Microwave-assisted extraction of black soldier fly larvae (BSFL) lipid

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Abstract. Black soldier fly larvae (BSFL) contain high lipids considered as a sustainable feedstock for lipid production to biofuels. In this study, microwave-assisted extraction of BSFL was prepared. The response surface methodology was employed to investigate the effects of parameters, namely, microwave power (230 - 290 W), solid-solvent ratio (1:10 - 1:20 g/ml), and extraction time (20 - 40 min) for maximum lipid extraction. The data were statistically analysed to predict the optimal combination of factors, and finally, experiments were conducted for verification. By comparing verification tests and predicted results, the optimised microwave-assisted extraction operating conditions were 260 W, 1:15 (w/v %), and 31 min with 30.53% (g/g) of extracted lipids were attained. Besides, compared with the Soxhlet method, the extracted yield from the microwave-assisted extraction technique was improved by 20% without significantly affecting lipid characteristics. Therefore, microwave-assisted extraction is an efficient lipid extraction technique from BSFL. This study also provides an insight into developing the microwave-assisted extraction techniques for producing high lipid yield and acceptable lipid stability to produce biofuels.

1. Introduction

The amount of food waste generated globally is reported to be 1.3 billion tonnes each year, which equals annual economic losses of USD 1 trillion [1][2]. The continuous increase in waste generation from domestic and agricultural activities such as fruits and vegetables are projected to exceed more than 9 billion by 2050 [3]. It will negatively contribute to environmental problems such as inadequate landfill spaces and groundwater pollution from the leachates and landfill gas emissions. In recognition of the issues, the United Nations (UN) under its Sustainable Development Goal set the goal to reduce the amount of food waste generated by half by 2030 as its main agenda. As Malaysia is one of the countries that pledged to comply with the UN Sustainable Development Goal, the government must develop its food waste management strategy by adopting sustainable but efficient conversion technology to mitigate the adverse effects of food waste on the environment and the community.

Biowaste conversion through Black soldier fly (BSF), *Hermetia illucens*, will be adopted in this research. It is a new emerging technology that has gained attention over the past few years as it requires no feed for its growth, while BSF itself is not a vector in disease transmission. But more importantly, it
has higher fat content either in its adult or larvae stages. BSFL consumes fruits, vegetable waste, animal manure, and human excrete and converts them into larval biomass and produces compost-like residue, reducing the number of waste materials. BSF larvae (BSFL) is not only a suitable source of lipids but also high in protein (32 – 58 %) and minerals as well as 15 – 39 % in lipids [4][5]. It is made BSFL as a source of protein and animal lipid with a high market value and a potential feedstock for biofuel production [6].

Extraction is one of the significant processing steps for lipid application. Extraction of lipids can be carried out using various methods, including Soxhlet extraction, solvent extraction, supercritical fluids extraction, and mechanical pressing. However, these conventional methods have many drawbacks, including long extraction times, low yield, high solvent consumption, and costly [7]. This traditional approach is microwave-assisted extraction, known as an effective biomass extractive-transesterification method [8]. Besides, microwave heating is cheaper than conventional heating with increased lipid production rate and reduced time and solvents [9]. However, the information on the optimisation study and characterisation of lipids from BSFL lipids in the application of microwave-assisted lipid extraction from BSFL fed on food waste is less reported in the literature. Therefore, this study utilizes the microwave-assisted extraction technique using the industrious farm insect and efficiently extracts the lipids through the microwave-assisted extraction technique.

2. Methodology

2.1. Black Soldier Fly Larvae Rearing Unit Set-up
A BSFL production unit made of a plastic container of 0.3m × 0.2m × 0.12m in dimension was set up for the fly’s rearing. Food wastes (to feed larvae) were collected from the wet market in Kangar, Perlis. The waste was first subjected to a size reduction process to less than 2 mm and then mixed with distilled water to form a homogenous slurry. The food waste slurry with 70-80% moisture content was kept in a freezer at -10℃ before further use.

2.2. Black Soldier Fly Larvae Cultivation
Black soldier fly eggs were purchased from Buggy Farm Enterprise, Bukit Mertajam, Penang, and used as a starting culture. Approximately 1000 eggs per kilogram of feed were inoculated on the food waste slurry in the BSFL rearing unit (Figure 1). The rearing of eggs was carried out at the ambient temperature and the relative humidity of 75%.

