

Metformin (1,1-dimethylbiguanide) as Potential Organic Base Catalyst for the Transesterification of Coconut Oil with Methanol

Juvinch R. Vicente^{1*}, Ida G. Pahila², Mae Grace G. Nillos^{3*}

¹Department of Chemistry, College of Arts and Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo, Philippines

²Biodiesel from Microalgae Project, Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo, Philippines

³Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo, Philippines

ABSTRACT

Biodiesel is conventionally produced by alkali-based transesterification, which is limited by the presence of water and the free fatty acid content of oil feedstock. This study investigated the potential of metformin (1,1-dimethylbiguanide) as an alternative organic base catalyst for the transesterification of coconut oil with methanol. Two parameters were considered in this work, the catalyst loading and the amount of water in the feedstock. When no water is present in the feedstock, metformin showed a significant FAME yield of $55 \pm 8\%$ at 1.0% w/w catalyst/oil. Increasing the amount of metformin to 2.0% w/w significantly increased FAME yield to $71 \pm 4\%$. In the presence of water (5.0%, w/w water/oil) however, the catalytic performance of metformin was practically lost, with FAME yields of only $5.5 \pm 0.3\%$ (1.0% w/w catalyst/oil) and $2.6 \pm 0.4\%$ (2.0% w/w catalyst/oil). Overall, metformin showed the ability as a catalyst for the transesterification of coconut oil with methanol. However, its efficiency is limited only to conditions where the water level in the feedstock is minimal.

KEYWORDS:

Fatty acid methyl ester (FAME); fatty acid; biodiesel; plant-based oils

INTRODUCTION

The energy demand is higher than ever. As such, more and more fossil fuel is needed to fulfill this demand. However, the world's fossil fuel production is expected to decline within ten decades (Surendhiran and Vijay, 2012). As a consequence, the search for alternative sources of energy to deal with the impending energy crisis has become a priority for public and private industry sectors worldwide (Campbell, 2008).

In recent years, researchers have been focused on exploring alternative sources of diesel fuel, particularly those produced from fats and oils through transesterification known as biodiesel (Pizarro *et al.* 2006) installation of liner material, and engineering fees. The majority of operational costs were due to

energy requirements for biomass drying, pumping water, and repayment of capital investment. On farms using anaerobic pretreatment, waste heat from burning of biogas could be used to offset the energy requirements of biomass drying. In addition, biogas combustion exhaust gas could then be recycled back to the algal system to supply dissolved inorganic carbon for optimal algal production and pH control. Under the best case (algal system coupled with anaerobic digestion pretreatment. Technically, biodiesel is defined as a fuel comprised of mono-alkyl esters of long-chain fatty acids from vegetable oil or animal fats (Xiong *et al.* 2008). Presently, biodiesel is derived from various sources of vegetable oil and animal fats feedstock. Some include edible oils such as palm, soybean, jojoba, sunflower seed, rapeseed, and coconut oil (Sercheli *et al.* 1999; Canoira *et al.* 2006; Reaume and Ellis, 2013; Santos *et al.* 2013; Wang *et al.* 2020). However, many argue that using edible oil sources directly affects availability of arable

*Corresponding Author:

Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas; email address: mgnillos@up.edu.ph

land and, more importantly, food security. For these reasons, some works resorted to produce biodiesel from non-edible sources (Payawan *et al.* 2010; Kumar *et al.* 2011; Attia *et al.* 2014; Chen *et al.* 2022). More recent works are also focused on microalgae-based biodiesel sources (Han *et al.* 2015; Heimann 2016; Vijayalakshmi *et al.* 2020). One challenge with most biodiesel is its inherent low cold flow properties. Biodiesel derived from coconut oil has the advantage of having better cold flow properties, lower cloud point and lower pour point temperature than most other sources owing to its higher percentage of medium chain fatty acids (MCFA) (Reaume and Ellis, 2013).

