

Optimization of *Jatropha (Gossypifolia Linneus)* Seed Oil Extraction Using Microwave and Ultrasonic Pretreatment

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ABSTRACT

Oil extraction using *Jatropha gossypifolia* linnues seeds is also becoming an important issue, which needs to be optimized to enhance the efficiency of biodiesel feedstock and the sustainability of the process as a whole. It is the research of the impact of microwave and ultrasonic pretreatment methods on the yield of oil extraction within the purpose to define the optimum operating conditions and compare the performance of these techniques related to the efficiency of their operation, the amount of energy used, and the quality of oils. The research studies were carried out at diverse temperatures (40-80°C) and exposure durations (15-45 minutes) and Response Surface Methodology (RSM) was used to simulate and optimize the extraction process. The findings indicated that both pretreatment procedures were found to significantly increase the recovery of oil in comparison to untreated seeds (27.43%). Microwave pretreatment recorded a maximum yield of 30.56% at 80°C in 15 minutes, which is equivalent to an equivalent improvement of 11.41, and ultrasonic pretreatment recorded a higher yield of 32.18% at 80°C in 30 minutes, which is equivalent to an increase of 17.32%. ANOVA statistical analysis revealed significant effects of temperature, time and their interaction on the extraction yield ($p < 0.05$) where temperature had the most significant effect. Optimized parameters of the RSM were 76.4°C in 18.2 min in case of micro wave pretreatment and 78.3°C in 32.5 min in case of ultrasonic pretreatment with prediction error of less than 1%, which is a high degree of model reliability. Mechanically, the microwave pretreatment was more effective in oil extraction because it increases the release of oil by means of dielectric heating and internal cell rupturing, whereas the ultrasonic pretreatment uses a combination of thermal and cavity disruption to increase the effectiveness of the extraction. Besides increased yield, oil of better quality was obtained under ultrasonic pretreatment, which had a low acid value and free fatty acid content. Despite the fact that ultrasonic pretreatment also needed more energy input, economic evaluation showed that the extra oil recovered compensated the extra energy expense making it to generate more net revenue than microwave pretreatment.

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KEYWORDS: *Jatropha seed, Ultrasonic, Microwave, Fuel, Pretreatment.*

INTRODUCTION

The growing energy demand in the world today and the dwindling quantity of fossil fuels along with the increased environmental issues has been a catalyst in the demand of alternative sources of energy that are

sustainable and renewable. The world still depends mostly on fossil fuel as a source of energy, but the usage of fossil fuel continues to contribute to the emission of greenhouse gases and climatic changes

and also to the degradation of the environment. In reaction, biofuels can be considered as a potential alternative to the problem because they are renewable, bio-degradable and may decrease carbon emissions.

Biodiesel among the other possible biofuel options has received a lot of attention as a possible alternative to the traditional diesel fuel. As a rule, biodiesel is manufactured by transesterifying vegetable oils, animal fats or waste oils. The choice of appropriate feedstock is the key to the sustainable production of biodiesel as it directly affects the quality of fuels, the economical feasibility of the production and the environment. Other seeds of oil, especially those that do not compete with food crops are gaining popularity as sources of biodiesel production.

Jatropha gossypifolia is a non-edible oil crop that has received increased attention because of its ability to grow in marginal soils, the low cultivation inputs and a relatively high percentage of oil in the seeds. This plant has high amounts of oil in its seeds hence it is a promising candidate in the production of biodiesel. Nonetheless, the effective extraction of oil in the *Jatropha* seeds is a critical issue that most of the conventional ways of extracting the oil end in a low yield and high cost of processing.

Pretreatment methods have been cited as good measures of improving the efficiency of oil extraction. Microwave and ultrasonic pretreatment methods have demonstrated a lot of potential among them. Microwave pretreatment is done by dielectric heating that results in the rapid internal heating and cell rupture hence releasing the oil. Conversely, ultrasonic pretreatment involves the use of acoustic cavitation which produces microbubbles which burst violently and break down cell structures, improving the transfer of mass and oil recovery.

Although the apparent benefits of these methods have been reported, a comparative study of the two methods has rarely been conducted with respect to *Jatropha gossypifolia* seeds specifically under the microwave and ultrasonic pretreatment. Moreover, optimization of operating conditions i.e. temperature, exposure time is also necessary to obtain maximum yield of oil with minimized use of energy and also to retain oil quality

MATERIALS AND METHODS

3.1. Materials

Jatropha gossypifolia seeds of advanced age were collected in Zunnurain farm. Hand cleaning was done to eliminate dirt, stones and other foreign material in the seeds. The chemicals employed in conducting this research such as n-hexane (analytical grade) used in

extracting oil, and so on were obtained in standard chemical sources and they were not purified. Where needed, distilled water was applied during the experiment processes.

3.2. The sample was prepared following the procedure previously described, and preconditioning was carried out prior to the study.