![Figure 1. Schematic diagram of BSFL cultivation in rearing set-up.](image-url)
2.3. **Larvae powder preparation**
The adult larvae were deactivated by soaking it in boiled water for 10 s and then was dried in a hot air oven (Memmert UF-110) maintained at 60 °C until a constant weight is achieved. The larvae were ground using a laboratory blender to get larvae powder and kept in a freezer at 4 °C until further use.

2.4. **Conventional Soxhlet extraction method**
The BSFL lipid content was extracted using Soxhlet extraction. 10 g of dried larvae powder was heated to reflux for 8 hours in petroleum ether as a solvent [10].

2.5. **Microwave-assisted extraction experiment**
A 10 g of dried larvae powder at 50% moisture content was placed in holders with petroleum ether as a solvent used for BSFL lipid extraction. The extraction was performed using a microwave at different microwave power, extraction time, and solid-to-solvent ratio. After lipid extraction, the mixed liquid phase was separated by centrifugation, and lipid was recovered using a rotary evaporator (Rotavapor R-210, Buchi Germany).

2.5.1. **One-factor-at-a-time (OFAT) method.** The effects of physical condition for lipid extraction were investigated by employing the OFAT method. In this research, five different microwave power regimes between 230 - 350 W, reaction time (10 - 50 minutes), and the solid-to-solvent ratio of 1:5 -1:25 (w/v) lipid yield were studied. Each experiment was carried out at one parameter while keeping other parameters at constants. All of these experiments were conducted in triplicate, and the average values were recorded.

2.5.2. **Optimisation using Response Surface Methodology (RSM).** All factors (microwave power, sample-to-solvent ratio, and extraction time) on lipid yield were optimised using response surface methodology via Box-Behnken Design (BBD) to increase the lipid extraction yield. The experiment levels (low, mid, high) were identified based on previous Section 2.4.1 are as shown in Table 1. Three independent parameters, which were microwave power ($X_1$), solid-to-solvent ratio ($X_2$), and extraction time ($X_3$) on the lipid yield ($Y$), were coded at three levels to obtain the coefficients of the quadratic models by using Design-Expert software.

### Table 1. List of parameters range and level for Box-Behnken Design.

| Parameters              | Low (-1) | Medium (0) | High (+1) |
|-------------------------|----------|------------|-----------|
| $X_1$: Microwave power (W) | 230      | 260        | 290       |
| $X_2$: Solid-to-solvent ratio (% w/v) | 1:10     | 1:15       | 1:20      |
| $X_3$: Extraction time (min) | 20       | 30         | 40        |

The software was used to analyse the microwave-assisted extraction experiment's optimum condition, and the optimal extraction conditions later validated in triplicate. The results were analysed by analysis of variance (ANOVA), and the responses and variables (in coded unit) were correlated by response surface analysis to obtain Equation (1):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{1,2} X_1 X_2 + \beta_{1,3} X_1 X_3 + \beta_{2,3} X_2 X_3 + \beta_{1,1} X_1^2 + \beta_{2,2} X_2^2 + \beta_{3,3} X_3^2$$

(1)
where \( Y \) is the response; \( \beta_0 \) is the intercept (constant); \( \beta_1, \beta_2, \beta_3, \beta_{1,2}, \beta_{1,3}, \beta_{2,3}, \beta_{1,1}, \beta_{2,2} \) and \( \beta_{3,3} \) are the linear, quadratic, and interaction effects coefficients that associate with variables \( X_1, X_2, \) and \( X_3 \).

2.5.3 Determination of lipid extraction yield. Crude lipid was obtained by evaporating solvent using rotary evaporation, and the obtained lipid yield was calculated using Equation (2):

\[
\text{Yield of lipids (wt\%)} = \frac{\text{Weight of extracted lipids}}{\text{Weight of dried biomass powder}} \times 100\% \quad (2)
\]

2.6. Analytical method

2.6.1. Proximate analysis of larvae product. The moisture content, crude protein, crude fat, and ash contents of BSFL was determined as referred to as the method described by Ljubojević et al. [11]. The moisture content of BSFL was determined after the samples dried at 105℃ to constant weight for 24 hours. The crude protein was determined by the Kjeldahl method (Tecator Kjeltec Auto 1030 Analyzer, Sweden). The ash was determined after burning at 550 ± 25℃.

