BBD and LHD are given in Table-1.We can see that there are differences in samplepoints of independent variables and their corresponding experimental (exp) oil yield.In the BBD, the range of oil yield obtainedwas between 26 – 41%. The lowest yield, 26% (run 13) was occurred mainly due tolow pressure and the seed without moisture.The highest oil yield of 41%(run 22) was mainly due to the application of high pressure, which implies oil yield is very responsive to pressure than other variables to release oil.

Similarly, it can be seen that the oil yield range is 31 – 41%. for LHD. The highest (run 4) and the lowest point of oil yield (run 6) have a significant relation with pressure. In both cases, the oil expression rate related to pressure andseed deformation also agrees with the single-factor experiment. Oilseeds have the oil body (organelle) to stores oil [34]. The membranes of the oil bodyis burst to release oil only when pressure energy overtake critical plastic deformation; other variables have only facilitated the condition. Such as temperature weakens the oil body and lowers oil viscosity to easily expressed by pressure. It is observed that the oil expression rate decrease as the oil inside the oil body decrease; in that case, the decreasing rate increase with applied pressure and temperature.

The ANOVA of BBD and LHD

The fitness and significance of the model werestatistically determined based on the analysis of variance (ANOVA) obtained from BBD and LHD response surface model given in Table 2. The large F-value at $p < 0.05$ indicates that the process variables significantly contribute to oil extraction. It can be seen that BBD model developed by ANOVA is statistically significant, with F-value 6.84 at$p <$ 0.05. Oil yield is significantly influenced by pressure, temperature, and press time. MC does not cause a major significantdifference in oil yield (p>0.1). Rather it hasa high quadratic effect on oil yield at the higher F-value of 23.34 (p=0.0003), indicating the importance ofthe MC treatment before pressing. The error due to the experiment (pure error) is 1.35.We observed that the sources of error are related to the experiment method, the machine, the environment, and measuring skill. Such errors are normal and non-avoidable but small enough to be acceptable.

Table-1: Experimental and predicted oil yield obtained by BBD and LHD method.

	Independent variables				**BBD Y (%)**	**Independent variables**				**LHD Y (%)**
run	**Tem**	**Pre**	**MC**	**Pt**	**exp**	**Tem**	**Pre**	**MC**	**Pt**	**exp**
1	**67.5**	**25**	**0**	**30**	**37.2**	**99**	**33**	**5.64**	**24**	**35.4**
2	**67.5**	**40**	**5.69**	**17.5**	**39.3**	**92**	**17**	**3.25**	**11**	**34.6**
3	**67.5**	**40**	**2.85**	**30**	**40.4**	**96**	**12**	**3.67**	**25**	**34.8**
4	**100**	**40**	**2.85**	**17.5**	**40.3**	**54**	**40**	**3.81**	**30**	**41**
5	**100**	**25**	**0**	**17.5**	**36.4**	**88**	**20**	**5.34**	**8**	**32.6**
6	**100**	**25**	**5.69**	**17.5**	**35.2**	**47**	**16**	**0.97**	**27**	**31**
7	**35**	**25**	**0**	**17.5**	**28.1**	**49**	**38**	**4.78**	**22**	**40.2**
8	**67.5**	**25**	**2.85**	**17.5**	**37**	**61**	**35**	**1.35**	**20**	**39.8**
9	**67.5**	**25**	**2.85**	**17.5**	**37.3**	**82**	**10**	**2.67**	**6**	**32**
10	**67.5**	**40**	**0**	**17.5**	**38.6**	**40**	**24**	**1.48**	**12**	**32.4**
11	**67.5**	**10**	**2.85**	**5**	**34.8**	**75**	**28**	**5.06**	**13**	**37.3**
12	**67.5**	**10**	**2.85**	**30**	**35.3**	**70**	**36**	**4.54**	**10**	**37.9**
13	**67.5**	**10**	**0**	**17.5**	**26**	**38**	**32**	**0.09**	**14**	**33**
14	**35**	**10**	**2.85**	**17.5**	**28.1**	**65**	**21**	**3.04**	**6**	**35.9**
15	**67.5**	**25**	**5.69**	**30**	**34.2**	**60**	**14**	**0.69**	**19**	**31.7**
16	**67.5**	**25**	**0**	**5**	**27.7**	**72**	**29**	**4.22**	**28**	**38**
17	**100**	**10**	**2.85**	**17.5**	**33.8**	**80**	**23**	**1.93**	**26**	**37.6**
18	**67.5**	**25**	**2.85**	**17.5**	**38.5**	**44**	**31**	**2.32**	**16**	**37.3**
19	**35**	**25**	**2.85**	**30**	**34.6**	**55**	**26**	**2.24**	**21**	**38**
20	**67.5**	**25**	**2.85**	**17.5**	**37.7**	**86**	**18**	**0.57**	**17**	**34.3**
21	**100**	**25**	**2.85**	**5**	**38.1**					
22	**35**	**40**	**2.85**	**17.5**	**41**					
23	**67.5**	**25**	**5.69**	**5**	**30.3**					
24	**67.5**	**40**	**2.85**	**5**	**37.2**					
25	**67.5**	**10**	**5.69**	**17.5**	**29.9**					
26	**67.5**	**25**	**2.85**	**17.5**	**37.3**					
27	**35**	**25**	**5.69**	**17.5**	**32.8**					
28	**35**	**25**	**2.85**	**5**	**33.5**					
29	**100**	**25**	**2.85**	**30**	**39.2**					

