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Application of the Hydrodeoxygenation of Black Soldier Fly Larvae Lipids in Green Diesel Production

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Abstract: To produce green diesel from black soldier fly larvae (BSFL; *Hermetia illucens*), the maximization of lipids in production and hydrodeoxygenation (HDO) reactions was investigated. In this study, BSFL were fed 12 diets based on three different substrates (ground corn, food waste, and meat by-product). The proximate compositions of larvae were analyzed, and rearing time, production rate, and feeding mixture prices were also recorded. To maximize the lipid yield, the effects of growing temperature, drying method, and extraction temperature were investigated. The HDO reaction of BSFL oil with 1 wt % Pt/Al_2O_3 catalyst was carried out in a trickle bed reactor. The components of the lipids produced under optimal conditions and the components of lipids produced through the HDO reaction were compositionally analyzed. As a result of being fed ground corn, food waste, and meat by-products, it was confirmed that the diet with 30% ground corn and 70% meat by-product led to the highest lipid content in the BSFL. After considering the prices of the diets, we found that the most ideal feeding conditions that could be applied to actual insect farming were 70% food waste and 30% meat by-products. From the perspective of the rearing period, the most appropriate BSFL-rearing temperature was a medium temperature of 38 °C. After harvesting the BSFL, it was confirmed that the lipid yield improved when extracted at a temperature of 65–75 °C after drying using a microwave. The analysis results showed that the carbon distribution in hydrodeoxygenated BSFL oil offered an advantage when used as drop-in fuel, and this represents a promising future step for the HDO of BSFL lipids.

Keywords: black soldier fly larvae; conversion; hydrodeoxygenation; biodiesel; green diesel

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1. Introduction

Biofuels are considered to be a promising way of reducing carbon dioxide emissions and are emerging as a viable option for future energy resources intended to replace fossil fuels [1]. The use of biodiesel, a biofuel, is growing in many countries with the expansion of renewable fuel standards. Three generations of biofuels—1, edible plant parts [2,3]; 2, non-edible plant parts [4]; and 3, algal photosynthetic microorganisms [5]—have been developed and extensively investigated for use in future energy resources. However, each has encountered its own challenges, such as food–feed–fuel competition [6], deforestation [7], large amounts of land use [8], and high-water consumption [9,10]. Such paradoxical situations can exacerbate climate change and potentially lead to food security issues [11]. Although vegetable oil, a raw material for biofuel, is known to be highly economical, vegetable oil production is unevenly distributed across countries, which may give rise to a global supply–demand problem in the near future [12].

Black soldier fly larvae (BSFL; *Hermetia illucens*) have garnered increased attention in biomass research [13,14]. BSFL-derived biomass has been proposed to be a promising alternative due to its amenability to efficient cultivation and high growth efficiency. Insects, in fact, produce more protein and fatty acids than mammalian livestock and can produce fewer greenhouse gases per unit of feed consumption. In terms of bio-oil, the efficiency of insect lipid production surpasses that of traditional forms of biomass, such as vegetable oils and microalgae, due to its short life cycle and ability to be rapidly reproduced and the miniaturization of breeding facilities [15,16]. Moreover, insects offer a significant advantage of low entry energy, making self-sufficiency possible in many countries. With respect to bioconversion, the breeding conditions of BSFL can be optimized (the type of feed used, breeding temperature, relative humidity, sex ratio, etc.) to maximize the lipid content in these insects [17,18]. Furthermore, the composition of a certain fraction of fatty acids in BSFL lipids can be further optimized to maximize the yield of the desired product [19,20]. The optimized insect-derived fatty acid properties can be tuned to retain better raw material characteristics. Regarding the fatty acids of vegetable oils, there have been difficulties in transportation, storage, and process operation due to their low fluidity at room temperature, as they mainly exist in the range of C_{16} to C_{18} [21]. However, fatty acids in insects are distributed in a wide range, ranging from C_{12} to higher hydrocarbons, and can have relatively high low-temperature fluidity compared to vegetable oils [22].

In this study, we attempted to optimize the productivity of BSFL lipids through cultivation, maximize lipid yield via extraction, and explore the potential of catalytic upgrading for green diesel production. The BSFL lipids obtained under optimal conditions were subjected to FAME conversion for compositional analysis, and their suitability for green diesel production was confirmed through catalytic conversion.

