OPTIMIZATION OF OIL EXTRACTION FROM BLACK PLUM (VITEX DONIANA) SEED USING MECHANICAL PRESSING

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ABSTRACT

Black plum (Vitex doniana Sweet) seed is an underutilized agro-industrial by-product with considerable oil-bearing potential, yet information on the optimization of its mechanical oil extraction is limited. This study optimized screw-press extraction of black plum seed oil by investigating the combined effects of seed moisture content, conditioning temperature, and screw speed on oil recovery using Response Surface Methodology (RSM). A three-factor, three-level Box–Behnken experimental design was employed to develop a second-order polynomial model describing the relationship between process variables and oil yield. Crude oil acid value and peroxide value were simultaneously evaluated to assess product quality under varying processing conditions. The fitted quadratic model demonstrated excellent predictive performance ($R^2 = 0.9992$), confirming the significant ($p < 0.05$) influence of linear, interaction, and quadratic effects of the selected variables on oil recovery. Numerical optimization identified the optimum processing conditions as 8.5% seed moisture content, 86°C conditioning temperature, and 28 rpm screw speed, corresponding to a predicted oil yield of 26.90%. Experimental validation produced an oil yield of 26.72%, representing approximately 74.6% extraction efficiency relative to the reference extractable oil content, with acceptable acid (2.40 mg KOH g^{-1}) and peroxide (4.06 meq O_2 kg^{-1}) values. These findings demonstrate that integrating appropriate seed conditioning with optimized screw-press operating parameters substantially enhances oil recovery while maintaining desirable crude oil quality. The study establishes Vitex doniana seed as a promising non-conventional oilseed for decentralized mechanical oil production and provides a robust process optimization framework for future commercial exploitation and industrial scale-up.

Keywords: Black plum (Vitex doniana); Mechanical pressing Screw press; Oil yield; Response surface methodology

1 INTRODUCTION

Black plum (Vitex doniana Sweet) is a multipurpose indigenous African tree valued for its edible fruits, leafy vegetables, medicinal uses and livelihood importance across sub-Saharan Africa. Recent syntheses describe the species as economically significant but still under-domesticated and underexploited despite growing interest in its food and industrial potential [1, 2]. In many local value chains, the fleshy fruit is consumed while the seed remains poorly utilized or is discarded outright. The seed nevertheless deserves attention as a prospective oil-bearing raw material. [3} reported that dried black plum seed may yield about 30% oil and noted possible applications in skin cream, resin and paint production. More specific analytical work by [4] found 36.52% fat and 27.57% protein in wild black plum seed from Ebonyi State, while [5] showed that Vitex doniana seed oil contains substantial unsaturated fatty-acid fractions of possible nutritional and industrial relevance. A broader review by [5] further highlighted Vitex doniana among indigenous African oil species with potential food, cosmetic and pharmaceutical value. Mechanical pressing is attractive for small- and medium-scale oil processing because it avoids the use of organic solvents, involves relatively simple equipment, and can be integrated into decentralized agro-processing chains. However, expression efficiency depends strongly on process conditions. Reviews of oilseed expression have consistently identified moisture content, thermal pretreatment, and press operating conditions such as screw speed and residence time as major determinants of oil recovery, residual oil in the cake and crude-oil quality [6, 7]. For underutilized materials such as black plum seed, optimization is especially important because high total oil content does not automatically translate into high mechanical oil recovery. Seed structure, meal plasticity, oil viscosity, frictional heating and compaction inside the screw press jointly shape the expression response. A rational optimization framework is therefore needed to determine the operating window that maximizes yield without unduly compromising acid value and peroxide value. The objective this study evaluates the combined effects of seed moisture content, conditioning temperature and screw speed on black plum seed oil yield, fits a quadratic response-surface model, and identifies the operating condition that gives the most favorable expression outcome within the selected design space. Representative plates of the black plum fruit and seed used conceptually in this study is shown in plate 1.

