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A Green Process for Producing Biodiesel from Feather Meal

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This paper describes a new and environmentally friendly process for developing biodiesel from commercial feather meal, a waste product of the poultry industry. Currently, feather meal is used as an animal feed, given its high protein content, and also as a fertilizer because of its high nitrogen content. In this work, we have extracted fat from the feather meal in boiling water (70 °C) and then transesterified the fat into biodiesel using KOH and methanol; 7−11% biodiesel (on a dry basis) is produced in this process. ASTM analysis of the prepared feather meal biodiesel confirmed that the biodiesel is of good quality and comparable to other biodiesels made from other common feedstocks. Given the amount of feather meal produced by the poultry industry, it is estimated that this process can create 150−200 million gallons of biodiesel in the United States and 593.2 million gallons worldwide.

KEYWORDS: Feather meal; biodiesel; biodiesel feedstock from nonfood sources; green process; alternative energy

INTRODUCTION

Biodiesel is a fuel comprised of monoalkyl esters of long chain fatty acids that are derived from vegetable oils or animal fats (*1*). In the United States, soy, corn, canola, and cotton seed oil are the primary sources for biodiesel production. The use of these feedstocks for a prolonged time is potentially detrimental to society and the environment (*3*). According to the U.S. Department of Agriculture (USDA), "Industrial consumption of vegetable oil, which is dominated by biodiesel production, accounts for 40% of the annual vegetable oil demand growth yet represents only 20% of the overall vegetable oil consumption. Demand for non-food use of oil is expected to grow 10% annually" (*4*). This growth causes the line between food and fuel economies to be blurred as both of these stocks are competing for the same oil resources. A successful biofuel industry will not be based on digestible starch from staple crops such as corn (*5*). Since the major production cost of biodiesel is from its feedstock, the economics of biodiesel production are not impressive with current vegetable oil prices (*6*). The main problem the biodiesel industry frequently faces is the availability of cheap and abundant, high-quality feedstock. Thus, finding alternative, nonfood, feedstocks such as waste vegetable oil, grease, and animal fats (beef tallow)(*7*, *8*) is considered a necessity for the industry. Recently, our research group has demonstrated spent coffee grounds as an alternative and versatile source of biodiesel (*9*). Through continued research to produce biofuels from nonfood sources, it has been discovered that feather meal offers another promising feedstock source for biodiesel production.

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According to the U.S. Census Bureau, feather meal (hydrolyzed poultry feathers) is defined as "the product resulting from the treatment under pressure of clean, undecomposed feathers from slaughtered poultry" (*10*). Feather meal is also prepared by rendering the feathers with other waste materials such as blood and offal from the poultry industry using high pressures. The rendering process involves the hydrolysis of polypeptide chains of feather proteins using supercritical water (*11*). The hydrolysis process converts high-molecular weight, nondigestible proteins of the feather, such as keratins, into small and digestible proteins. The molecular weight and the nutritional values of the newly formed proteins or polypeptides depend on the time, temperature, and pressure of the supercritical hydrolysis process (*12*). Interestingly, these feather meal samples contain certain amounts of fat. The fat content of the feather meal varies from 2 to 12% depending upon the type of feathers used. For example, chicken feathers contain approximately 11% fat content, while turkey and duck feathers contain approximately 6.7% fat content (*13*). A brief description of the eco-friendly extraction of fat (biodiesel feedstock) from chicken feather meal and its successful conversion to biodiesel (**Figure 1**) is presented here.

MATERIALS AND METHODS

Materials. Foster Farms supplied the feather meal samples (chicken feather). Fatty acid methyl esters (99% purity), anhydrous methanol (HPLC grade), tannic acid (ACS grade), and potassium hydroxide (KOH, 86% assays) were purchased from Sigma Aldrich and were used as received.