2. Materials and Methods

2.1. Meterials

The BSFL used in this study were reared at the Korea Beneficial Insects Laboratory. Co., Ltd. (Gokseong-gun, Jeollanam-do, Republic of Korea). The BSFL were cultivated in an experimental box with dimensions of 400 × 600 × 150 mm (length × width × height). The initial weight of the introduced eggs, on average, was 25 g, and their initial food supply weighed 7.5 kg. The trial colony was maintained under controlled conditions at a temperature of 27 ± 2 °C, a relative humidity of 65 ± 5%, and with a natural light cycle (16:8 L:D). Three different diets were prepared, consisting of ground corn, food waste, and meat by-products, to formulate a total of twelve diets. Three of the diets were supplied by local farms and facilities in Korea. Ground corn was purchased from a local feed supplier in Yeongam-gun, Jeollanam-do, Republic of Korea. Food waste was gathered at a local environmental waste facility in Songpa-gu, Seoul, Republic of Korea, and meat by-products were purchased from another local feed supplier in Gimje-si, Jeollabuk-do, Republic of Korea. The proportions of different feeding mixtures are shown in Table 1. After a period of 6 to 14 days, the larvae were harvested. The average length of the larvae was approximately 20 mm, and their width was approximately 5 mm, as shown in Figure S1.

Table 1. Proportions of different feeding mixtures.

Feeding Mixtures	Ground Corn (wt %)	Food Waste (wt %)	Meat By-Product (wt %)
A	100	0	0
B	70	30	0
C	50	50	0
D	30	70	0
E	70	0	30
F	50	0	50
G	30	0	70
H	0	100	0
I	0	70	30
J	0	50	50
K	0	30	70
L	33	33	33

2.2. Lipid Extraction

The collected larvae were dried using either a microwave, an oven, or a rotary dryer. To enhance the productivity of the BSFL lipids, the influences of growing temperature, dryer type, and extraction temperature were evaluated. The crude BSFL lipids were stored at room temperature. The lipid content was measured using the Soxhlet extraction method [23]. The lipid yield was calculated using the following equation:

$$Lipid\ yield\ (\mathrm{wt}\ \%) = \frac{weight\ of\ crude\ lipid}{weight\ of\ dry\ matter\ and\ crude\ lipid} \times 100$$

2.3. Fatty Acid Methyl Ester (FAME) Production Using Extracted BSFL Lipids

The extracted BSFL lipids were analyzed for their fatty acid composition using FAME analysis. This analysis method allowed us to determine the fatty acid composition in the BSFL lipids [24]. A total of 10 g of BSFL lipids was transferred into 200 mL of methanol, and 10 mL of sulfuric acid was added. Additionally, 10 mL of BSFL lipids was introduced into the flask. The mixture was then heated to 80 °C and allowed to react for 4 h. Subsequently, the reaction mixture was cooled to room temperature. For the extraction of the oil, 40 mL of hexane was added into a separate funnel. Finally, the oil layer was extracted, and the obtained oil was further analyzed using a gas chromatography–flame ionization detector (GC-FID) as well as gas chromatography–mass spectrometry (GC-MS).

2.4. Hydrodeoxygenation (HDO) of BSFL Lipids

In the HDO reaction, extracted BSFL lipids were used to remove and convert green diesel. The HDO of the BSFL lipids was conducted in a trickle bed reactor, as shown in Figure S2. In this experiment, 1 wt % Pt/Al_2O_3 was prepared using the procedure reported in our previous report [25]. Approximately 180 g of the 1 wt % Pt/Al_2O_3 catalyst was packed, and the H_2 pressure was adjusted to 40 bar through the back pressure regulator. The reaction pressure was 40 bar, and the reaction temperature was in the range of 340 to 440 °C. The H_2-to-lipid ratio was fixed at 1000, with a weight hourly space velocity of 2.0 h^{-1}. The liquid product obtained from the hydrodeoxygenation process was collected in a container for liquid recovery. The overall yield of the liquid product was determined through weight measurements.

2.5. BSFL Lipids and Hydrodeoxygenated BSFL Oil Analysis

The BSFL lipids and hydrodeoxygenated BSFL oil were characterized using elemental analysis (EA), thermo-gravimetric analysis (TGA), GC-FID, and GC-MS.

EA analysis (Flash 2000, Thermo Fisher Scientific K.K., Altrincham, UK) was used to quantify the C, H, O, N, and S content in the samples. TGA (TGA N-1000, Scinco, Seoul, Republic of Korea) was used to determine the similarity of volatile components in the material. The hydrodeoxygenated BSFL oil was analyzed using GC-FID (iGC7200A, DS Science, Gwangju-si, Republic of Korea) for quantification. The BSFLO was also identified by using a GC-MS (6890N/5975C, Agilent Technologies, Santa Clara, CA, USA) instrument to determine the composition.