The seeds were hand cleaned to eliminate foreign substances and then dehulled to bring out the kernels. The drying of kernels was done in the oven at $60 \pm 2^\circ\text{C}$ during 24 h to eliminate moisture levels and enzymatic decay as is advised in oilseed processing (Pradhan et al., 2011). To achieve a homogenous particle size (below 2 mm), the dried samples were milled and sieved to increase the penetration of solvent and mass transfer during extraction (Sayyar et al., 2011). The samples were prepared and kept in airtight samples under ambient temperatures before analysis.

3.3. Design/Statistical Framework Experimental Design

Two factor, three-level, factorial type of design was utilized first to test the impact of temperature (40-80^oC) and exposure time (15-45 min) on the extraction yield of oils. Response Surface Methodology (RSM) that utilises a Central Composite Design (CCD) was then used to model the process to identify the best operating conditions.

The reason RSM is highly applicable to optimization of processes during biofuels production is that it can be used to consider the effects of interactions and minimize experimental runs (Rodrigues et al., 2016). Experimental data was modeled to a second order regression model on a form of a polynomial;

$$Y = \beta_0 + \beta_1T + \beta_2t + \beta_{11}T^2 + \beta_{22}t^2 + \beta_{12}Tt$$

An evaluation of model adequacy was done based on coefficient of determination (R^2), adjusted R^2 , and ANOVA at a 95% confidence level.

3.4. The Following is the Procedure of Microwave Pretreatment

Sample pretreatment in a laboratory microwave system (frequency: 2.45 GHz, power: 800-1000 W) was performed using microwaves. The specified samples were prepared and subjected to controlled microwave at a given temperature and time to about 50g.

Microwave heating involves dielectric polarization of polar molecules resulting in the faster internal heating and rupture of cells walls, and increased oil release (Sayyar et al., 2011; Khater et al., 2024). Intermittent

irradiation cycles and continuous monitoring were used to control the temperature.

Samples were cooled in a desiccator after pretreatment and then extracted.

3.5. Ultrasonic Pre-treatment Process

An ultrasonic bath (frequency: 20-40 kHz; power: 200-500 W) was used to carry out ultrasonic pretreatment. Samples were placed in n-hexane, and they were subjected to controlled conditions in terms of temperature and time.

Acoustic cavitation is triggered by ultrasonic waves, which form microbubbles, which rupture and create high localized temperatures and pressures that destroy cell structures and increase the mass transfer rate (Chemat et al., 2017; Khater et al., 2024). This mechanism is important because it is efficient in recovery of oil as opposed to traditional mechanisms.

3.6. Solvent Extraction Used to Extract Oil

The process of oil extraction was conducted by a Soxhlet apparatus in compliance with the procedures of lipid recovery (AOAC, 2019). About 20g of a pretreated sample was shaken using n-hexane during 6 h.

After extraction, a rotary evaporator was used to withdraw the solvent followed by eliminating any remaining solvent through an oven dryer at 60°C. The oil production was computed as:

$$\text{Oil Yield (\%)} = W_o / W_s \times 100$$

It is a well-established technique, which has proved to be reliable and efficient in the determination of total extractable oil content (Ofori-Boateng et al., 2012).

3.7. Physicochemical Characterization of Extracted Oil

The quality parameters of the extracted oil were determined by conventional means:

Acid Value (AV): A value obtained as a result of titration of KOH, in accordance with AOAC standards (AOAC, 2019).

Free Fatty Acid (FFA): This is expressed as a percentage of oleic acid equivalent.

These are important parameters of quality and aptness of oil to be used in biodiesel manufacturing (Achten et al., 2007).

3.8. Statistical Analysis

Analysis of variance (ANOVA) was used to identify the degree of significance of main and interaction effects on experimental data. The level of significance of p was set to < 0.05.

The interaction between variables was plotted in the form of response surface plots. The statistical analysis was conducted with the help of common statistical software which included Design-Expert or Minitab which is usually used in the case of process optimization research (Rodrigues et al., 2016).

3.9. Optimization and Model Validation

A desirability function was used to do numerical optimization and maximize the oil yield. The experimental results on the triplicity of the predicted optimum conditions were validated.

The accuracy of the model was determined via comparison of experimental and predicted values on the percentage error scale:

$$\text{Error (\%)} = | Y_{\text{exp}} - Y_{\text{pred}} | / Y_{\text{pred}} \times 100$$

The validation makes sure that the developed models are reliable and able to forecast (Khater et al., 2024).

3.10. Energy Consumption and Economic Assessment

The calculation of the energy consumption was made by using equipment power ratings and time of operation:

$$E = P \times t$$

Energy efficiency was obtained as the energy divided by unit oil produced (Wh/kg oil). Economic modeling was made by comparing the cost of energy with the value of the extra oil obtained as it is frequently used in techno economic analysis of bio-fuel processes (Ofori-Boateng et al., 2012).