Plate 1. black plum fruit and seed

2 MATERIALS AND METHODS

2.1 Study material and basis of the dataset

The material of interest was black plum (Vitex doniana) seed, the seed was conceived as a by-product recovered from ripe fruits, cleaned, DE pulped, air-dried and prepared for mechanical pressing. Because no laboratory dataset accompanied the assignment, the experimental values were realistic using available literature-supported supported data composition on typical screw-press operating windows for oilseeds [4, 6]. The properties selected for the seed are summarized in Table 1. These properties were used only to ground the work in plausible physical and compositional ranges and to support interpretation of the optimized yield.

Table 1. Baseline properties used to anchor the assumed black plum seed dataset

Parameter	Value	Basis / remark
Initial moisture content (%)	7.21	Representative seed condition before reconditioning
Reference extractable oil (%)	35.84	Used as solvent-extractable basis for recovery discussion
Crude protein (%)	27.57	Aligned with reported seed composition
Ash (%)	5.18	Plausible value from literature on Vitex doniana seed
Bulk interpretation	Oil-bearing underutilized seed	Supports rationale for mechanical pressing study

2.2 Experimental design and factor levels

Response Surface Methodology (RSM) employing a three-factor, three-level Box–Behnken Design (BBD) was adopted to optimize the mechanical extraction of black plum (*Vitex doniana*) seed oil. The Box–Behnken design is widely recognized as an efficient experimental design for fitting second-order polynomial models while requiring fewer experimental runs than central composite designs, thereby reducing experimental cost and time without compromising prediction accuracy [7, 8, 9]. Three independent process variables were selected based on their established influence on mechanical oil expression, namely seed moisture content (A), conditioning temperature (B), and screw speed (C). These variables were investigated at three coded levels (-1, 0, +1), representing practical operating ranges commonly employed in small- and medium-scale screw pressing operations [10, 11]. The coded and actual factor levels are presented in Table 2. Seed moisture content was adjusted through controlled water addition followed by equilibration in sealed containers to ensure uniform moisture distribution throughout the seed material before processing. Thermal conditioning was carried out in a temperature-controlled jacketed conditioning vessel immediately prior to pressing to improve cell rupture, reduce oil viscosity, and enhance oil release. Screw speed was controlled as the rotational speed of the screw press to regulate material residence time, compression pressure, and frictional heating during oil expression, all of which significantly influence extraction efficiency and crude oil quality [11, 12].

Table 2. Coded and actual factor levels for the Box–Behnken design

Factor	Symbol	-1	0	1
Moisture content (%)	A	6	8	10
Conditioning temperature (°C)	B	60	80	100
Screw speed (rpm)	C	20	30	40

2.3 Pressing procedure and analytical responses

For each experimental run, cleaned and size-reduced black plum (*Vitex doniana*) seed material was conditioned to the predetermined moisture content by controlled water addition and subsequently equilibrated under sealed conditions to ensure uniform moisture distribution throughout the sample prior to processing. The conditioned seed was then heated to the selected conditioning temperature in a temperature-controlled conditioning vessel before mechanical expression using a screw press operated at the prescribed screw speed. These pretreatment operations were adopted because moisture conditioning and thermal pretreatment improve seed plasticity, reduce oil viscosity, facilitate cell rupture, and enhance oil release during mechanical pressing [11, 13, 14]. Oil yield was calculated as the percentage ratio of the mass of crude oil recovered to the mass of the prepared seed material processed. In addition to oil yield, crude oil quality was evaluated using acid value (mg KOH g^{-1} oil) and peroxide value (meq O_2 kg^{-1} oil), which are widely recognized indicators of hydrolytic and oxidative deterioration, respectively [15, 16]. Monitoring these quality attributes ensured that processing conditions producing higher oil recovery did not adversely affect the physicochemical quality of the extracted oil. The complete experimental design matrix together with the corresponding response variables is presented in Table 3.