Abbreviations: exp, experimental; pred, predicted; Tem, temperature; Pre, pressure; Pt, press time

The ANOVA of LHD reveals similar findings to the earlier explanation mentioned for BBD in this work. The LHD model is significant and explains variancebetter than BBD for its larger model F-value. The Sum of Square (SS) of the model reveals that LHD is better in estimating variables effect,but it cannot estimate the pure error in modeling due to the absence of repeatability. Models lack fit for excess points beyond model terms [35].Both ANOVA results agree that pressure is highly significant and MC is the least significant to oil yield andall process variables have a similar characterization effect on oil yield. It is observed that variables with higher significance tend to decline the effect shortly.

Response surface quadratic model equations (Eq. 3 and Eq. 4) were constructed from the regression model of oil extraction show inrelationship between process variables. Eq. 3 belongs to BBD model and Eq. 4. belongs to LHD model.The equation, oil yield (Y), constitutes 4-variables (A, B, C, and D) representing temperature, pressure, MC, and press time. In the equation, as the Y value increases, the factors approach the asymptotic condition and get an optimum point where no more oil can be extracted. The maximum extracted oil of 41.11% was obtained at the optimum value of temperature (73 ^{o}C), pressure (37 MPa), moisture (2.6% w.b), and press time (21 min). Previously, the efficiency (20 min) for maximum oil is reported by [7]. In the same manner, pressing time from 20 – 30 min does not significantly increase yield for palm oil, even may lead to a decrease in oil yield [36].The accuracy to which the model predicts oil expressionwas observed fromthe R^2 value of0.87 and RMSE 1.4in BBD whereasthe LHD model has higher prediction efficiency at the R^2 0.98 and RMSE 0.4. The models are effectively descriptive about the relationship between variables and responses.