Extraction and Purification of Fat from Feather Meal. The feather meal sample (100 g) was stirred with 300 mL of water at 70 °C for 20 min. The adsorbed fat on the protein content of the feather meal was melted and floated on the surface of the water layer. The top layer was decanted and centrifuged for 10 min (5000 rpm; Beckman model J2-21

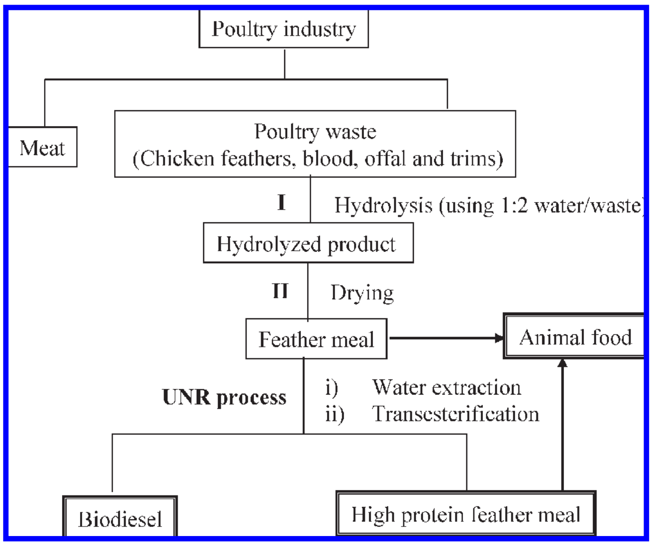

Figure 1. Schematic representation of biodiesel production from poultry waste.

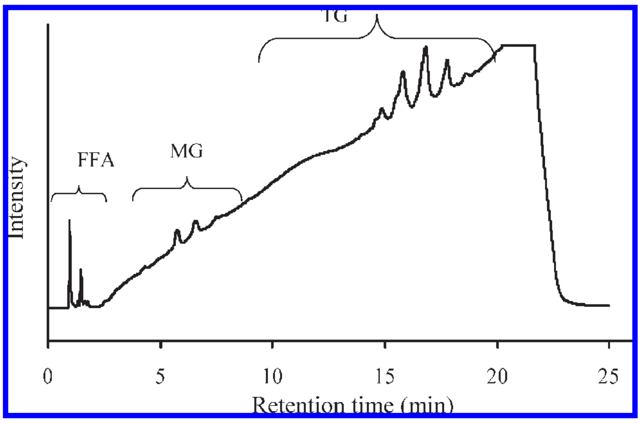

Figure 2. HPLC chromatogram of fat extracted from the feather meal indicating the presence of a small amount of free fatty acids (FFA), monoglycerides (MG), and triglycerides (TG).

centrifuge) to collect the fat content (7.5 g) of the feather meal. The collected fat was mixed with a basic solution of potassium hydroxide (KOH) to remove the free fatty acids (FFA) in the form of soap. The soap was separated from the fat content by centrifugation. The purified fat (6.9 g) was processed to the next step, transesterification.

Transesterification of Fat from Feather Meal. Transesterification of the purified fat (6.9 g) described above was conducted to convert the triglycerides to biodiesel. In this process, the recovered fat content was preheated to 100 °C and cooled to room temperature to remove the traces of water present; a solution of methanol (1:9 molar ratios) and 1 wt % KOH (as a catalyst) were added to the fat. The reaction mixture was refluxed at 70 °C for 1 h. Optimization of the transesterification reaction was achieved by varying the amounts of methanol and potassium hydroxide. The reaction time for the complete transesterification was monitored via high-performance liquid chromatography (HPLC, Shimadzu LCsolution). A steel column was used with 150 mm × 3.2 mm packed with C_{18} particles with a diameter of 7 μm for HPLC analysis. Gradient elution was set by mobile phases A (methanol) and B [4:5 (v/v) 2-propanol/hexane mixture]. The course of the gradient was as follows: reached 50% B from 0 to 20 min, changed to 100% A from 20 to 21 min, and then held for an additional 4 min. The dosing volume was 100 μL, and the dilution of the sample was 1:20 in phase B. Spectrophotometric detection in the UV region at 205 nm was used (*14*).

Purification and Characterization of Biodiesel. After the transesterification process, the reaction mixture was allowed to cool to room temperature overnight. The bottom layer, glycerin, was separated from the