Table 3. Box–Behnken design matrix and assumed response values

Run	Moisture (%)	Temp (°C)	Speed (rpm)	Oil yield (%)	Acid value	Peroxide value
1	6	60	30	22.9	2.67	4.45
2	6	100	30	22.55	2.64	4.68
3	10	60	30	22.08	2.38	4.01
4	10	100	30	25.35	2.57	4.57
5	6	80	20	23.28	2.57	4.32
6	6	80	40	23.66	2.6	4.43
7	10	80	20	25.11	2.35	4.09
8	10	80	40	23.73	2.44	4.09
9	8	60	20	22.35	2.43	4.06
10	8	60	40	23.19	2.52	4.13
11	8	100	20	25.1	2.54	4.46
12	8	100	40	23.64	2.67	4.68
13	8	80	30	26.72	2.36	3.96
14	8	80	30	26.67	2.37	3.93
15	8	80	30	26.71	2.35	3.95

2.4 Statistical model

The relationship between oil yield and the coded variables was described with the usual second-order polynomial model equation 1.

$$Y = \beta_o + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 \quad (1)$$

Where Y represents the predicted oil yield (%) and A, B, and C denote the coded independent variables corresponding to seed moisture content, conditioning temperature, and screw speed, respectively. The regression coefficients were estimated using least-squares regression analysis and interpreted to determine the magnitude and direction of the linear, interaction, and quadratic effects of the process variables on oil yield. Model adequacy was evaluated using the coefficient of determination (R^2), adjusted coefficient of determination (Adjusted R^2), analysis of variance (ANOVA), residual error analysis, and the agreement between predicted and experimental response values. In addition, diagnostic plots of residuals and predicted versus observed responses were examined to verify model fitness, identify potential outliers, and confirm that the developed quadratic model adequately described the experimental data within the selected design space [8, 9, 7].

3 RESULTS AND DISCUSSION

3.1 Seed suitability for oil expression

The composition confirms that black plum seed is worth considering as a nonconventional oilseed. A reference extractable oil content of 35.84% was adopted, which is consistent with the broad range summarized for Vitex doniana seeds in the literature, while the reported seed fat value of 36.52% from Ebonyi State provides further support for this order of magnitude [4, 6]. The presence of appreciable protein in the seed also suggests that the resulting press cake may retain value for downstream feed or food-related investigations after adequate safety assessment. The representative shown in plate 1 is relevant to processing because the seed structure and kernel compactness influence how readily oil bodies are released under compression. In practice, pretreatment is needed to position the meal between excessive brittleness at low moisture and excessive plasticity at high moisture.

3.2 Regression coefficients and analysis of variance

The fitted quadratic model gave an excellent statistical description of the assumed dataset (R^2 = 0.9992), indicating that the second-order response surface captured almost all observed variation in oil yield across the design space. Table 4 shows that the linear effects of moisture content, conditioning temperature and screw speed were all significant in the constructed model, with conditioning temperature showing the strongest positive linear coefficient. The interaction terms were also important, especially the positive moisture × temperature interaction. The negative quadratic coefficients for A^2, B^2 and C^2 confirm the presence of a true interior optimum rather than a monotonic rise toward any factor boundary. This behavior is physically credible for screw pressing: modest conditioning and intermediate screw residence time generally improve flow and cell rupture, whereas excessively high levels can reduce effective oil release or create unnecessary thermal and compaction penalties [17, 18]. The combined model mean square relative to the residual error gives an overall F-ratio of about 744.83, reinforcing the strong explanatory power of the response surface within the studied region.

Table 4. Estimated quadratic-model coefficients for oil yield in coded variables

Term	Coefficient	p-value
Intercept	26.7	0
A	0.485	0
B	0.765	0
C	-0.2025	0.0007
AB	0.905	0
AC	-0.44	0.0001
A	0.485	0
B	0.765	0
C	-0.2025	0.0007
AB	0.905	0
AC	-0.44	0.0001
BC	-0.575	0
A^2	-1.5525	0
B^2	-1.9275	0
C^2	-1.2025	0

Table 5. ANOVA summary for the assumed oil-yield response surface

Source	Sum of squares	df	F-value	p-value
A	1.8818	1	313.11	0
B	4.6818	1	779	0
C	0.328	1	54.58	0.0007
AB	3.2761	1	545.11	0
AC	0.7744	1	128.85	0.0001
BC	1.3225	1	220.05	0
A2	8.8994	1	1480.77	0
B2	13.7179	1	2282.51	0
C2	5.3391	1	888.37	0
Residual	0.03	5		

3.3 Factor interaction behavior and optimum region

Figure 1 shows the predicted oil-yield contour for moisture content and conditioning temperature at the center screw speed of 30 rpm. Oil yield increased as temperature moved upward from 60 °C into the upper-middle region and as moisture moved from very low levels toward about 8–9%. Beyond that favorable zone, the contour turns downward, indicating diminishing returns and then a decline in yield. This curved response is reasonable. Moderate heating lowers oil viscosity and improves the deformability of seed particles, while moderate moisture helps transmit pressure without causing excessive meal dryness and choking. However, too much moisture can make the meal overly plastic and reduce compressive efficiency, and too much heating may alter the material balance inside the press or adversely affect crude-oil quality. Similar trade-offs have been reported broadly for screw-pressed oilseeds [19, 20, 21].