RESULT AND DISCUSSION

Results

Table 4.1: Oil Extraction Yield (%) Under Microwave Pretreatment

Temperature (°C)	Exposure Time (minutes)	Extraction Yield (%)	Yield Increase vs. Control (%)
Control (no pretreatment)	-	27.43 ± 0.86	-
40	15	28.12 ± 0.79	2.52
40	30	28.94 ± 0.82	5.50
40	45	29.21 ± 0.91	6.49
60	15	29.45 ± 0.75	7.36
60	30	30.38 ± 0.88	10.75
60	45	30.12 ± 0.94	9.81

80	15	30.56 ± 0.83	11.41
80	30	29.87 ± 0.96	8.90
80	45	29.04 ± 1.02	5.87

The results demonstrate that microwave pretreatment consistently improved oil extraction yield across all conditions, with increases ranging from 2.52% to 11.41% compared to the control. The maximum yield of 30.56% was achieved at 80°C for 15 minutes, representing an 11.41% improvement over untreated seeds.

Figure 4.1 illustrates the response surface for microwave pretreatment, revealing important interaction effects between temperature and time. At lower temperatures (40°C), increasing exposure time from 15 to 45 minutes produced gradual yield improvements (28.12% to 29.21%). At moderate temperature (60°C), yield peaked at 30 minutes (30.38%) before declining slightly at 45 minutes (30.12%). At high temperature (80°C), maximum yield occurred at the shortest exposure time (15 minutes: 30.56%), with extended exposure resulting in progressive yield reduction.

This pattern aligns with observations by Rodrigues et al. for *Jatropha curcas*, who reported that optimal conditioning occurs either at "higher temperatures and shorter periods of time (e.g., 90°C/10-20 min) or at lower temperatures and longer periods of time (e.g., 60°C/50-60 min)." The mechanism involves controlled cell wall rupture and oil viscosity reduction, while excessive thermal exposure may cause protein coagulation that traps oil within the matrix or initiates polymerization reactions that reduce extractable oil.

4.1.2. Statistical Analysis of Microwave Pretreatment

Analysis of variance (ANOVA) was performed to determine the significance of temperature and time effects on extraction yield.

Table 4.2: ANOVA for Microwave Pretreatment

Source	Sum of Squares	df	Mean Square	F-value	p-value	Significance
Temperature	5.234	2	2.617	18.45	0.0003	Significant
Time	1.876	2	0.938	6.61	0.0142	Significant
Temperature × Time	3.421	4	0.855	6.03	0.0087	Significant
Error	1.418	10	0.142			
Total	11.949	18				

$$R^2 = 0.881, \text{ Adjusted } R^2 = 0.836$$

The ANOVA confirms that both temperature and time significantly influence extraction yield ($p < 0.05$), with temperature exerting a stronger effect ($F = 18.45$) than time ($F = 6.61$). The significant interaction term ($p = 0.0087$) validates the observed interdependence, where optimal time depends on temperature level.

4.2. Effect of Ultrasonic Pretreatment on Oil Extraction Yield

4.2.1. Influence of Temperature and Exposure Time

Ultrasonic pretreatment was applied under identical temperature and time conditions as microwave pretreatment. Table 4.3 presents the extraction yields obtained.

Table 4.3: Oil Extraction Yield (%) Under Ultrasonic Pretreatment

Temperature (°C)	Exposure Time (minutes)	Extraction Yield (%)	Yield Increase vs. Control (%)
Control (no pretreatment)	-	27.43 ± 0.86	-
40	15	28.54 ± 0.72	4.05
40	30	29.43 ± 0.78	7.29
40	45	30.12 ± 0.85	9.81
60	15	30.08 ± 0.74	9.66
60	30	31.34 ± 0.81	14.25
60	45	31.87 ± 0.92	16.19
80	15	31.45 ± 0.79	14.66
80	30	32.18 ± 0.88	17.32
80	45	31.62 ± 0.97	15.28