2.6.2. Fourier transform infrared spectrometry (FTIR) spectroscopy. 1g of raw BSFL sample, and BSFL extracted lipid sample was used in the FTIR analysis. Infrared spectra were obtained in KBr pellets in an FTIR unit by scanning wave numbers ranging from 650 to 4000 cm\(^{-1}\) with a 4 cm\(^{-1}\) [12].

2.6.3. Differential scanning calorimeter analysis (DSC). The DSC profile of extracted lipid was acquired using a differential scanning calorimeter with the aluminum crucible. The thermal program involved rapid heating of the sample from room temperature to 110℃, with a heating rate of 5℃/min and held under the isothermal condition for 10 minutes. Then the extracted lipid was cooled from 30℃ to -50℃ [19].

3. Results and discussion

3.1. Proximate composition of dried larvae powder

Table 2 shows the comparison between the proximate analysis results of BSFL in this study and other insect biomass. The crude protein is the most abundant component in the BSFL, which contains 41.42±0.04%. This result agrees with the study reported by Oonincx et al. [13], which had the composition of crude proteins in BSFL are 38–46%. Meanwhile, the crude fat content in BSFL is slightly lower when compared with termites [14]. BSFL shows the highest moisture content (85.78 ± 78%) among the five insects due to the BSFL’s strong water absorbability in its gut and stored in the body [4].

| Insect biomass          | Crude fat (%) | Crude protein (%) | Moisture Content (%) | Ash Content (%) | References     |
|-------------------------|--------------|-------------------|----------------------|----------------|----------------|
| BSFL                    | 30.8 ± 0.26  | 41.42 ± 0.04      | 85.78 ± 0.02         | 3.47 ± 0.12    | This study     |
| Termite                 | 36.55 ± 0.50 | 42.63 ± 0.18      | -                    | 2.34 ± 0.23    | [13]           |
| Mealworm beetle larvae  | 13.07 ± 3.88 | 17.85 ± 3.33      | 62.00 ± 4.6          | 1.51 ± 0.79    | [14]           |
| Palm weevil larvae      | 18.35 ± 0.05 | 11.3 ± 0.05       | 40.80 ± 0.12         | 0.28 ± 0.01    | [15]           |
3.2. **Effect of microwave power on extracted BSFL lipid yields**

In the investigation of microwave power's effect on extracted lipid yield, the microwave-assisted extraction was carried out at five microwave power levels 230 W to 350 W. In contrast, the extraction time and solid-to-solvent ratio were kept constant. The microwave power provides localized heating in the sample and acts as a driving force for MAE to destroy the biomass matrix so that the solute within the matrix is able to diffuse out and dissolve in the solvent. Figure 2 depicts the effect of different ranges of microwave power on BSFL lipid content. The highest lipid content (30.2 ± 0.3 %) was found at the microwave power of 260 W. The suitable microwave power provided localised heating in the sample, which acted as a driving force for extraction to destroy the BSFL matrix structure that allowed the lipid cab to diffuse and dissolved in the solvent [17]. The amount of lipid reduced when the microwave power was imposed over 290 W to 350 W due to very high microwave power provides high heat energy to the BSFL sample matrix, leading to thermal degradation of compounds, thus lowering the extraction lipid yield. The microwave power of 260 W has extracted the highest lipid yield content, and a microwave power range between 230 W and 290 W would be acceptable for optimisation.

![Figure 2. Effect of microwave power on extracted lipid yields.](image)

3.3. **Effect of extraction time on extracted BSFL lipid yields**

In the lipid extraction process, time is another crucial factor for extraction. A long extraction period may incur higher operating costs. The extraction time was varied at 10 min, 20 min, 30 min, 40 min, and 50 min 500 °C to get the optimum extraction time with a maximum yield of the BSFL lipid. The microwave power was maintained at 260 W with a fixed ratio of solid-to-solvent of 1:15 (w/v %). Figure 3 shows the effect of extraction time on lipid yield. The lipid content was increased from 10 min to 30 min. The optimum extraction time was 30 min with the highest lipid yield of 31.0 % was obtained, whereas further increment of extraction time over 30 min resulted in a drastically reduced lipid yield. Comparably, Alfolabi et al. [12] evaluated lipid extraction time from eel fish using the microwave-assisted method within 10 to 30 min and found that the lipid yield increased as the extraction increased. According to Veggi et al. [17], excessive and prolonged extraction time causes the sample over-exposed under high temperature, leading to degradation and oxidation of lipid, and reduced lipid yield.
3.4. Effect of solid-to-solvent ratio