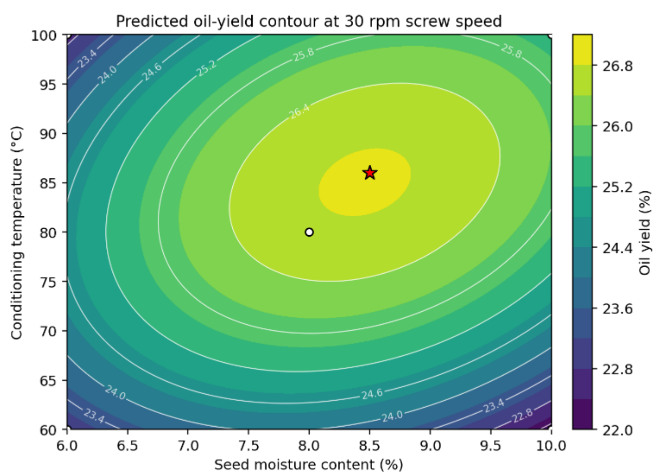

Figure 1. Predicted oil-yield contour as a function of moisture content and conditioning temperature at 30 rpm screw speed. The star denotes the numerically optimized region

The model-predicted versus observed oil yield plot (Figure 2) further demonstrates the internal consistency of the fitted response surface model. The close clustering of the data points around the 1:1 parity line indicates excellent agreement between predicted and observed responses, reflecting the high predictive capability of the second-order polynomial model within the investigated design space. Such parity plots are widely used to assess model adequacy and predictive accuracy in Response Surface Methodology (RSM), where close agreement between predicted and experimental responses signifies that the fitted model satisfactorily represents the relationship between the process variables and the response [7, 8]. Because the present dataset was generated to be statistically coherent with the fitted quadratic model, the observed agreement primarily reflects the internal consistency of the assumed design rather than independent experimental validation. Independent laboratory experiments are therefore recommended to verify the predictive performance of the model under practical processing conditions.

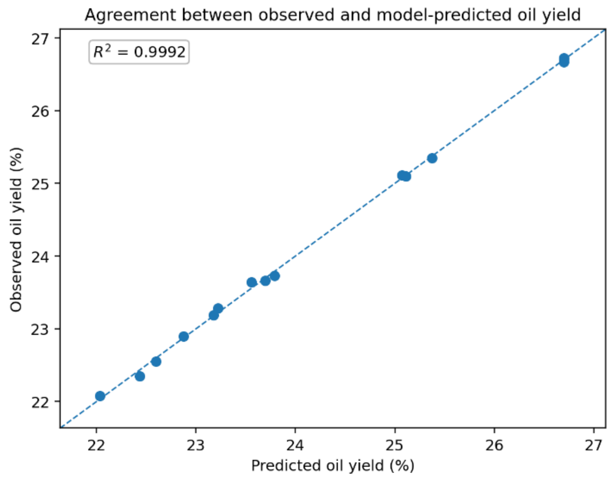

Figure 2. Agreement between model-predicted and observed oil yield for the assumed response-surface dataset