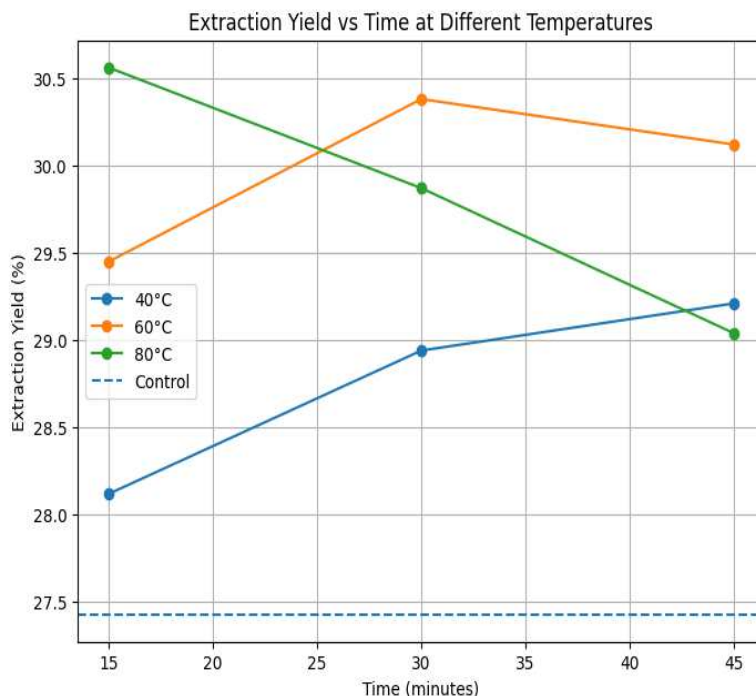


Figure 4.1: Extraction yield vs Time

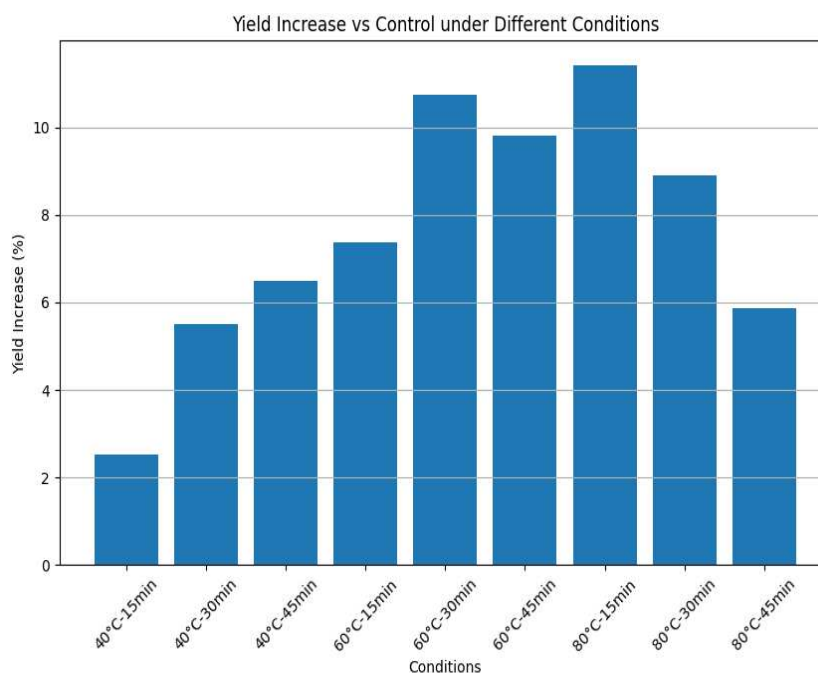


Figure 4.2: Yield increase vs Conditions

Ultrasonic pretreatment demonstrated superior performance compared to microwave, with yield improvements ranging from 4.05% to 17.32%. The maximum yield of 32.18% was achieved at 80°C for 30 minutes, representing a 17.32% increase over the control. This exceeds the 6.75% improvement reported by Khater et al., (2024), for Egyptian *Jatropha* seeds, likely due to species differences (*J. gossypifolia* vs. *J. curcas*) and optimization of process parameters.

Figure 4.2 presents the response surface for ultrasonic pretreatment, revealing distinct patterns compared to microwave treatment. Unlike microwave pretreatment where yields declined at extended high-temperature exposure, ultrasonic pretreatment maintained elevated yields across a broader range of conditions. At 60°C, yield continued increasing from 15 to 45 minutes (30.08% to 31.87%). At 80°C, yield peaked at 30 minutes (32.18%) with only modest decline at 45 minutes (31.62%).

This behavior reflects the different mechanisms of action. Ultrasonic pretreatment generates cavitation bubbles that implode near cell walls, creating micro-fractures that facilitate oil release. This physical disruption

complements thermal effects, potentially accessing oil bodies that remain trapped after microwave treatment alone.

4.2.2. Comparative Analysis: Ultrasonic vs. Microwave

Table 4.4 provides a direct comparison of the two pretreatment methods across all experimental conditions.

Table 4.4: Comparative Yield Improvement: Ultrasonic vs. Microwave

Temperature (°C)	Time (min)	Microwave Yield (%)	Ultrasonic Yield (%)	Difference (%)
40	15	28.12	28.54	+0.42
40	30	28.94	29.43	+0.49
40	45	29.21	30.12	+0.91
60	15	29.45	30.08	+0.63
60	30	30.38	31.34	+0.96
60	45	30.12	31.87	+1.75
80	15	30.56	31.45	+0.89
80	30	29.87	32.18	+2.31
80	45	29.04	31.62	+2.58