Figure 4 shows the effect of the solid-to-solvent ratio on lipid extraction ranging from 1:5 to 1:20 (w/v) on BSFL lipid extraction with all other parameters at optimum conditions. As the solid-to-solvent ratio increased from 1:15 to 1:15 (w/v), the extracted lipid yield was found to be increased from 8.9 to 30.7%. Further increase of solid-to-solvent ratio above 1:15 did not show much improvement in lipid yields. Therefore, the optimum solid-to-solvent ratio was found to be an optimum ratio for further study. Considering the extraction procedure for optimisation, the proportion of 1:10 to 1:20 (w/v) was selected for further analysis. Ibrahim and Zaini [8] mentioned the solvent volume must be adequate to ensure the solid particles are entirely immersed in the solvent during microwave-assisted extraction, especially for a matrix that swells in the extraction process. Besides, too high in the solid-to-solvent ratio may also decrease the energy, and extra time is needed to reflux the extraction solution [18]. On the other hand, the inadequate solvent volume resulted in low lipid recovery due to non-uniform distribution and microwaves exposure.

3.5. Optimization of microwave-assisted extraction method

In this study, the effects of three extraction parameters on the lipid yield and the optimum extraction conditions were analyzed using the Box-Behnken design (BBD). The previous OFAT indicated the optimum range of parameters microwave power, solid-to-solvent ratio, and extraction time were 230 – 290 W, 1:10 to 1:20 (w/v %), and 20 to 40 min, respectively. Table 3 indicates the BBD matrix of the experimental and predicted response of lipid content (%). In total, 17 experiments were designated according to the BBD experimental set-up.
Table 3. Experimental and predicted values of lipid content (%) obtained by Box – Behnken Design in Response Surface Methodology (RSM).

| Run | Microwave power ($X_1$) | Sample – to – solvent ratio ($X_2$) | Extraction time ($X_3$) | Lipid content, % |
|-----|--------------------------|-----------------------------------|------------------------|-----------------|
| 1   | 230                      | 10                                | 30                     | 22.46           |
| 2   | 290                      | 10                                | 30                     | 20.65           |
| 3   | 230                      | 20                                | 30                     | 26.35           |
| 4   | 290                      | 20                                | 30                     | 19.97           |
| 5   | 230                      | 15                                | 20                     | 20.76           |
| 6   | 290                      | 15                                | 20                     | 19.91           |
| 7   | 230                      | 15                                | 40                     | 23.72           |
| 8   | 290                      | 15                                | 40                     | 20.17           |
| 9   | 260                      | 10                                | 20                     | 20.89           |
| 10  | 260                      | 20                                | 20                     | 21.01           |
| 11  | 260                      | 10                                | 40                     | 25.07           |
| 12  | 260                      | 20                                | 40                     | 22.18           |
| 13  | 260                      | 15                                | 30                     | 30.23           |
| 14  | 260                      | 15                                | 30                     | 30.53           |
| 15  | 260                      | 15                                | 30                     | 30.36           |
| 16  | 260                      | 15                                | 30                     | 29.96           |
| 17  | 260                      | 15                                | 30                     | 30.89           |

3.6. Statistical analysis and optimization of extracted lipid yield with BBD

Table 4 shows the ANOVA results for the quadratic model allow for microwave-assisted extraction prediction with the highest BSFL lipid content response within the range of experimental factors. Based on Table 4, the determination of the model of 0.9953 and p-value of <0.0001 indicated a high adjustment of the model, where the proposed model did not explain only 1.92% of the total variation. It compares the range of the predicted values at the design points to the average prediction error. Hence the ratio of the model was 285.89 indicates an adequate signal. Besides that, the significant variables that affect lipid extraction were studied. In this case, microwave power ($X_1$), extraction time ($X_2$), and interaction of $X_1X_2$ (microwave power and extraction time) $X_1^2$, $X_2^2$ and $X_1X_2$ were significant with a p-value of 0.0034, 0.0007, and 0.0004, respectively. However, all quadratic effect shows more prominence (p<0.0001) compared to the other inputs.
Table 4. Analysis of variance (ANOVA) for the quadratic model of extracted lipid yield.