Conventional biodiesel production involves transesterification of triglycerides from various oil feedstocks with small molecule alcohols like methanol or ethanol (Lotero *et al.* 2005; Xiong *et al.* 2008). Several methods are employed for carrying out transesterification reactions including the conventional batch process, supercritical processes (Sawangkeaw *et al.* 2011; Bernal *et al.* 2012; Singh *et al.* 2021) pressure (15.0–20.0MPa), ultrasonic methods (He and Van Gerpen 2012; Attia *et al.* 2014; Wang *et al.* 2020), and microwave methods (El Sherbiny *et al.* 2010; Zhang *et al.* 2010; Kumar *et al.* 2011; Gude *et al.* 2013; Larraza and Malko, 2020; Yusoff *et al.* 2022) produced by seed-bearing shrubs, can provide an alternative and do not have competing food uses. However, these oils are

characterized by their high free fatty acid contents. Using the conventional transesterification technique for the production of biodiesel is well established. In this study an alternative energy stimulant, “microwave irradiation”, was used for the production of the alternative energy source, biodiesel. The optimum parametric conditions obtained from the conventional technique were applied using microwave irradiation in order to compare the systems. The study showed that the application of radio frequency microwave energy offers a fast, easy route to this valuable biofuel with the advantages of enhancing the reaction rate (2 min instead of 150 min).

Transesterification reaction often yields a mixture of fatty acid methyl ester (FAMES) or fatty acid ethyl esters (FAEEs) depending on the alcohol used (Chopade *et al.* 2012). Transesterification of triglycerides with either methanol or ethanol primarily employs the use of alcohol-soluble alkali catalysts typically, sodium and potassium hydroxides (NaOH or KOH) or methoxides (NaOCH₃ or KOCH₃), mainly because of their low cost and their efficiency to promote transesterification of various feedstocks at relatively mild conditions (Ma *et al.*, 1998; Kim *et al.*, 2004). This process is summarized in Figure 1. Briefly, the alcohol (e.g. CH₃OH) is first deprotonated by the base catalyst (B) to form an alkoxide, which is a nucleophile that readily attacks the carbonyl groups of the triglyceride forcing the substitution of the alkoxy