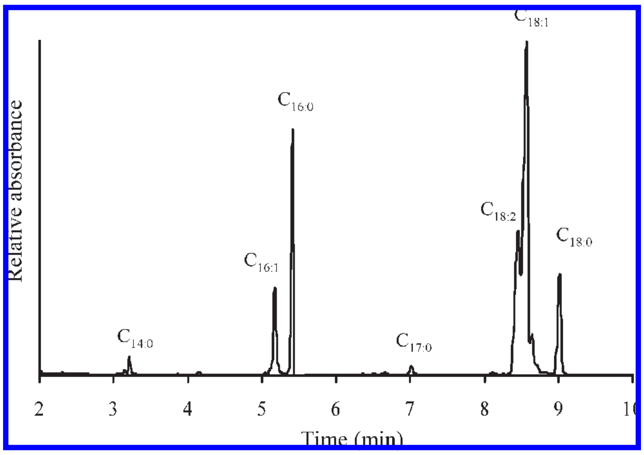

Figure 3. Gas chromatogram of the biodiesel showed different methyl esters of fatty acids present in the biodiesel produced from feather meal. Identification of individual methyl esters was achieved using mass spectroscopy (MS) (details are in the Supporting Information).

Table 1. Fatty Acid Profile of Biodiesel Produced from Feather Meal Fat (calculated from GC−MS data using an internal standard)

retention time (min)	methyl esters of fatty acids	wt %
5.41	hexadecanoic acid (palmitic acid, C_{16}:0)	28.86
8.46	octadecadienoic acid (linoleic acid, C_{18}:2)	14.44
8.58	octadecenoic acid (oleic acid, C_{18}:1)	46.10
9.02	octadecanoic acid (stearic acid, C_{18}:0)	10.06

Table 2. ASTM Analysis of Feather Meal Biodiesel

test name	test method	limit	result
free glycerin (mass %)	ASTM D 6584	MAX 0.020	0.004
monoglycerides (mass %)	ASTM D 6584	N/A	0.061
diglycerides (mass %)	ASTM D 6584	N/A	0.056
triglycerides (mass %)	ASTM D 6584	N/A	0.003
total glycerin (mass %)	ASTM D 6584	MAX 0.240	0.123
flash point, closed cup (°C)	ASTM D 93	MIN 130	154
sodium and potassium (ppm)	EN 14538	MAX 5	5
KF and water (ppm)	ASTM D 6304	N/A	188
viscosity at 40 °C (cS)	ASTM D 445	1.9−6.0	5.48
oxidative stability by Rancimat (h)	EN 14112	MIN 3.00	6.46
sim. distribution, 90% recovery (°C)	ASTM D 2887	MAX 360	355
cetane index	ASTM D 976	N/A	61
cloud point (°C)	ASTM D 2500	N/A	23
pour point (°C)	ASTM D 97	N/A	6

biodiesel. The top layer was then washed twice with warm water (40−45 °C) and with acidified water (0.5 wt % tannic acid) to remove the excess methanol and the traces of catalyst (*15*, *16*). The purified biodiesel was characterized using a Shimadzu gas chromatograph coupled with a mass spectroscope (GC−MS) and with a Shimadzu LCsolution HPLC system.

RESULTS AND DISCUSSION

In the process of hydrolyzing the proteins, the rendering process also releases the fat content of the feathers (which is approximately 2−4%) (*17*). The fat from the feathers and the rest of the waste materials such as blood and offal are adsorbed on the low-molecular weight protein content of the feather meal. When the feather meal was stirred with hot water, the fat melted and started floating on the surface of the water. A total of 6.9% of the fat was extracted using water as a solvent (Figure S1 of the Supporting Information) with stirring for 20 min. The total fat content of the feather meal was determined prior to water extraction using hexane extractions on samples from the same

Table 3. Total Poultry Industry Annual Production of Meat, Waste Products, and Tentative Amount of Biodiesel That Coulc Be Produced from the Waste Products in 2008

poultry industry	meat produced in the United States (million pounds)	poultry industry waste[a] (million pounds)	total fat content (wt %)	tentative biodiesel production (million gallons/year)
broilers	37125[a]	9700	11[b]	139
turkeys	6135[a]	1603	6.7[b]	14
				total = 153[c]

[a]The total mass loss from a living broiler to the meat is estimated to be 26.13%. It requires 50257 million pounds of live chicken to produce 37125 million pounds of meat (Haley, M. M. Livestock, Dairy, and Poultry Outlook; United States Department of Agriculture. LDP-M-165, March 19, 2008). [b]Total amount of fat in chicken feather meal (11%) and turkey feather meal (6.7%) (*13*). [c]Using an average of $3/gallon, this process is estimated to have a $459 million market. We project that a medium size plant should produce biodiesel at the cost of $1/gallon using this process.