| Source                  | Sum of Squares | df | Mean Square | F-value | p-value |
|-------------------------|----------------|----|-------------|---------|---------|
| Model                   | 285.89         | 9  | 31.77       | 141.41  | < 0.0001* |
| $X_1$ - Microwave Power | 4.95           | 1  | 4.95        | 22.02   | 0.0034  |
| $X_2$ - Solvent-to-solute Ratio | 1.65   | 1  | 1.65        | 7.33    | 0.0352  |
| $X_3$ - Extraction Time | 9.18           | 1  | 9.18        | 40.87   | 0.0007  |
| $X_1$$X_2$              | 1.82           | 1  | 1.82        | 8.11    | 0.0292  |
| $X_1$$X_3$              | 11.17          | 1  | 11.17       | 49.75   | 0.0004  |
| $X_2$$X_3$              | 2.27           | 1  | 2.27        | 10.08   | 0.0192  |
| $X_1^2$                 | 52.84          | 1  | 52.84       | 235.22  | < 0.0001 |
| $X_2^2$                 | 26.77          | 1  | 26.77       | 119.17  | < 0.0001 |
| $X_3^2$                 | 92.67          | 1  | 92.67       | 412.54  | < 0.0001 |
| Residual                | 1.35           | 6  | 0.2246      |         |         |
| Lack of Fit             | 0.8669         | 2  | 0.4334      | 3.61    | 0.1273+ |
| Pure Error              | 0.4809         | 4  | 0.1202      |         |         |
| Correlation Total       | 287.24         | 15 |             |         |         |
| Standard Deviation      | 0.474          |    |             |         |         |
| Mean                    | 24.65          |    |             |         |         |
| Coefficient of Variation (CV) (%) | 1.92  | | | | |
| Coefficient of determination ($R^2$) | 0.9953  | | | | |
| Adjusted $R^2$          | 0.9883         |    |             |         |         |
| Adequate Precision      | 28.5507        |    |             |         |         |

*symbol indicates the result is significant, +symbol indicates the result is insignificant.

The central point of BBD showed the highest lipid content. The quadratic model of lipid yield was expressed as Equation (3).

$$Y = 30.39 - 0.9631X_1 - 0.5556X_2 + 1.07X_3 - 2.36X_1X_2 - 0.6750X_1X_3 - 0.7525X_2X_3 - 3.98X_1^2 - 2.83X_2^2 - 5.27X_3^2$$ (3)

Figure 5 shows the three-dimensional response surface for lipid extraction was plotted based on the generated quadratic model and represents the interaction between factors ($X_1$$X_2$, $X_1$$X_3$, and $X_2$$X_3$). By maintaining microwave power at the center point (260W), the increase of solid-to-solvent ratio and extraction time shows the increment of the quadratic effect on the lipid (Figure 5(a)). The highest lipid yield was obtained in the response surface plot range of 1:10 to 1:15 (w/v %) and extraction time within 20 to 31 mins. Besides, the response surface concerning the effect of microwave power and extraction time depicts an excellent dome-shaped contour, suggesting both variables were recognized to impart more influence and showed perfect interactions correspond to the optimal point at 260 W and 31 min. (Figure 5(b)). A cross-referencing with the ANOVA Table 4 confirms the significant interaction between microwave power and extraction time was directly produced the highest lipid extraction from dried larvae powder.
The optimal condition to attain the highest lipid yield (30.53%) was microwave power of 260 W, extraction time of 31.13 min, and the solid-to-solvent ratio of 1:15 (w/v %), estimating the value of 30.53% of extracted lipid. One set of experiments was conducted in triplicate to validate the model. 30.12% of extracted lipid was attained, and the error was less than 1%, which proved that the experimental value was accepted and the model is confirmed.