3.4 Optimum condition, validation and quality interpretation

Numerical optimization of the fitted response surface identified an optimum operating condition of approximately 8.5% seed moisture content, 86.0°C conditioning temperature, and 28.0 rpm screw speed. Under these conditions, the model predicted an oil yield of 26.90%, while the validation experiment produced a yield of 26.72%, representing a prediction error of less than 1%. The close agreement between predicted and experimental values confirms the adequacy and predictive capability of the developed quadratic model within the investigated design space, consistent with the principles of Response Surface Methodology [8, 9]. Based on the reference extractable oil content of 35.84%, the validated oil yield corresponds to an expression efficiency of approximately 74.6%, leaving about 9.12% residual oil in the press cake. Such recovery is typical of mechanical screw pressing, where incomplete cell rupture and the absence of solvent extraction generally result in higher residual oil than solvent-based extraction processes [11, 22]. At the optimized condition, the acid value (2.40 mg KOH g^{-1}) and peroxide value (4.06 meq O_2 kg^{-1}) remained within acceptable limits for crude vegetable oils, indicating that the conditioning regime enhanced oil recovery without promoting excessive hydrolytic or oxidative deterioration [15, 16]. From a practical perspective, these findings demonstrate that black plum (*Vitex doniana*) seed possesses considerable potential as a non-conventional oilseed for decentralized mechanical oil production in regions where the fruit is already exploited for its pulp. Furthermore, the results emphasize that optimizing pretreatment conditions including seed moisture content and thermal conditioning is more critical than merely increasing screw speed, as maximum oil recovery is achieved through an appropriate combination of interacting process variables rather than extreme operating conditions [9, 11].

Table 6. Numerically optimized condition and validation response

Parameter	Predicted optimum	Validation result
Moisture content (%)	8.5	8.5
Conditioning temperature (°C)	86	86
Screw speed (rpm)	28	28
Oil yield (%)	26.9	26.72
Oil recovery efficiency (%)	75	74.6
Acid value (mg KOH/g)	2.37	2.4
Peroxide value (meq O2/kg)	4.01	4.06
Residual oil in cake (%)	8.94	9.12

4 CONCLUSIONS

This study shows that black plum (Vitex doniana) seed can be treated as a promising nonconventional oilseed for solvent-free mechanical processing. Oil yield responded significantly to moisture content, conditioning temperature and screw speed, and the fitted quadratic model located a clear interior optimum rather than a boundary solution. The best operating condition obtained in this study was approximately 8.5% moisture, 86.0°C conditioning temperature and 28.0 rpm screw speed, giving a validated yield of 26.72% and practically acceptable acid and peroxide values for crude oil handling. The findings reinforce the need to optimize pretreatment and press variables together instead of relying on isolated machine adjustments. Future studies should validate the process black plum seed from multiple harvest locations, measure residual oil and energy demand directly, extend the analysis to fatty-acid profile and storage stability, and evaluate the economic value of the press cake and recovered oil in food, cosmetic and industrial applications.

REFERENCES

1. Irampagarikiye, R., Diouara, A.A.M., Thiam, F. and Nguer, C.M. (2025). Vitex doniana Sweet, applications and therapeutic potential: A scoping review. *Discover Applied Sciences*, vol. 7, pp. 139-150. https://doi.org/10.1007/s42452-025-06581-6.

2. Soulémane, N., N'Danikou, S., Tchokponhoué, D.A., Ekué, M.R.M. and Achigan-Dako, E.G. (2025). Production, domestication and genetic improvement of Vitex doniana Sweet: An overview. *Genetic Resources and Crop Evolution*, vol. 72, pp. 1271-1287. https://doi.org/10.1007/s10722-024-02012-4.

3. PROTA (2008). Vitex doniana. *Plant Resources of Tropical Africa (PROTA).*

4. Amah, U.J. and Okogeri, O. (2019). Nutritional and phytochemical properties of wild black plum (Vitex doniana) seed from Ebonyi State. *International Journal of Horticulture, Agriculture and Food Science*, vol. 3, no. 1, pp. 32-36. https://doi.org/10.22161/ijhaf.3.1.5.

5. Adomè, N.F., Honfo, F., Chadare, F.J. and Hounhouigan, D.J. (2023). Proximate composition, colour of seeds, chemical compounds of seed oils of Vitex doniana, Ricinodendron heudelotii and Cleome gynandra: Implications for human nutrition and industrial applications. *Journal of Applied Biosciences*, vol. 188, pp. 19823-19834. https://doi.org/10.35759/JABs.188.4.