3. Results

3.1. Main Effects of Parameters' Performance

3.1.1. Effect of Feeding Mixtures

The nutrient compositions for each substrate are shown in Table 2. The effects of different feeding mixtures on the growth performance of the BSFL and the price of the mixtures are shown in Table 3. As a result of rearing BSFL under 12 feeding conditions, the average crude lipid content was found to be the highest at 30.55%, corresponding to diet G. An average crude lipid content of 29.01% was found to be the second highest lipid content under the rearing conditions of diet F. The crude lipid content was found to be approximately 26–27% when ground corn and food waste were mixed at 30%, 50%, and

70%. Under the mixed feeding conditions of 30%, 50%, and 70% of meat by-products and food waste, the crude lipid content was found to be approximately 15–21%. In the case of diet I, where the average production rate was 5.40 kg, the crude lipid content was low, at an average of 19.77%. There was no significant effect on the rearing period when meat by-products were added to the food waste diet.

Table 2. Nutritional analysis of substrates used in the trial.

	Crude Protein (wt %)	Crude Lipid (wt %)	Crude Ash (wt %)	Crude Fiber (wt %)	Moisture (wt %)	Calcium (wt %)	Phosphorus (wt %)
Ground corn	16.0	4.0	6.0	8.0	12.0	0.70	1.20
Food waste	23.05	9.37	16.60	16.20	3.77	4.81	1.06
Meat by-product	28.34	3.43	2.50	0.19	65.03	0.018	0.13

Table 3. Effects of different feeding mixtures on larval growth performance.

Feeding Mixtures	Mean ± SE				
	Moisture (%)	Crude Lipid (%)	Period (Day)	Production Rate (kg/Clutch)	Feeding Mixtures Price (USD/kg)
A	3.53 ± 0.3	26.92 ± 2.0	8.33 ± 0.3	3.39 ± 0.4	0.51
B	5.06 ± 0.4	26.69 ± 2.0	8.00 ± 0.5	4.54 ± 0.2	0.36
C	7.03 ± 0.4	26.27 ± 0	6.17 ± 0.3	3.57 ± 0.2	0.26
D	4.54 ± 0.1	27.19 ± 1.2	7.17 ± 0.3	3.24 ± 0.3	0.16
E	6.88 ± 0.1	27.22 ± 0.3	6.00 ± 0.5	5.23 ± 0.3	0.36
F	4.92 ± 0.2	29.01 ± 0.8	7.17 ± 0.3	3.29 ± 0.2	0.26
G	5.27 ± 0.1	30.55 ± 0.3	8.00 ± 0.5	3.63 ± 0.2	0.16
H	7.63 ± 0.2	21.28 ± 0.7	10.33 ± 0.6	3.68 ± 0.1	0.01
I	9.42 ± 0.1	19.77 ± 0.6	8.23 ± 0.9	5.40 ± 0.4	0.01
J	5.10 ± 0.2	18.24 ± 0.8	10.17 ± 0.3	4.55 ± 0.2	0.01
K	10.48 ± 0.3	15.89 ± 1.4	10.33 ± 0.3	4.63 ± 0.1	0.01
L	6.48 ± 0.1	25.81 ± 1.2	6.00 ± 0.5	4.56 ± 0.2	0.18

3.1.2. Effect of Growing Temperature

The effects of different growing temperatures are shown in Figure 1. The BSFL rearing periods were measured at six different temperature conditions: 28 °C, 32 °C, 35 °C, 38 °C, 40 °C, and 42 °C. The results revealed that at a temperature of 38 °C, the average rearing time was the shortest, amounting to 7.0 ± 0.58 days. In contrast, the longest average rearing time was exhibited at the lowest temperature of 28 °C, amounting to 14.0 ± 0.58 days. At 32 °C, the average rearing period was 11.7 ± 0.33 days, and at 35 °C, it was 8.7 ± 1.33 days. At both 40 °C and 42 °C, the average rearing period remained consistent at 7.7 ± 0.33 days. When the temperature of the substrate exceeded 40 °C, the length of the rearing period increased.

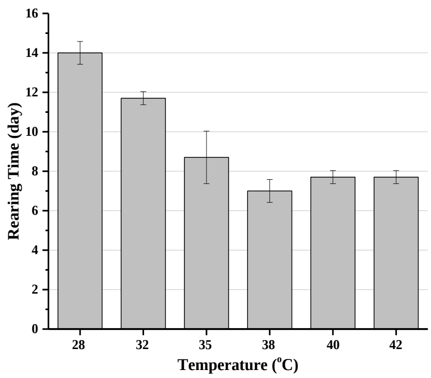

Figure 1. The effect of temperature on BSFL rearing time.