$$Y\,(\%) = 3.51178 + 0.29479A + 0.56358\mathrm{B} + 5.26369\mathrm{C} + 0.293\mathrm{D} - 0.00328205\mathrm{AB} - 0.015964\mathrm{AC} + 0.0\mathrm{AD} - 0.018805\mathrm{BC} + 0.0036\mathrm{BD} - 0.039453\mathrm{CD} - 0.000766075A^2 - 0.0015963\mathrm{B}^2 - 0.4921\mathrm{C}^2 - 0.00405867\mathrm{D}^2 \qquad \text{Eq. 3}$$

$$Y(\%) = 7.46238 + 0.35404A + 0.35276\mathrm{B} + 4.63017\mathrm{C} + 0.28360\mathrm{D} - 0.000763334\mathrm{AB} - 0.022946\mathrm{AC} + 0.001.77764\mathrm{AD} - 0.037501\mathrm{BC} + 0.00243494\mathrm{BD} - 0.0004822.84\mathrm{CD} - 0.00203091\mathrm{A}^2 + 0.000172903\mathrm{B}^2 - 0.30384\mathrm{C}^2 - 0.010068\mathrm{D}^2 \qquad \text{Eq. 4}$$

Table-2: ANOVA of BBD and LHD response model.

Source	BBD			LHD		
	SS	F-Value	p-value	SS	F-Value	p-value
Model	422.29	6.84	0.0005	169.67	18.5	0.0023
A-temperature	51.75	11.74	0.0041	1.21	1.84	0.2327
B-pressure	199.36	45.21	< 0.0001	23.03	35.15	0.0019
C-MC	4.94	1.12	0.3077	1.19	1.82	0.2351
D-press time	31.1	7.05	0.0188	5.84	8.92	0.0306
AB	10.24	2.32	0.1498	0.015	0.023	0.8855
AC	8.71	1.98	0.1816	0.56	0.86	0.3972
AD	0	0	1	0.17	0.26	0.6293
BC	2.58	0.58	0.4574	0.3	0.46	0.5259
BD	1.82	0.41	0.5307	0.11	0.16	0.7019
CD	7.87	1.79	0.2028	6.79E-03	0.01	0.9229
A^2	4.25	0.96	0.3431	1.35	2.06	0.2103
B^2	0.84	0.19	0.6698	5.51E-04	8.40E-04	0.978
C^2	102.91	23.34	0.0003	2.81	4.29	0.0931
D^2	2.61	0.59	0.4546	1.96	2.99	0.1444
Residual	61.74			3.28		
Lack of Fit	60.38	17.87	0.0068			
Pure Error	1.35					
Cor Total	484.03			172.95		

Comparison of Experiment Designs

The experiment designs were evaluated based on the design suitability, appropriateness, and accuracy in modeling data for the oil extraction process. Table 3 shows the frequency statistics summary of the comparison between LHD and BBD physical data.Data is tested by data distribution, central tendency, dispersion, and normality. Data normality was observed from standard error of skewness (SES) 0.434/0.512 for BBD/LHD and standard error of kurtosis (SEK) 0.845/0.992 for BBD/LHD, respectively. The values of skewness and kurtosis are normality indicators [37]. Normality is about sample estimation from the variables range. In this way, BBD has better skewness and kurtosis for independents but hasa larger Standard Error Mean (SEM) becauseany BBD has three levels. In another way, LHD has as many levels as the number of runs(n=20) that arenot accumulated at the center, upper or lower ends. Due to this reason, experiments with LHD can help predict the corner space that usually difficult to reach outby BBD in the experiment.

Table-3: Frequency statistics comparison summary for LHD and BBD data.

	Factor	SEM	Std. dev	Skewness	SES	Kurtosis	SEK	Range	Min	Max
LHD	Temperature	4.292	19.195	0.057	0.512	-1.221	0.992	61	38	99
	Pressure	2.016	9.016	-0.025	0.512	-1.137	0.992	30	10	40
	Mc	0.38309	1.713	0.021	0.512	-1.208	0.992	5.55	0.09	5.64
	Time	1.69	7.559	-0.038	0.512	-1.218	0.992	24	6	30
BBD	Temp	67.5	21.276	0	0.434	-0.459	0.845	65	35	100
	Pressure	25	9.82	0	0.434	-0.459	0.845	30	10	40
	Mc	2.85	1.862	-0.005	0.434	-0.459	0.845	5.69	0	5.69
	Time	17.5	8.183	0	0.434	-0.459	0.845	25	5	30

Abbreviations: SEM, standard error mean; SES, standard error of skewness; SEK, standard error of kurtosis.