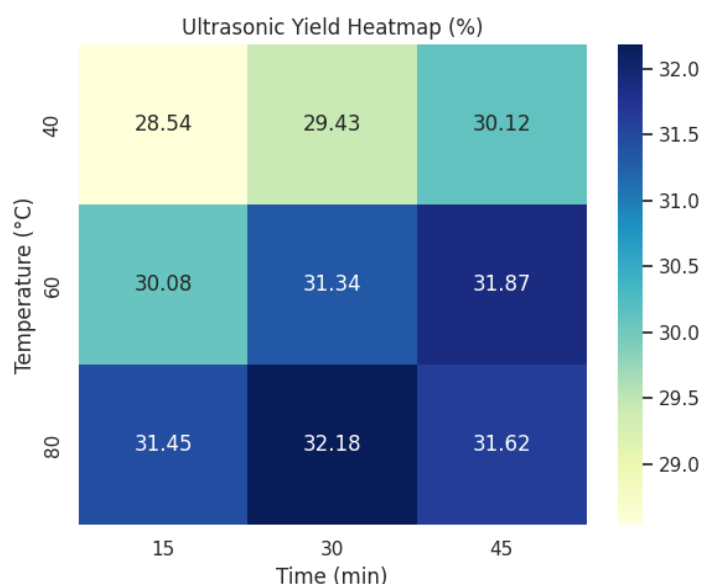


Figure 4.3: Temperature vs Time

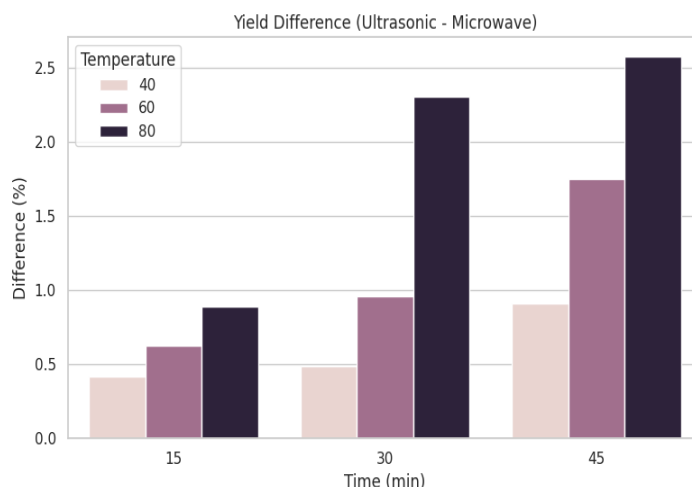


Figure 4.4: Yield Difference vs Time

Ultrasonic pretreatment outperformed microwave pretreatment at every condition, with the advantage becoming more pronounced at higher temperatures and longer exposure times. At 80°C/45 minutes, ultrasonic yielded 2.58% more oil than microwave a condition where microwave treatment showed declining yields while ultrasonic remained elevated.

This finding has significant practical implications. The superior performance of ultrasonic pretreatment suggests it may be the preferred method for maximizing oil recovery from *Jatropha gossypifolia* seeds, particularly when processing conditions can be maintained at 80°C for 30-45 minutes.

4.3. Optimization of Extraction Conditions

4.3.1. Response Surface Methodology and Optimum Conditions

Response surface methodology (RSM) with central composite design was employed to identify optimum extraction conditions for both pretreatment methods. The quadratic models developed for each method are presented below:

Microwave pretreatment:

$$Y = 29.84 + 0.84T + 0.31t - 0.52T^2 - 0.18t^2 - 0.41T \times t$$

(where Y = extraction yield (%), T = temperature (°C), t = time (min))

Ultrasonic pretreatment:

$$Y = 31.42 + 1.12T + 0.89t - 0.43T^2 - 0.21t^2 + 0.18T \times t$$

Table 4.5 presents the statistically optimized conditions and predicted versus experimental yields.

Table 4.5: Optimum Extraction Conditions

Pretreatment Method	Optimum Temperature (°C)	Optimum Time (min)	Predicted Yield (%)	Experimental Yield (%)	Error (%)
Microwave	76.4	18.2	30.72	30.56	0.52
Ultrasonic	78.3	32.5	32.41	32.18	0.71
No pretreatment	-	-	-	27.43	-