3.7. Functional group analysis of biomass BSFL and its extracted lipid

Figure 6 shows the results of the FTIR spectrum of dried larvae powder and extracted lipids. The results obtained a very close agreement with Wang et al. [19] for the extracted lipid. The FTIR spectra show a strong absorbance between 2854.0 cm\(^{-1}\) and 2926.4 cm\(^{-1}\). These indicated the presence of methyl and methylene groups, which caused aliphatic C–H stretching vibration. The absorption peak of 1745.7 cm\(^{-1}\) in extracted lipids represented by the stretching vibration of the C=O group in ketones and carboxylic acid. The peak of alkenes (-C=C- stretch) was found at 1616.6 cm\(^{-1}\) and the X–H stretching vibration (X=C, N) represented by the absorbance peak between 1377.3 cm\(^{-1}\) and 1465.5 cm\(^{-1}\). These peaks confirm the existence of the triglyceride functional group for lipids. The aromatic amine (C–N stretch) and C–O stretch or C–H bend of the ester group was confirmed at the absorbance peak 1160 cm\(^{-1}\) and 1112.8 cm\(^{-1}\).

As for the dried larvae powder, the absorption peak of 3438.2 cm\(^{-1}\) represented the hydroxyl group (O–H) stretching [12] that was absent in extracted lipids. This might be due to the removal of the hydroxyl group during the extraction process.
Figure 6. (a) The dried larvae powder (b) microwave-assisted extracted BSFL lipid.

3.8. Cold flow properties

Figure 7 depicts the DSC profile for the extracted lipid of dried larvae powder. The profile shows an endothermic and exothermic peak. The exothermic peak is presented when the measurement temperature starts at 37 ℃. The coldest endothermic peak shifted to higher temperatures, which reached 38.96 ℃. The endothermic peak is associated with the melting of lipids. An enthalpy of 17.80 J/g is reported for the melting peak in DSC measurement. The melting profile possibly indicated the content of high melting saturated triglycerides of fatty acid constituted in the sample. It was observed that the percentage of saturated fatty acids, such as lauric acid and stearic acid of BSFL is the highest composition [20].
Figure 7. DSC profile of extracted lipid under optimal prediction conditions.

3.9. Comparison of BSFL lipid obtained by different extraction method

Comparative analysis of extracted lipids from dried larvae powder using conventional Soxhlet extraction method and microwave-assisted extraction is shown in Table 5. The microwave-assisted extraction yielded 30.53±0.04% of lipid with an extraction time of 31 min compared to the Soxhlet extraction method with higher lipid content (34.24 ± 0.23 %) with an extraction time of 105 min. Based on the results obtained, there was a remarkable difference in extraction time, indicating the microwave-assisted extraction could shorten the extraction time up to 20% compared to the Soxhlet technique; even the extracted lipid using conventional is slightly higher compared to the microwave-assisted extraction method.

| Extraction techniques                   | Optimised conditions                                      | Lipid yield (%) |
|-----------------------------------------|-----------------------------------------------------------|-----------------|
| Conventional soxhlet extraction        | Solvent used: Petroleum ether                             | 34.24 ± 0.23    |
|                                         | Extraction time 105 min                                   |                 |
|                                         | Temperature: 50 ℃                                        |                 |
| Microwave-assisted extraction           | Solvent used: Petroleum ether                             | 30.53 ± 0.04    |
|                                         | Microwave power: 260 W                                   |                 |
|                                         | Extraction time: 31 min                                   |                 |
|                                         | Solid-to-solvent ratio: 1:15 (w/v %)                      |                 |

4. Conclusion

The microwave-assisted extraction gave an effective method to extract the lipid from BSFL fed in food waste compared to other traditional extraction methods. The results showed that the highest BSFL extracted lipid through OFAT analysis could be obtained in the central point experiment. Further optimisation of lipid extraction using RSM coupled with BBD was conducted. It indicated that the optimum microwave power, solid-to-solvent ratio and extraction time, and mixing rate were 260 W, 1:14.7 g/ml, and 31 minutes. The extracted lipid produced under this optimum condition was 30.33 ± 0.03 %. The predicted values of optimal lipid content were obtained at 30.53 %, which was in agreement with the predicted values. This result has shown that the microwave-assisted extraction method is more effective compared to other extraction methods such as the Soxhlet method which took 6-7 hours to extract 32.51±0.39% of lipid [20]. The dried larvae powder and extracted lipids were subjected to FTIR
analysis to determine the functional groups. The disappearing of the O–H stretching of the hydroxyl group (3438.2 cm\(^{-1}\)) from dried larvae powder indicated removing the hydroxyl group during the extraction process. The appearance of X–H stretch in extracted lipids indicated the presence of triglyceride functional groups.

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