During the experiment, LHD has more back-forth machine settings (make the work less efficient) that also may lead to error, but it can give better normal oil yield as shown in Fig. 1. For the observed cases, both methods are sound; it can change inputs variable to observe the effect on response and can be considered as an appropriate method to supply multivariable data for the experiment.

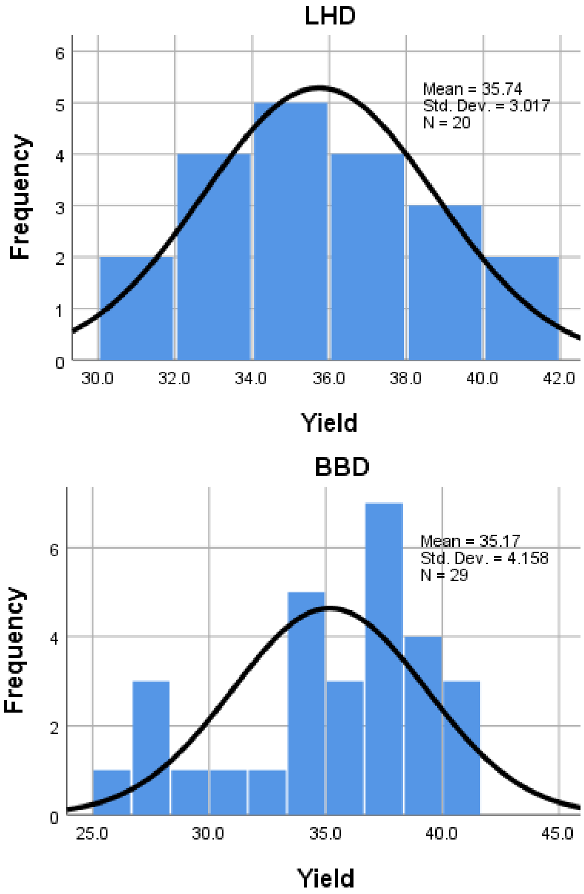

Fig. 1: Histograms of oil yield.

Table 4 shows the comparison of experiment and model results obtained from LHD and BBD methods. Comparison is based on the experiment resultand model accuracy to predict observed oil yield. From the experiment, theratio of space design is 1.57 for BBD and 1.32 for LHD, respectively. This shows more oil yield range extracted belongs to BBD. The larger space is good to view performance range, or in some cases, the study may target to obtain smaller or higher values. The larger range more identifies targets not to be used to get high oil yield.The mean value of experimental oil yield is 35.16% (for BBD) and 35.74% (for LHD) while mean model prediction is 37.55% (for BBD) and 38.18% (for LHD. The maximum extracted oil yield (41%) is located between the model prediction interval (PI). The value is not variable with the methods that show both methods have an agreement on the experimental oil yield and predicted oil yield.

Model predictability can be observed from the R^{2}value [38]. The smaller value of PRESS (Predicted Residual Sum of the Square) indicates the LHD model fits each experimental oil yield ata smallercoefficient variation (CV) of 2.26. Coefficient variation (CV) is the ratio of the standard error estimate to mean of observed response expressed as a percentage [27] and it shouldbe less than 10% to form anadequate response [39].R^{2}should not be less than 0.8% [40]. It is observed R^2 is closer to 1 and CV is small, which indicates models have fulfilled the criteria of reproducibility for precision and reliability of the experiment. Therefore the values of R^2, Adj R^2, and Pred. R^2, PRESS, and CV% confirm that the LHD model has a better prediction for observed oil yield.