3.1.3. Effect of the Drying Method

To enhance the crude lipid yield, three different drying methods were applied to the harvested BSFL to analyze the lipid extraction efficiency. As shown in Table 4, when a hot air dryer was used, the larvae were dried at around 50–65 °C for 36 h. The extraction yield under this condition was the lowest, amounting to 40.8%. In contrast, using a rotary dryer with hot air at temperatures of 110–120 °C for 1 h resulted in an extraction yield of 57.9%, which was approximately 18% higher than that obtained with the hot air dryer. In the case of the microwave, the larvae were dried for 15 min, and the extraction lipid yield was found to be 67.7%, which was the highest among the three drying methods. These results indicate that microwave drying was the most efficient method for lipid extraction, followed by the use of the rotary dryer, while the hot air dryer yielded the lowest extraction efficiency.

Table 4. Effects of different drying methods on lipid yield in BSFL.

	Mean ± SE		
	Hot Air Dryer	**Rotary Dryer**	**Microwave**
Crude lipids (g)	123.73 ± 6.82	176.86 ± 3.40	206.96 ± 3.46
Dry matter (g)	183.59 ± 8.79	130.46 ± 5.60	100.36 ± 5.69
Lipid Yield (wt %)	40.83 ± 2.83	57.95 ± 1.80	67.66 ± 1.83

3.1.4. Effect of Extraction Temperature

Table 5 shows the effect of extraction temperature. When the BSFL were extracted under temperature conditions of 22–25 °C, the lipid extraction yield from the BSFL averaged 39.7%. However, when the extraction process was conducted at temperatures ranging from 35–45 °C, the lipid extraction yield increased to an average of 53.6%. This represents a significant improvement of 13.6% compared to the treatment at room temperature. Furthermore, when the dried insects were subjected to an extraction process at temperatures of 65–75 °C, the lipid extraction yield averaged 67.6%. This indicates a substantial increase of 27.9% compared to the room temperature treatment and a 14.0% improvement over the 35–45 °C treatment.

Table 5. Effect of extraction temperature on lipid yield in BSFL.

	Mean ± SE		
	25–30 °C	**35–45 °C**	**65–75 °C**
Crude lipids (g)	120.31 ± 5.58	160.56 ± 5.68	203.86 ± 6.52
Dry matter (g)	187.01 ± 3.39	143.76 ± 6.49	100.46 ± 5.67
Lipid Yield (wt %)	39.73 ± 1.09	53.6 ± 2.09	67.6 ± 1.83

3.2. Characterization of BSFL Lipids and Hydrodeoxygenated BSFL Oil

3.2.1. Hydrodeoxygenation of BSFL Lipids

Figure S3 shows both the BSFL lipids and hydrodeoxygenated BSFL oil. The hydrodeoxygenation reaction using 1 wt % Pt/Al_2O_3 resulted in liquid product yields ranging from 82.28% to 87.83%. Figure S3a shows the crude BSFL lipid fraction, and Figure S3b shows the hydrodeoxygenated BFFL oil. A change in the color of the BSFL oil from dark brown to yellow after undergoing the hydrodeoxygenation reaction is evident. Table 6 shows the results of an elemental analysis, indicating a reduction in oxygen content from 12.42 to 0.30 after the deoxygenation reaction. Figure 2 shows the TGA results for commercial diesel, BSFL lipids, and hydrodeoxygenated BSFL oil. In the case of commercial diesel, weight loss began at 50 °C and ended at 300 °C. In the case of BSFL lipids, the weight loss amounted to approximately 10% at 300 °C. When the temperature was subsequently increased, a weight loss of up to 90% occurred at a temperature range from 300 °C to 350 °C. The hydrodeoxygenated BSFL oil showed similar weight-loss behavior to commercial diesel, with most of the weight loss occurring at 250 °C. The temperature at which 99% weight loss occurred was found to be 300 °C, similar to that for commercial diesel.

Table 6. Elemental composition of the BSFL lipids and hydrodeoxygenated BSFL oil determined using elemental analysis.

	Content (wt %)				
	N	C	H	S	O
BSFL lipids	0.48	74.67	12.43	0.04	12.42
Hydrodeoxygenated BSFL oil	0.56	83.93	15.21	Trace	0.30