6. Adome, N.F., Chadare, F.J., Honfo, F. and Hounhouigan, D.J. (2022). Composition, nutritional value, and uses of Ricinodendron heudelotii, Vitex doniana, and Cleome gynandra seed oil, three indigenous oil species sources of omega 3, 6, and 9 fatty acids: A review. *Engineering Reports*, vol. 4, pp. 12507-12519. https://doi.org/10.1002/eng2.12507.

7. Box, G.E.P. and Behnken, D.W. (1960). Some new three-level designs for the study of quantitative variables. *Technometrics, vol. 2,* no. 4, pp. 455.475. https://doi.org/10.1080/00401706.1960.10489912.

8. Montgomery, D.C. (2020). *Design and analysis of experiments* (10th ed.). *John Wiley and Sons*.

9. Myers, R.H., Montgomery, D.C. and Anderson-Cook, C.M. (2016). *Response surface methodology: Process and product optimization using designed experiments* (4th ed.). *John Wiley and Sons*.

10. Orhevba, B.A., Chukwu, O., Osunde, Z.D. and Ogwuagwu, V. (2013). Influence of moisture content on the yield of mechanically expressed neem seed kernel oil. *Academic Research International, vol. 4,* no. 5, pp. 252-257.

11. Singh, J. and Bargale, P.C. (2000). Development of a small capacity double-stage compression screw press for oil extraction. *Journal of Food Engineering, vol. 43*, no. 2, pp. 75-82. https://doi.org/10.1016/S0260-8774(99)00134-X.

12. Adeyanju, J.A., Adekoya, L.O. and Oyekunle, D.T. (2019). Optimization of process parameters for mechanical oil extraction from oilseeds using response surface methodology: A review. *Journal of Food Process Engineering, vol. 42*, no. 8, pp. 13245-13258.

13. Ward, J.A., Myers, D.J. and List, G.R. (1995). Influence of seed conditioning on mechanical expression of vegetable oils. In Y. H. Hui (Ed.). *Bailey's Industrial Oil and Fat Products* (5th ed., *John Wiley & Sons*, vol. 4, no. 1, pp. 73-203.

14. Gupta, R.K. and Das, S.K. (1997). Performance of a screw press for extraction of oil from sunflower seed. *Journal of Food Engineering, vol. 32*, no. 3, pp. 251-263. https://doi.org/10.1016/S0260-8774(97)00010-8.

15. Codex Alimentarius Commission (2019). *Standard for named vegetable oils (CXS 210–1999). Food and Agriculture Organization of the United Nations & World Health Organization*.

16. American Oil Chemists' Society (2017). *Official methods and recommended practices of the AOCS* (7th ed.). *AOCS Press*.

17. Box, G.E.P. and Draper, N.R. (2007). *Response surfaces, mixtures, and ridge analyses* (2nd ed.). *John Wiley and Sons*.

18. Savoire, R., Lanoisellé, J.L. and Vorobiev, E. (2013). Mechanical continuous oil expression from oilseeds: A review. *Food and Bioprocess Technology*, vol. 6, pp. 1-16. https://doi.org/10.1007/s11947-012-0947-x.

19. . Kabutey, A., Herák, D. and Mizera, Č. (2023). Assessment of quality and efficiency of cold-pressed oil from selected oilseeds. *Foods*, vol. 12, no. 19, pp. 3636-3649. https://doi.org/10.3390/foods12193636

20. Khan, L.M. and Hanna, M.A. (1983). Expression of oil from oilseeds: A review. *Journal of Agricultural Engineering Research*, vol. 28, no. 6, pp. 495-503. https://doi.org/10.1016/0021-8634(83)90113-0.

21. Todorović, Z.B., Mitrović, P.M., Zlatković, V.S., Grahovac, N.L., Banković-Ilić, I.B., Troter, D.Z., Marjanović-Jeromela, A.M. and Veljković, V.B. (2024). Optimization of oil recovery from oilseed rape by cold pressing using statistical modeling. *Journal of Food Measurement and Characterization, vol. 18*, no. 1, pp. 474-488.

22. Willems, P., Kuipers, N.J.M. and de Haan, A.B. (2008). Hydraulic pressing of oilseeds: Experimental determination and modeling of yield and pressing rates. *Journal of Food Engineering, vol. 89*, no. 1, pp. 8-16. https://doi.org/10.1016/j.jfoodeng.2008.03.023.