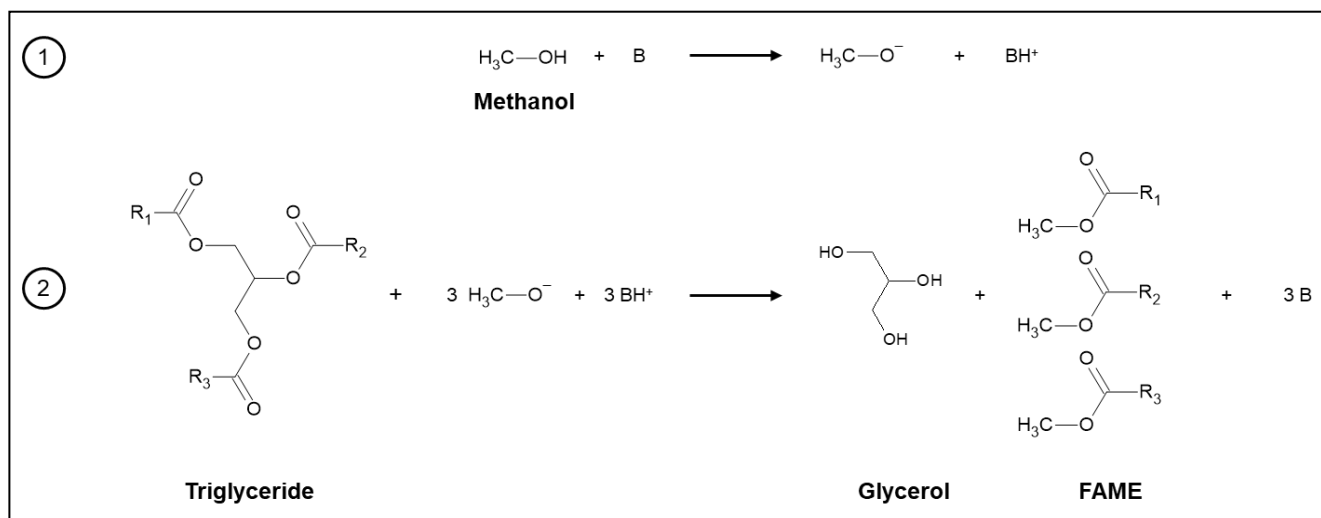


Figure 1. A schematic diagram of a base-catalyzed transesterification of triglycerides with methanol (typically, R = C11 to C19). (1) Methanol is first deprotonated by the base-catalyst forming methoxide (nucleophile). (2) The resulting alkoxides then attack the carbonyl groups of the triglyceride, forcing the alkoxy group of the glycerol backbone to be substituted forming FAMES.

group of the glycerol backbone forming FAMES. However, a major problem during alkali-catalyzed transesterification reaction is that the presence of high free fatty acid (FFA) content of the feedstock neutralizes the catalyst, hence more base catalyst is required. Also, this produces emulsions which make the separation of the final products difficult (Kim *et al.* 2004; Payawan *et al.* 2010). Overall, these factors lead to lower biodiesel yield (Akbar *et al.* 2009).

Acid catalysts are often employed to augment the drawbacks brought about by the high FFA content of feedstock since these catalysts are not susceptible to FFAs. Nonetheless, this type of catalysis is much slower compared to base catalysis and effective only at higher temperatures (Crabbe *et al.* 2001; Kiss *et al.* 2006).

Another alternative transesterification process for biodiesel production is the use of enzymes, such as lipase (Tan *et al.* 2010; El-Shimi *et al.* 2013; Kalita *et al.* 2022). However, major disadvantages of enzyme-catalyzed transesterification include slower reaction rates and possible inactivation of the enzymes by methanol. In addition, enzymes are more costly compared to conventional chemical catalysts. This problem is often circumvented by the immobilization of the enzymes on a solid support to allow their recycling (El-Shimi *et al.* 2013).

Recently, nitrogen-containing organo bases such as guanidines, biguanides, and amidines have been attracting much attention in organic synthesis due to their potential application as catalysts (Ishikawa *et al.* 2009; Racar *et al.* 2023) (Figure 2). They have already shown promising catalytic activities for important organic reactions such as Knoevenagel reactions,

Michael addition, Epoxidation, and Aldol reactions (Blanc *et al.* 2000; Pratt *et al.* 2006; Alizadeh *et al.* 2012). More importantly, a limited number of studies reported the high conversion of soybean and jatropha seed oil into fatty acid methyl esters (FAME) by these catalysts at relatively fast reaction rates (Sercheli *et al.* 1999; Payawan *et al.* 2010). The main advantage of organic bases is that they can tolerate high FFA levels in feedstock because the guanidine-FFA complex is soluble in the reaction mixture and does not form soap or emulsions (Schuchardt *et al.* 1998; Sercheli *et al.* 1999; Racar *et al.* 2023).

Free fatty acid (FFA) and moisture content of the oil feedstock are important parameters in biodiesel production via transesterification (Pramanik, 2003). This is primarily because the presence of FFA and moisture in the oil feedstock have been shown to lead to a lower yield of alkali base-catalyzed transesterification of oil (Akbar *et al.* 2009). Because of this, oil for biodiesel production must have sufficiently low moisture and FFA content (<3%). The utilization of an organic base catalyst, that is not sensitive to the FFA content of oil for biodiesel production, may help minimize the need to refine oil feedstock, and its associated cost could be avoided.

In this study, metformin (1,1-dimethylbiguanide), which is readily available as an oral medication for Type-2 diabetes, was evaluated for its potential as an organic base catalyst for the transesterification of coconut oil with methanol. The effects of the water content of oil and catalyst concentration on FAME yield from the transesterification of coconut oil with methanol were evaluated.