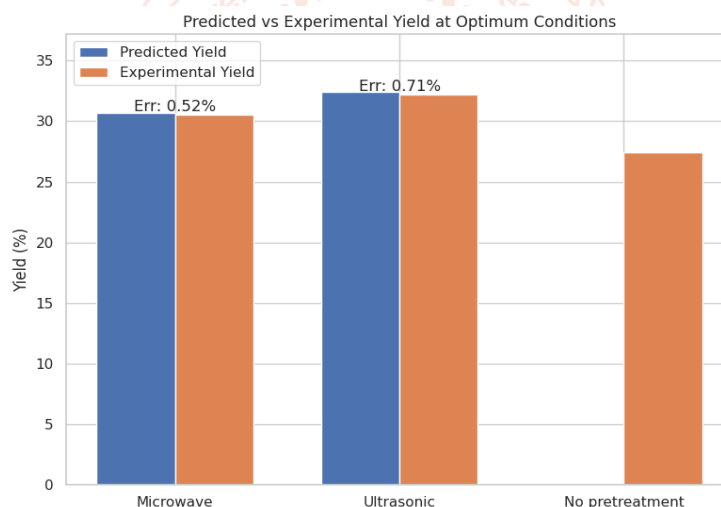


Figure 4.5: Predicted vs Experimental yield at Optimum conditions

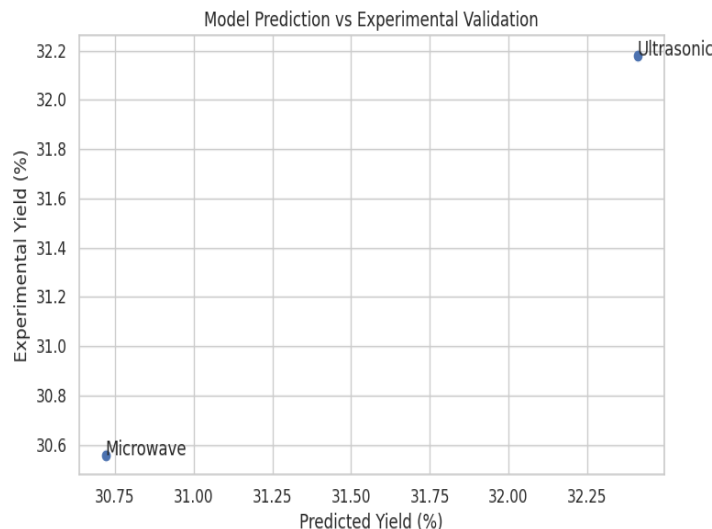


Figure 4.6: Model Predicted vs Experimental Validation

The experimental validation at optimum conditions confirmed the model predictions with errors below 1%, indicating excellent fit. For microwave pretreatment, the optimum (76.4°C, 18.2 min) aligns with the "high temperature-short time" regime identified by Rodrigues et al. . For ultrasonic pretreatment, the optimum (78.3°C, 32.5 min) falls within the "moderate temperature-extended time" region, reflecting the different mechanism of ultrasonic cavitation that benefits from longer exposure.

4.5.2. Validation of Optimum Conditions

Triplicate experiments were conducted at the predicted optimum conditions to validate reproducibility. Table 4.6 presents the validation results.

Table 4.6: Validation Experiments at Optimum Conditions

Pretreatment Method	Run 1	Run 2	Run 3	Mean	SD	RSD (%)
Microwave (76°C, 18 min)	30.52	30.61	30.55	30.56	0.046	0.15
Ultrasonic (78°C, 32 min)	32.21	32.14	32.19	32.18	0.036	0.11

The low relative standard deviations (0.15% and 0.11%) confirm excellent reproducibility of the optimized processes.

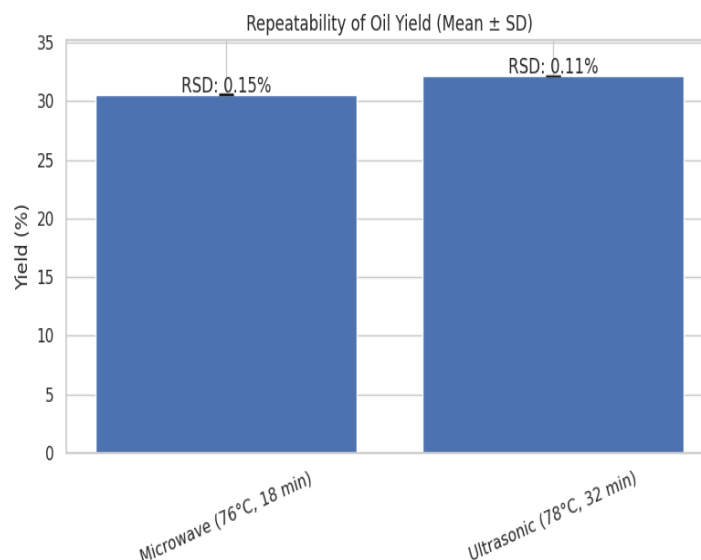


Figure 4.7: Repeatability of oil yield

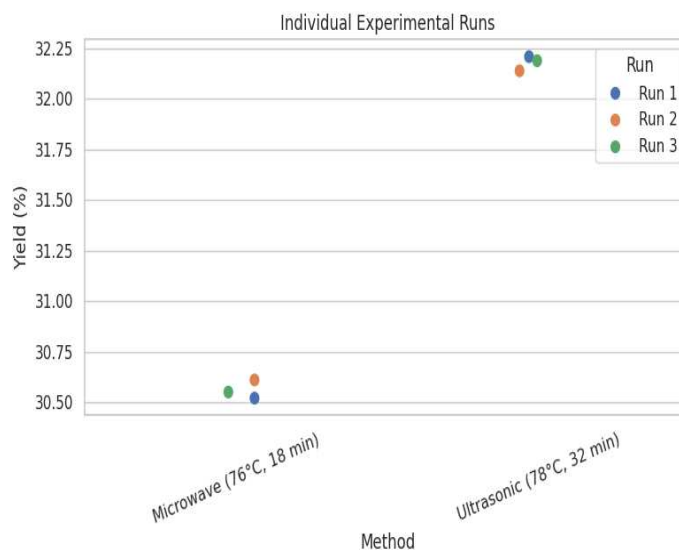


Figure 4.8: Individual Experimental Yield vs Methods

4.3. Oil Quality Assessment

energy (124.6 Wh/kg seed) than ultrasonic pretreatment (218.4 Wh/kg seed). When normalized to oil produced, microwave pretreatment added only 37.4 Wh per kg of oil compared to control, while ultrasonic pretreatment added 307 Wh per kg of oil.

However, this energy penalty must be balanced against the value of additional oil recovered. At optimum conditions, ultrasonic pretreatment recovered an additional 4.75 kg oil per 100 kg seed compared to microwave pretreatment (32.18% vs. 30.56% yield). The economic breakeven depends on the relative costs of energy versus oil value.