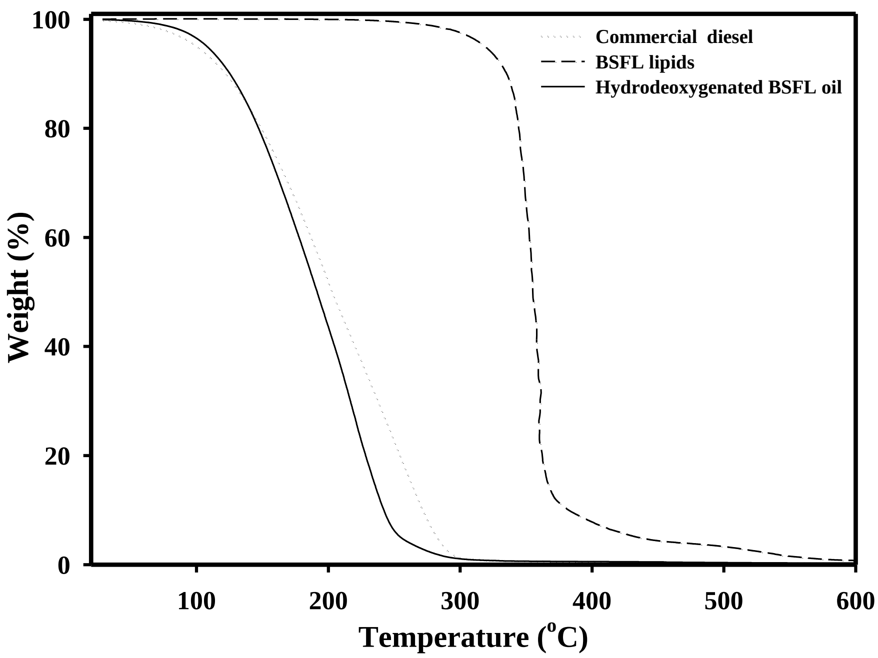

Figure 2. TGA curves for commercial diesel, BSFL lipids, and hydrodeoxygenated BSFL oil.

3.2.2. Composition Analysis

The characterization of BSFL lipids and hydrodeoxygenated BSFL oil was completed using GC-FID and GC-MS. Figure 3 shows a GC-FID chromatograph of FAMEs in the BSFL oil. Table 7 presents the chemical compositions of FAMEs in the BSFL oil. The major peaks that appeared within the C_{12} to C_{20} range are shown [26]. The BSFL-derived fatty acid was composed of seven types of FAMEs, and the major constituents of the FAMEs were methyl laureate ($C_{12:0}$, 25.723%), methyl palmitate ($C_{16:0}$, 16.946%), and 8,11-Octadecadienoic acid, methyl ester ($C_{18:2}$, 39.764%). These findings align closely with the values reported in previous research [24]. According to Park et al. [24], the compositions of FAMEs in BSFL oil were as follows: methyl laureate ($C_{12:0}$, 23.6%), methyl oleate ($C_{18:1}$, 23.2%), methyl palmitate ($C_{16:0}$, 20.3%), and methyl linoleate ($C_{18:2}$, 15.9%). In this study, C_{18} FAMEs showed a peak area corresponding to 8,11-Octadecadienoic acid, with an area percentage of 39.764%. It is possible that the $C_{18:1}$ and $C_{18:2}$ co-eluted. Subsequently, a GC-FID analysis was conducted after the hydrodeoxygenation of the BSFL lipids. Figure 4 shows a GC-FID chromatograph of hydrodeoxygenated BSFL oil. The products obtained after hydrodeoxygenation were predominantly of carbon chain length, in the range of C_9 to C_{20}. Figure 5 shows the chemical composition of hydrodeoxygenated oil from BSFL. Normal alkanes made up approximately 90% of the composition. The C_{17} normal alkane displayed the highest quantity (17.96 wt %) among the normal alkanes. The iso-alkanes constituted 6% of the composition, while cyclo-alkanes and aromatic compounds made up 3% and 1%, respectively.

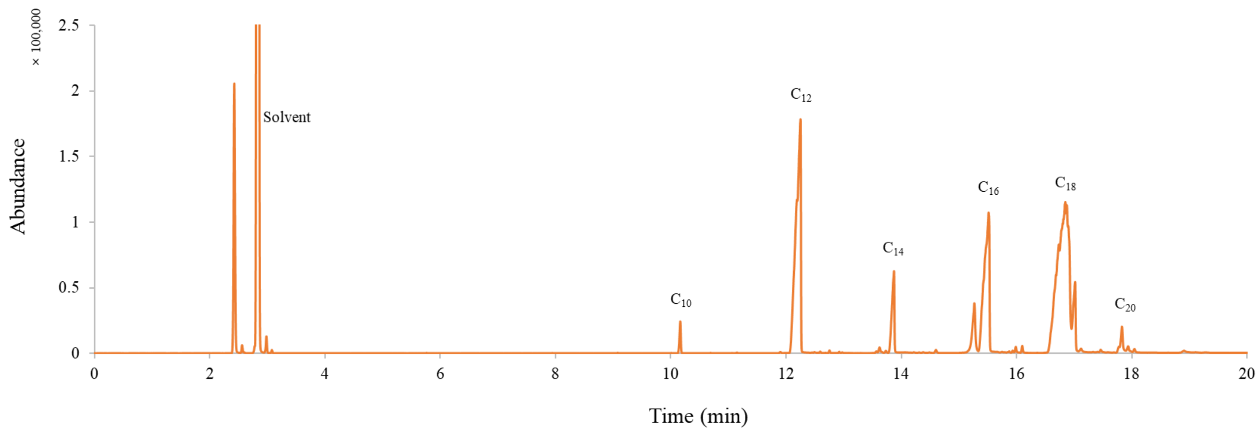

Figure 3. Chromatogram of FAMEs in BSFL lipids using GC-FID.