Comparatively, BBD suits design more, easier, efficient, and most popular in designing, modeling, and optimizing multivariable processing. LHD is suited to user design options, more flexible but less efficient for the experiment. Researchers usually need a pilot test for their new experiment only with a small sample size to save time. One great advantage of LHD is its flexibility to experiment with sucha small sample size for multiple factors.

Physicochemical property of the oil

The oil quality parameters are determined to check quality at the optimum extraction point. Table 5 shows measured value, codex value, and literature values of oil property and composition. The measured value is performed at the optimum condition. The obtained peroxide value 8 *g/100 g* oil is good to give a better ability to defend rancidity, which is caused when triple oxygen (${}^3O_2$) and single oxygen (${}^1O_2$) react with oil [41]. The acid value of 4 mg KOH/g is below 6 mg KOH/g as recommended and the iodine value (116.9 g/100g) is in the standard range of codex [42]. Acid value and peroxide may increase because triacylglycerol decomposes and oxidizedby pressing temperature, as observed in Torreya Grandis kernel seed reported by [43]. Peroxide value indicates the degree of oxidation and acid value indicates the amount of free fatty acid that represents the most important oil characteristics [44]. The linoleic and oleic make 84% of the total fatty acid composition (FAC). Largely, the seed has similar property and composition with Sudanese cultivars reported by [45]. Overall, the oil propertyand compositionis not affected by the process condition.

Table-4: Comparison of experiments and model results for LHD and BBD methods

	Experiment	Obs	Min	Max	Mean	Std. Dev.	Ratio
Experiment result	BBD Y (%)	29	26	41	35.16	4.15	1.57
	LHD Y (%)	20	31	41	35.74	3.01	1.32
	Response	Mean	Std Dev	SEP	95% PI low	95% PI high	
Model result	BBD Y (%)	37.55	2.0999	2.3	32.62	42.49	
	LHD Y (%)	38.18	0.8094	1	35.59	40.78	
	p-value	p-value	R^2	Adj. R^2	pred. R^2	PRESS	CV %
Accuracy	BBD	0.0005	0.87	0.7449	0.2772	349.84	5.97
	LHD	0.0023	0.98	0.928	0.2898	122.83	2.26

Abbreviation: Obs, observation;SEP, standard error prediction; PI, prediction interval; Y, oil yield; PRESS, predicted residual sum of the square; CV %, coefficient variation of the model

Table-5: Oil property and fatty acid composition.

	Parameters	Codex value [a]	Measured value	Literature [b]
Oil property	Refractive index	1.465 - .469	1.4696±0.001	1.473
	Peroxide (g/100g)	<10 (meq KOH/kg oil)	8±0.01	2.2-9.1
	Acid value (mg/g)	6 mg KOH/g Oil	4.98±0.05	3.1-6.6
	Iodine value (g/100g)	104-120	116.99 ± 0.47	101.1-114.8
FAC	Palmitic	7.9-12	9.53±0.2	12.9 ± 0.06
	Linoleic	41.5-47.9	41.87±0.2	36.4 ±0.05
	Oleic	35.9-42.3	42.27±0.52	47.5 ±0.02
	Stearic	4.8-6.1	5.58±0.2	3.00 ±0.07

Sources: [a]Codex Alimentarius (2001), [b]Khier et al. (2008).

Conclusions

In this study,the empirical comparison test has been successfully conducted between LHD and BBD interms of process designing, modeling, and performanceof a range of oil extraction. The result shows that the way the data generated are statistically different, but the experimental oil yield and its corresponding model prediction output does not significantly vary with the methods. Both methods are good enough to provide data for the application of multivariable processes. LHD has a great advantage for a multivariable experiment of any size; the model also has better response estimation than the BBD model. It is observed that BBD is more appropriateto design, easier, efficient, andmost popular in designing, modeling, and optimization of multivariable processing. LHD is suitedto user design options, more flexible, more accurate, and less efficient than BBD in practical application.Thus, the study demonstrated that BBD experiment method is more suitable and approperiate for this study than LHD method.

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