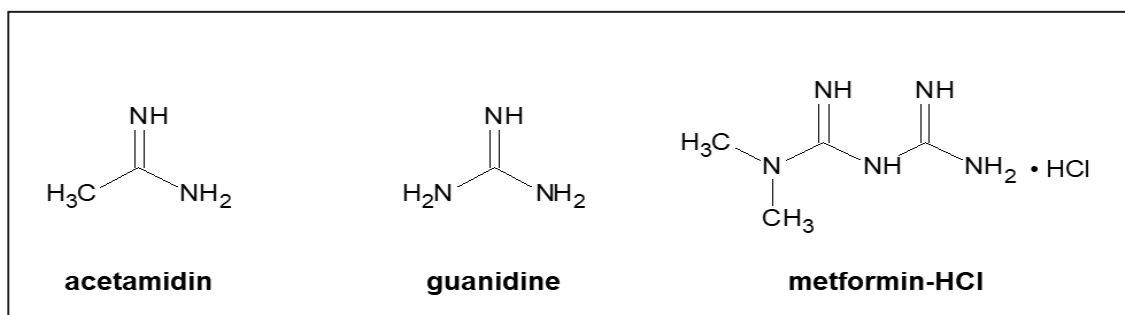


Figure 2. Some examples of amidines, guanidines, and biguanides

This study evaluated the potential of an organic base catalyst, metformin, for the efficient production of biodiesel through the transesterification of oil with methanol. Metformin in its salt form (metformin hydrochloride) is a very cheap and readily available material. Furthermore, unlike NaOH, this catalyst is not corrosive to reaction vessels, which may lead to a reduction of cost on equipment maintenance. Also, because of the compound's organic functional groups, the development of a heterogeneous catalyst based on this compound would be relatively easier. Coconut oil, which is a common feedstock in biodiesel production, was utilized in this study primarily due to its availability, however, the results obtained in this work could provide the basis for applications on other oil feedstocks as well. Results from this study provide valuable information on potential alternative transesterification reactions that could help improve current practices on biodiesel production.

MATERIALS AND METHODS

Chemicals

Refined, bleached, and deodorized Coconut Oil (Minola™) with Vitamin A (~0.003%) used in this experiment was purchased from a local supermarket. Methanol (CH₃OH) (99.8%), anhydrous sodium sulfate (Na₂SO₄), and sodium hydroxide (NaOH) were all analytical grade from Scharlau. Metformin tablets (as 500 mg metformin hydrogen chloride) were purchased -(RiteMed™) from a local pharmacy. Molecular sieves (1.6 mm) was purchased from Sigma-Aldrich.

Coconut oil and methanol were dried by adding appropriate amounts of pre-dried molecular sieve. Sodium sulfate and molecular sieve were dried by heating at 110°C in an oven for at least an hour and were kept inside the desiccators when not used. metformin hydrogen chloride was dissolved in distilled water and added with an equimolar amount of NaOH. The resulting mixture was then oven-dried at 110°C overnight.

Transesterification of Coconut Oil with Methanol

About 10.0 grams of coconut oil (ave. MW: ~670 g/mol) (Seneviratne and Jayathilaka, 2016) and 3.8 mL methanol (equivalent to about 6:1 methanol to

oil mole ratio) in which a nominal amount of catalyst (1.0% or 2.0% w/w catalyst/oil) was dissolved, were placed in two separate 100-mL amber bottles and heated to 60°C over a hot plate. When both oil and methanol (with catalyst) reached 60°C, the two mixtures were mixed and immediately covered. The resulting mixture was placed in screw-capped 100-mL amber bottles.

The transesterification process was done for 60 minutes for the NaOH-catalyzed reaction and 120 minutes for the metformin-catalyzed reaction. A longer reaction time was used for metformin to ensure that equilibrium was achieved. The reaction for metformin was done for 120 minutes as previously used by Payawan *et al.* 2010 for other organic bases. At the end of the reaction, about 6.0 mL of the resulting mixture was transferred to pre-cleaned and dried test tubes, after which an equal amount of 0.10 M HCl was added to neutralize the catalyst (Santos *et al.* 2013). The phases of the resulting mixture were then separated by centrifugation for 10 minutes and the upper (biodiesel and unreacted oil) layer was recovered. The recovered biodiesel was rinsed at least three times with distilled water until the washings become clear. Centrifugation was done between washings to separate the aqueous layer from the biodiesel. The washed biodiesel was dried with anhydrous sodium sulfate (Na₂SO₄) and stored at 4°C until chemical analyses commenced.