Table 7. Fatty acid composition of BSFL lipids.

Peak No.	Retention Time (min)	Area (%)	FAME Species	Compound Name
1	10.16	0.970	10:0	Decanoic acid, methyl ester
2	12.25	25.723	12:0	Dodecanoic acid, methyl ester
3	13.87	4.691	14:0	Tetradecanoic acid, methyl ester
4	15.27	3.459	16:1	9-Hexadecenoic acid, methyl ester
5	15.51	16.946	16:0	Hexadecanoic acid, methyl ester
6	16.85	39.764	18:2	8,11-Octadecadienoic acid, methyl ester
7	17.01	4.326	18:0	Octadecanoic acid, methyl ester

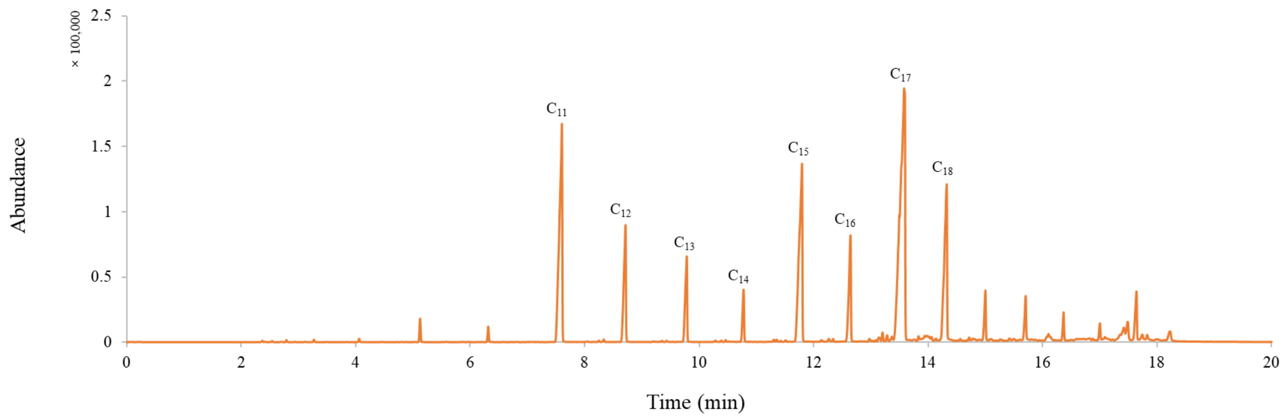

Figure 4. Chromatogram of hydrodeoxygenated BSFL oil using GC-FID.