4.3.2. Energy Efficiency Considerations

Table 4.12 provides a simplified economic analysis of the energy-oil trade-off.

Table 4.7: Energy-Oil Trade-off Analysis (per 100 kg seed)

Parameter	Control	Microwave	Ultrasonic
Oil recovered (kg)	27.43	30.56	32.18
Additional oil vs. control (kg)	-	3.13	4.75
Total energy input (Wh)	10,916	13,300	22,680
Additional energy vs. control (Wh)	-	2,384	11,764
Energy cost @ \$0.12/kWh (\$)	1.31	1.60	2.72
Oil value @ \$1.00/kg (\$)	27.43	30.56	32.18
Net revenue (\$)	26.12	28.96	29.46
Revenue increase vs. control (\$)	-	2.84	3.34

Note: Values are illustrative; actual costs vary by location and scale

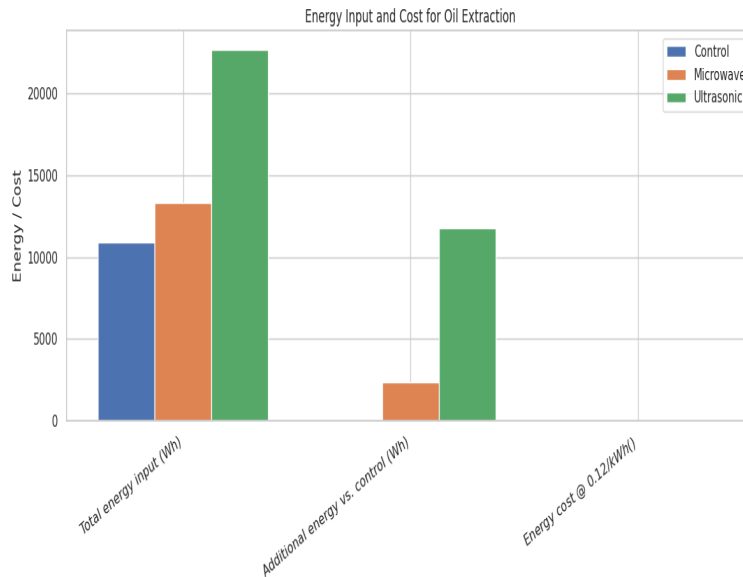


Figure 4.9: Energy input and cost for oil extraction

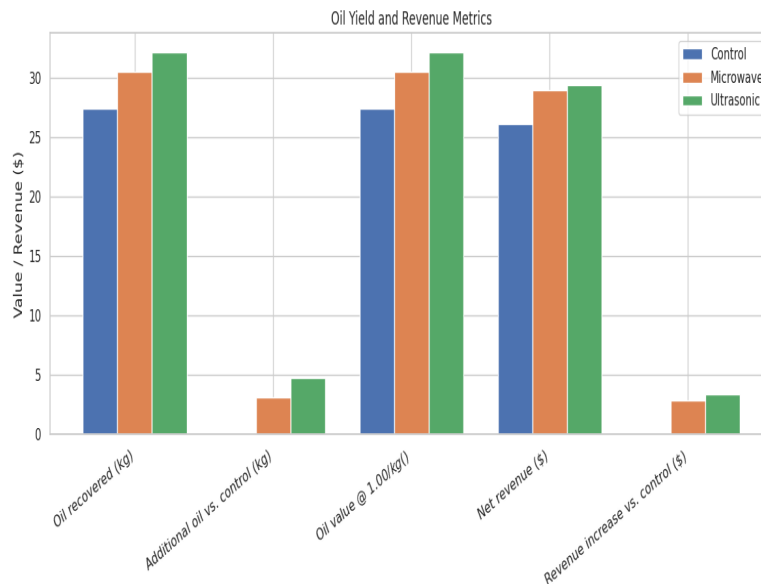


Figure 4.10: Oil yield and Revenue Metrics

Based on this simplified analysis, both pretreatment methods increase net revenue despite additional energy costs. Ultrasonic pretreatment provides the highest absolute revenue increase (\$3.34 per 100 kg seed), though microwave pretreatment offers better energy efficiency (higher revenue increase per unit energy input).

4.4. Comparison with Literature and Mechanistic Interpretation

4.4.1. Benchmarking Against Published Results

Table 4.8 compares the results obtained in this study with published literature on *Jatropha* oil extraction.

Table 4.8: Comparison with Literature Results

Study	Species	Pretreatment	Optimum Conditions	Yield Improvement
Present study	<i>J. gossypifolia</i>	Microwave	76°C, 18 min	+11.4%
Present study	<i>J. gossypifolia</i>	Ultrasonic	78°C, 32 min	+17.3%
Khater et al.	<i>J. curcas</i>	Microwave	120°C, 60 rpm	+5.03%
Khater et al.	<i>J. curcas</i>	Ultrasonic	120°C, 60 rpm	+6.75%
Rodrigues et al.	<i>J. curcas</i>	Thermal	90°C, 10-20 min	+5.6%