batch. Hexane was used, instead of ether, for the solvent extraction to minimize the extraction of unwanted polar compounds, such as free fatty acids found in the feather meal. The total fat content from the tested batch was approximately 11%, increasing the time of extraction and/or the usage of the ultrasonication technique might further improve the fat extraction capabilities (*13*). The advantage of this process is it eliminates the costs of additional solvent use. Moreover, using water as a solvent helps in the removal of FFA, which ultimately provides high-quality feedstock. After the feather meal had been stirred with water, the pH of the water was changed from 5.5 to 4.5, which indicated the dissolution of FFA in the water. Preheating of the fat content prior to the transesterification helped to remove the trace amounts of water present in the reaction mixture. The HPLC chromatogram of the fat content obtained from feather meal is shown in **Figure 2**. Small amounts of FFA and monoglycerides (MG) were also observed.

Catalyst (1 wt %) and a 1:9 (molar ratio) oil/methanol mixture were optimum conditions for the transesterification reaction (*18*). Transesterification kinetics were measured by monitoring the TG peaks in the HPLC chromatogram. Complete transesterification was further confirmed by American Society for Testing and Materials (ASTM) D 6584. Complete transesterification was observed within the first 15 min. Faster reaction times were attributed to the greater volume of methanol used in the reaction. Gas chromatography (GC) measurements of the biodiesel prepared as described above showed a combination of various types of methyl esters (**Figure 3**). Individual peaks in the GC results were analyzed and identified using mass spectroscopy (MS) (data not shown here). It is noted that feather meal biodiesel contains a wide variety of fatty acid methyl esters ranging from C14 to C22. The major composition of feather meal biodiesel consists of methyl esters of palmitic (C16:0), steric (C18:0), linoleic (C18:2), and oleic (C18:1) acids. The composition of feather meal biodiesel is mentioned in **Table 1**. We observed that the fatty acid profile of feather meal did not differ significantly from the fatty acid profile of chicken fat (*19*). Feather meal biodiesel contained oleic acid (∼46%) and palmitic acid (∼29%) as major free fatty acids. Biodiesel containing compounds with carbon chain lengths of ≥15 produces superior-quality fuel (*20*). The presence of saturated fatty acids (∼40 wt %) gave a good oxidative stability to biodiesel. To further evaluate the quality of the biodiesel, we have conducted ASTM analysis of the produced biodiesel.

The ASTM set the complete and comprehensive tests for biodiesel evaluation (ASTM D 6751). While there are many different parts of the test, fuel must pass the entire battery of tests to be marketed as a fuel for use in diesel engines and to comply with the Environmental Protection Agency (EPA) standards. The complete ASTM analysis (**Table 2**) showed that it has good cetane number and high oxidation stability, which are good qualities in a biofuel for commercialization.

Currently, feather meal use is limited to animal food and nitrogen fertilizer. Removal of the fat content from the feather meal increases the protein content and results in a higher-grade animal feed. Additionally, since this process removes the fatty acid content from the feather meal, the nitrogen content increases, and feather meal becomes a better nitrogen source for fertilizer applications. On the basis of a 10% oil yield, the United States' poultry industry could produce approximately 153 million gallons of biodiesel annually from feather meal (**Table 3**). If this technology expands worldwide, it could potentially produce 593.2 million gallons of biodiesel, according to the United Nations Food and Agriculture Organization Report for 2005. This technology can be expanded to other poultry industries (duck and turkey) and can potentially contribute to reducing the demand for foreign oil and help solve further petroleum demands.

In conclusion, a green process for producing biodiesel from feather meal has been illustrated. The removal of the fat content from feather meal produces a better food source for animals and fertilizer for agriculture. Considering the total U.S. and world production of poultry waste, this process has the potential to create approximately 139 million gallons and 593.2 billion gallons of biodiesel per year, respectively. This research aims to achieve the goal "food for hunger and waste for fuel".

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Supporting Information Available: A complete schematic of the extraction process (Figure S1), centrifuged water layer after the feather meal had been stirred with hot water (Figure S2), feather meal images before and after the fat extraction process (Figure S3), fat content and biodiesel made from feather meal (Figure S4), HPLC chromatogram of feather meal biodiesel (Figure S5), and mass spectroscopy data of fatty acid methyl esters (Figure S6). This material is available free of charge via the Internet at http://pubs.acs.org.

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