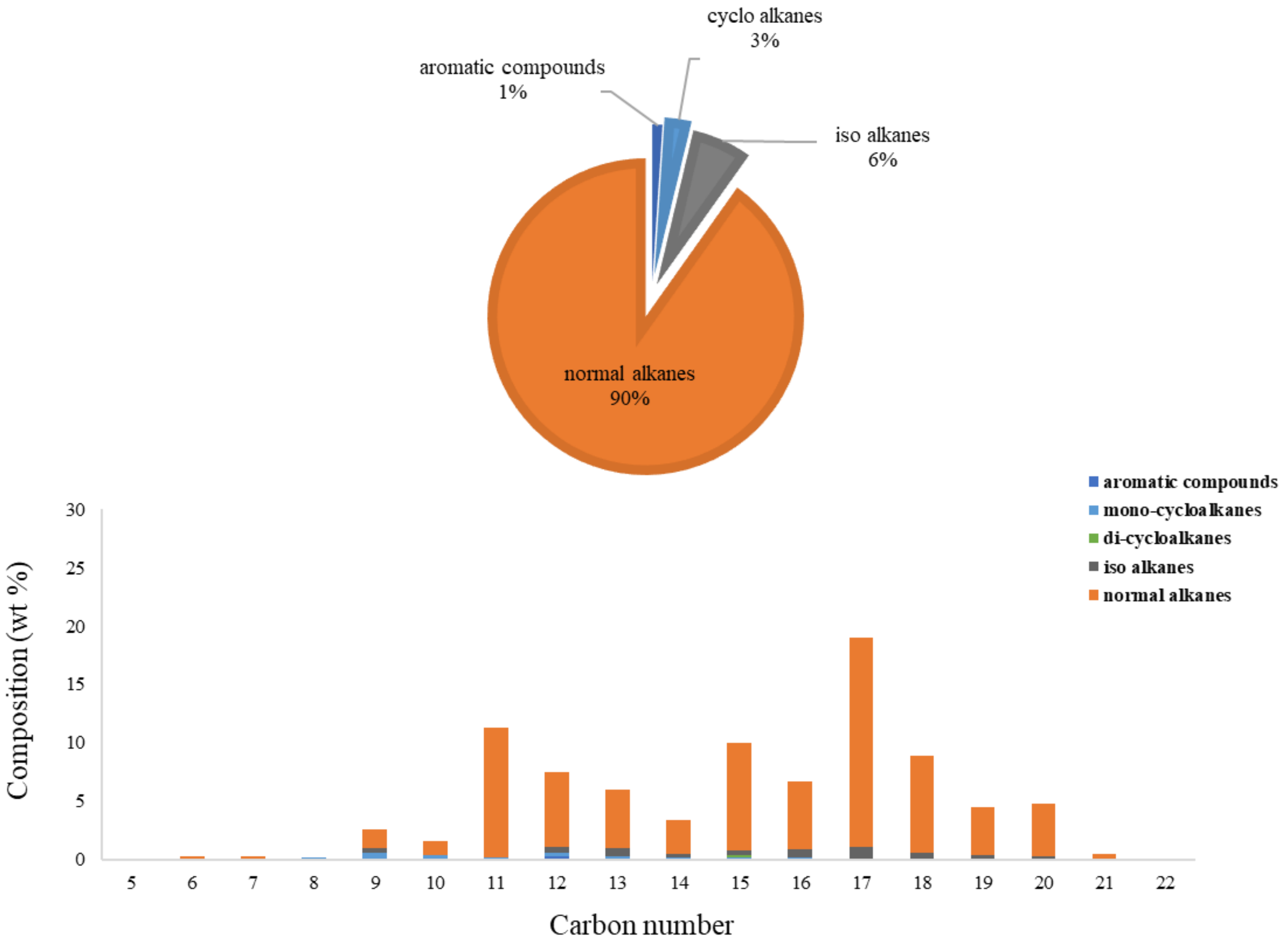

Figure 5. Hydrocarbon composition of hydrodeoxygenated BSFL oil.

4. Discussion

4.1. Process Performance

Black soldier fly larvae (BSFL) have been reported to consume a wide range of organic substrates and have been used for small-scale waste disposal purposes, including compost, straw, and food waste [27]. BSFL are also considered an alternative for animal feed due to their high protein and lipid content when fed plant-based waste. The lipids of BSFL are important feedstocks for green diesel production, as they are used in catalytic reactions [28]. In our study, four parameters were investigated to enhance the lipid yield for the mass production of BSFL oil. The lipid composition of BSFL, one of the parameters for increasing the lipid yield, can be modified through diet. As shown in Table 3, the most optimal insect production diet is E (an average rearing period of 6 days and a production rate of 5.23 kg), but the price of the substrate is high, so it is not economically feasible. The second dietary condition (with an average rearing period of 6 days and a production rate of 4.51 kg) does offer some potential for shortening the rearing period but still presents economic concerns in the context of overall feed efficiency. The most ideal feeding condition that can be applied to actual insect farming production is dietary condition I (an average rearing period of 8 days and a production rate of 5.40 kg). Diet *I* has advantages in terms of feed efficiency, reducing the rearing period, and insect yield. When the proportion of meat by-products exceeds 30%, a disadvantage appears in the form of increased viscosity, which leads to a lower larvae collection rate. Therefore, the appropriate mixing ratio for meat by-products is less than 30%. The effect of growing temperature indicates that as the substrate temperature increases from 28 °C to 38 °C, the rearing period is progressively shortened [29]. Therefore, the most suitable rearing temperature for BSFL appears to be a substrate temperature of 38 °C, which, in this case, resulted in the shortest rearing period. Hence, larvae rearing management should ideally be carried out within the range of 35 °C to 40 °C. For maintaining increased lipid yields during large-scale production and processing, it should also be considered that yields can be maximized by changing the drying method applied to the BSFL or the temperature at which they are extracted [30]. We confirmed that the extraction yield is maximized when a microwave is used for drying. In addition, it was confirmed that the lipid extraction yield increased under conditions of 65–75 °C when dried BSFL were introduced into the extractor. We suggest that the introduction of a separate, continuous boiling system may be necessary in order to maintain an increase in the lipid extraction yield during mass production and processing. Considering the potential for reducing rearing time and increasing production during the rearing and lipid extraction processes, it is expected that lipid extraction will be economically feasible.