Effects of Water Content of Coconut Oil and Catalyst Concentration

Effect of Water Content. For experiments with 0.0% w/w water content, 10.0 g of dried coconut oil was used as the feedstock. To obtain a feedstock with 5.0% w/w water/oil, 0.5 grams of distilled water was added to 9.5 grams of dried coconut oil followed by thorough mixing with a magnetic stirrer for an hour. The resulting feedstocks were then heated to 60°C with stirring in a screw-capped bottle before mixing with 3.8 mL of methanol with dissolved catalysts. Control experiments were also prepared where both feedstocks were mixed with 3.8 mL pure methanol in the absence of the catalyst.

Effect of Catalyst Concentration. The concentration of the catalysts was varied by dissolving appropriate amounts of catalyst to a fixed amount of

methanol. To obtain a nominal concentration of 1.0% and 2.0% w/w catalyst/oil, 0.4 grams and 0.8 grams of catalysts, respectively, were dissolved to 15.0 mL (12.0 g) methanol in a screw-capped bottle and heated to 60°C. From this, 3.8 mL methanol was transferred to bottles containing the coconut oil feedstocks.

Analysis of FAME

FAME was analyzed through refractometry, which is a rapid and inexpensive method with results previously reported to be in good agreement with those of GC-MS results for the transesterification of soybean oil with methanol and ethanol (Santos *et al.* 2013). The methods described here were based on Tubino *et al.* (2014) and Santos *et al.* (2013) with some modifications as described below. The transesterification reaction was monitored by determining the amount of free fatty acid methyl esters (FAME) in the biodiesel produced after the reaction.

Preparation and Evaluation of "pure" biodiesel. Five hundred milligrams (500.0 mg) of NaOH (1.0 % w/w catalyst/oil) was dissolved in 15.0 g (excess) methanol and heated to 60°C. Fifty grams (50.0 g) of coconut oil was also heated to the same temperature. Once the desired temperature was reached for both oil and alcohol, they were mixed inside a flat bottom flask and refluxed at 60°C with stirring for 1

hr. The glycerol (lower phase) was discarded after the reaction, and the same amount of base and methanol was added to the remaining liquid phase. The reaction was repeated for another hour to ensure maximal conversion of the coconut oil to biodiesel. The resulting mixture was rinsed first with an equal volume of 0.10 M HCl (Santos *et al.* 2013). The phases were then separated using centrifugation and the upper layer was recovered. The biodiesel was then rinsed at least three times with distilled water with separation by centrifugation between rinsing. Finally, the resulting product was dried with sodium sulfate and transferred to a pre-cleaned and dried amber bottle.

Refractive Index Calibration Curve. From the pure biodiesel produced above, a series of biodiesel-oil solutions were prepared. The following concentrations were used to establish the calibration curve: Pure coconut oil, 5%, 10%, 20%, 30%, 50%, 70%, 80%, 95% (w/w) biodiesel in coconut oil, and pure biodiesel. The refractive index (RI) values of the solutions above were measured using an Abbe refractometer which was thermostatically controlled by an external bath to maintain a temperature of 40°C. The measured RI values of the solutions were then plotted against known concentrations, and a best-fit line was generated by linear regression shown in Figure 3.