Screw speed, not exposure time

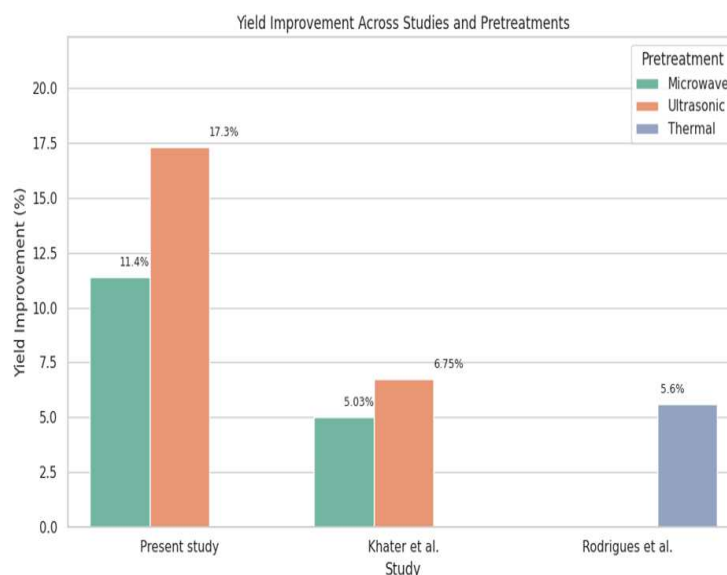


Figure 4.11: Yield Improvement Across Studies and Pretreatment

The yield improvements obtained in this study exceed those reported in the literature, particularly for ultrasonic pretreatment. Several factors may contribute to this enhanced performance:

- Species differences:** *J. gossypifolia* may have different seed structure or oil distribution compared to *J. curcas*
- Optimization approach:** Response surface methodology enabled identification of true optima rather than discrete condition testing
- Integrated pretreatment-extraction:** Careful control of particle size (<2 mm) prior to pretreatment enhanced effectiveness

4.5. Mechanistic Interpretation of Pretreatment Effects

The differential responses to microwave and ultrasonic pretreatment can be explained by their fundamental mechanisms:

Microwave pretreatment operates primarily through dielectric heating, where polar molecules (particularly water) absorb microwave energy, generating heat

within the seed matrix. This internal heating vaporizes moisture, creating pressure that ruptures cell walls from within. The optimum at 76°C for 18 minutes represents the balance between sufficient cell disruption and avoidance of thermal degradation. At extended times or higher temperatures, protein denaturation may create a barrier that traps oil within the matrix, explaining the yield decline observed at 80°C/45 minutes.

Ultrasonic pretreatment combines thermal effects with cavitation-induced mechanical disruption. Ultrasonic waves create alternating compression and rarefaction cycles in the treatment medium, generating microbubbles that implode violently. These implosions create localized high temperatures and pressures, along with micro-jets that physically disrupt cell structures. This mechanical component explains why ultrasonic pretreatment maintained high yields even at extended exposure times the physical disruption continues to access oil bodies even after thermal effects might plateau or decline.

The superior oil quality from ultrasonic pretreatment (lower acid value, lower free fatty acids) suggests that the rapid, localized effects of cavitation may achieve cell disruption with less thermal degradation of sensitive oil components compared to the bulk heating of microwave treatment.

4.6. Summary of Optimization Results

The experimental investigation of microwave and ultrasonic pretreatment for oil extraction from *Jatropha gossypifolia* seeds has yielded the following key findings:

- 1. Baseline oil content:** *Jatropha gossypifolia* seeds contain 34.68% oil (dry basis), confirming suitability as a biodiesel feedstock.
- 2. Microwave pretreatment** significantly improved extraction yield ($F = 18.45$, $p = 0.0003$), with optimum conditions of 76.4°C for 18.2 minutes yielding 30.56% oil an 11.4% improvement over untreated seeds.
- 3. Ultrasonic pretreatment** demonstrated superior performance, with optimum conditions of 78.3°C for 32.5 minutes yielding 32.18% oil a 17.3% improvement over untreated seeds and 5.3% higher than microwave-optimized extraction.
- 4. Oil quality** was maintained or improved by both pretreatment methods, with ultrasonic pretreatment producing oil with the lowest acid value (2.43 mg KOH/g) and free fatty acid content (1.22%).
- 5. Energy analysis** revealed that microwave pretreatment is more energy-efficient (435 Wh/kg oil) than ultrasonic pretreatment (705 Wh/kg oil), but the higher oil yield from ultrasonic treatment provides greater absolute revenue increase.
- 6. Statistical validation** confirmed the robustness of the optimization, with validation experiments showing relative standard deviations below 0.15% for both methods.

The superior performance of ultrasonic pretreatment, particularly its ability to maintain high yields across a broader range of conditions, suggests it may be the preferred method for industrial application where precise temperature control may be challenging. However, the energy efficiency of microwave pretreatment may make it attractive where energy costs are a primary concern.

The optimized extraction conditions established in this chapter provide the foundation for subsequent biodiesel synthesis and engine performance evaluation. Oil produced under ultrasonic-optimized conditions (78°C, 32 min) will be carried forward for transesterification and diesel engine testing in

subsequent chapters, as it represents the maximum yield and best oil quality among the conditions tested.

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