4.2. Production for Green Diesel

Green diesel is produced via a process that converts fatty acids into hydrocarbon compounds by removing the oxygen contained within them [31]. In this study, the possibility of producing green diesel using a BSFL lipid hydrodeoxygenation reaction was confirmed. HDO, performed here using BSFL lipids, is a reaction that removes the oxygen contained in fatty acids in the form of CO_2, CO, and H_2O and reduces the number of carbon atoms converted to carbon dioxide (decarboxylation) and carbon monoxide (decarbonylation) [32]. The results of the EA demonstrated that the O content of hydrodeoxygenated BSFL oil decreased and that the HDO progressed in a continuous reaction over the catalyst. It was confirmed by the TGA results that the oil produced through HDO, but not crude oil, was similar to commercial diesel. This fuel, with a medium-chain range of distribution of hydrocarbons such as C_{10} to C_{14}, was observed to reduce the melting point to a greater extent than other HDO products [33,34]. Thus, it has the advantage of improving cold flow properties. In previous research, vegetable oils were made to undergo HDO and were converted into normal alkanes to produce green diesel [35]. The vegetable oils used in previous studies were mainly composed of C_{16} and C_{18} fatty acids [32,36]. Therefore, the main composition of normal alkanes derived from vegetable oils consisted of a long-chain-range hydrocarbon distribution, such as C_{15} to C_{18}. Srifa et al. reported that palm oil is composed of oleic acid ($C_{18:1}$, 45.8%), palmitic acid ($C_{16:0}$, 37.4%), and linoleic acid ($C_{18:2}$, 11.1%) [37]. The authors also suggested that the liquid product of palm oil hydrodeoxygenation exhibited a distribution in the C_{15} to C_{18} range of normal alkanes. In the study by Liu et al., Jatropha oil was found to contain high percentages of oleic acid ($C_{18:1}$, 38.3%), linoleic acid ($C_{18:2}$, 36.2%), and palmitic acid ($C_{16:0}$, 14.8%) [38]. The hydrodeoxygenation of Jatropha oil resulted in yields of C_{15} to C_{18} normal alkanes ranging from 53.63% to 78.37%. These normal alkanes became unsuitable for satisfying the cold flow properties as their concentration increased [35,39]. One distinguishing feature of BSFL oil, as compared to vegetable oils, is the presence of lauric acid ($C_{12:0}$, 25.723%). The hydrodeoxygenated BSFL oil contained 26.50% normal alkanes with carbon chains ranging from C_{10} to C_{14} and 41.33% normal alkanes with carbon chains ranging from C_{15} to C_{18}. HDO products derived from BSFL lipids were found to contain C_{11} alkane originating from C_{12} fatty acids. Furthermore, C_{15} alkane and C_{17} alkane were found to be derived from long-chain-range fatty acids also present in BSFL oil. Therefore, the utilization of hydrodeoxygenated BSFL oil, which was simultaneously converted into both low- and high-boiling-point hydrocarbons, reduced post-treatment processes such as distillation. It also demonstrated economic viability as a drop-in fuel compared to the conversion of vegetable-based oils.

5. Conclusions

In this study, we focused on investigating the optimal growth conditions for BSFL oil production to maximize the extraction of insect lipids. We analyzed the BSFL oil with the highest yield and conducted hydrodeoxygenation reactions to assess its potential for utilization as a green diesel. The results of the HDO process demonstrated that the carbon distribution of BSFL lipids exists within a similar range to the carbon distribution of diesel. Consequently, the composition of hydrodeoxygenated BSFL oil may contribute to green diesel production as a type of drop-in fuel. To the best of our knowledge, the HDO of BSFL oil has not yet been investigated as a method of green diesel production, and the optimization of the reaction system and separation/purification conditions should be explored in future research.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16020584/s1. Figure S1: Photographs of black soldier fly larvae (*Hermetia illucens*); Figure S2: Experimental apparatus; Figure S3: Photographs of (a) BSFL lipids and (b) hydrodeoxygenated BSFL oil.

Author Contributions: J.E.L.: data curation and writing—original draft. H.S.J.: writing—review and editing. Y.J.Y.: visualization and investigation. G.B.H.: visualization. Y.K.P.: data curation and software. Y.C.Y.: data curation and software. J.H.J.: conceptualization, methodology, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available upon request.

Conflicts of Interest: Authors Young Kyu Park and Young Cheol Yang were employed by the company Korea Beneficial Insects Laboratory, Co., Ltd. (KBIL). The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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