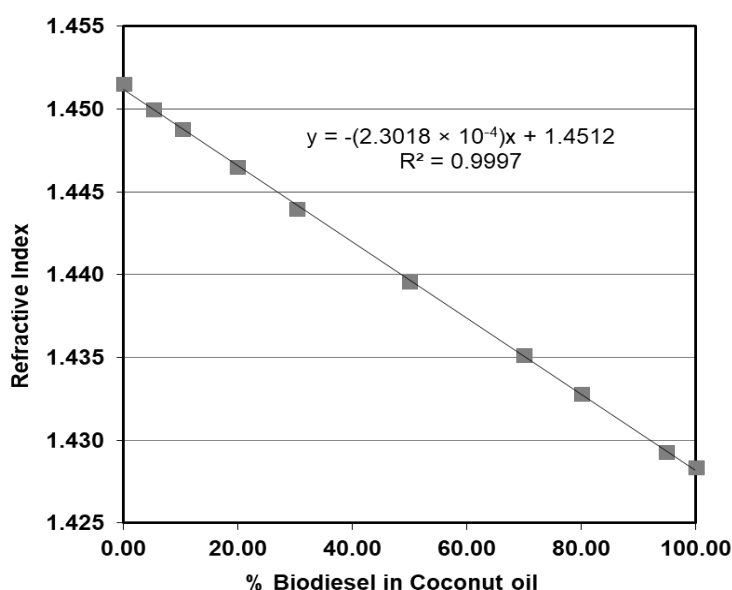


Figure 3. Refractive index at 40°C as a function of %w/w biodiesel in dry coconut oil. A series of solutions of biodiesel in coconut oil with known concentrations were prepared by mixing the "pure" biodiesel described in the methods section with dry coconut oil.

Measurement of FAME yield. The refractive index (RI) values of purified samples from transesterification were measured using an Abbe refractometer maintained at 40°C. The refractometer was rinsed with isopropyl alcohol between analyses of different samples. The concentrations of FAME in the biodiesel produced were then determined using the equation of the best-fit line generated above.

Data Analysis

The individual effects and interaction between variables for each catalyst were studied using a two-level full factorial design. The levels of the factors chosen were based on previous reports (Santos *et al.* 2013) and trial runs. All experiments were done in triplicates and the values are reported as mean \pm standard deviation. Control treatments, which are treatments with no catalyst added, were also done for two water content levels.

One-way Analysis of Variance (ANOVA) was used to determine significant differences in the FAME yield between the two catalysts studied (NaOH and metformin) within and between the water content of oil (0.0% and 5.0% w/w water/oil). The same analysis was performed to determine significant differences in FAME yield between two catalyst concentrations

(1.0% and 2.0% w/w catalyst/oil). For treatments with significant differences, post hoc analysis by pairwise t-test was done to see the differences between the treatment means. Two-way ANOVA was also done to study possible interactions between the variables under investigation.

RESULTS AND DISCUSSION

Effect of Catalyst Concentration on the amount of FAME of Biodiesel

Catalyst type and its concentration play very important roles in the production of biodiesel fuel (Ma *et al.* 1998; Fukuda *et al.* 2001; Kim *et al.* 2004; Ejikeme *et al.* 2010; Atadashi *et al.* 2012; El-Shimi *et al.* 2013). Thus, the effect of catalyst concentration was considered in this study. To investigate the effect of catalyst loading, an appropriate amount of NaOH or metformin was added to excess methanol to obtain a nominal catalyst concentration of 1.0% and 2.0% (w/w of oil). The transesterification reaction was monitored by determining the amount of FAME (%) in the biodiesel produced (Figure 4).

Figure 4A shows the effect of catalyst concentration on the transesterification of coconut oil

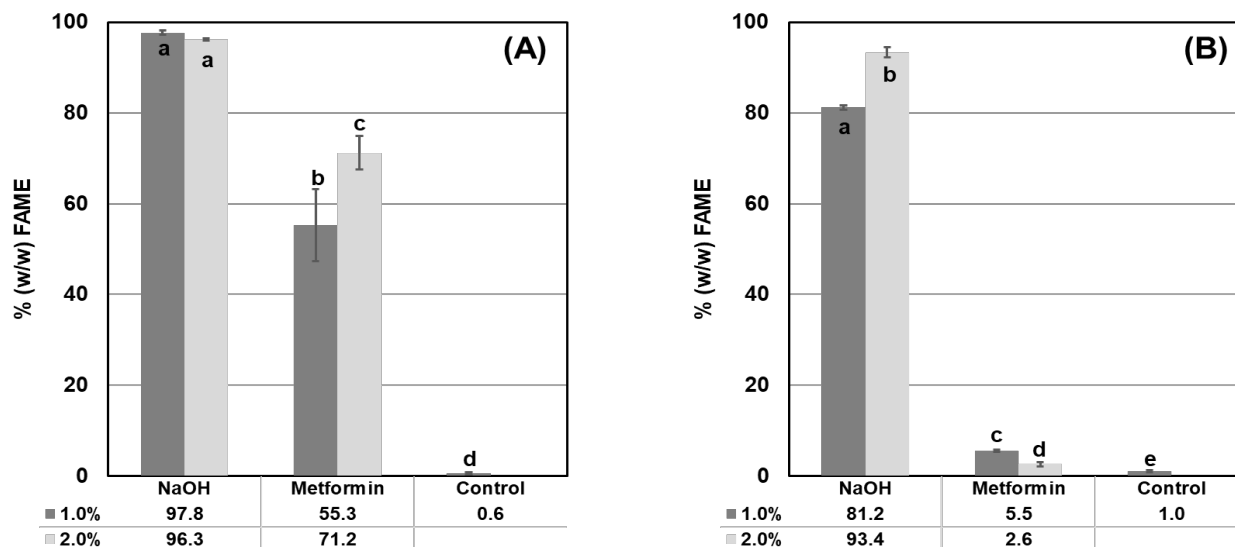


Figure 4. Percent (%) FAME of biodiesel produced from transesterification of coconut oil with methanol catalyzed by NaOH and Metformin at (A) 0.0% water content, and (B) 5.0% water content. N = 3 for each treatment; Values indicated mean \pm standard deviation. Treatments sharing the same letter are not significantly different ($p=0.05$). Dark gray bars indicate 1.0% catalyst (w/w), while light gray bars indicate 2.0% catalyst (w/w).

with methanol treatments where no water was added to the oil. No significant difference was observed between the FAME yield of the reactions catalyzed by 1.0% and 2.0% NaOH (Figure 4A, left). This result agrees with the report of Vyas et al. (2011). The slight decrease in the FAME yield of the reaction catalyzed by 2.0% NaOH is attributed to the formation of soaps (Vyas *et al.* 2011). This was confirmed in the experiment as suds were observed during the purification of biodiesel catalyzed by 2.0% NaOH. The free fatty acids (FFA) that reacted with NaOH could have been produced from the hydrolysis of oil by residual water left after the oil and alcohol were dried by the addition of molecular sieves (Figure 5). This is possible since according to Helwani et al., (2009), the water content in oil as little as 0.06% could already result to a significant decrease in the FAME yield of the transesterification reaction. In another study, Jitputti et al. (2006) also reported that during alkali metal hydroxide-catalyzed transesterification, even if water-free vegetable oil and alcohol are used, water is produced from the reaction of the hydroxide and alcohol. Thus, the reaction could still suffer the negative effects of soap formation.

In contrast to that of NaOH-catalyzed reactions, a higher FAME yield was measured for the transesterification of coconut oil catalyzed by 2.0% metformin than that of 1.0% (Figure 4A, middle). This result implies that increasing the amount of metformin would result in an increase in the concentration of FAME in the biodiesel produced. This is possible since biguanides do not form soaps with FFA (Schuchardt *et al.* 1998; Sercheli *et al.* 1999). Therefore, an excess amount of metformin does not result in a lowering of FAME yield associated with the formation of soap via saponification.

In Figure 4B, it is apparent that the addition of water in oil resulted in a significant difference in the FAME produced in transesterification reactions catalyzed by NaOH. This time, a higher FAME yield was observed at 2.0% NaOH (Figure 4B, left). In general, water hydrolyzes triglycerides which increases the oil's FFA content (Atadashi *et al.* 2012) (Figure 5). Consequently, in the presence of water, more NaOH is needed to neutralize the produced FFAs (Kim *et al.* 2004). Therefore, a higher concentration of NaOH was favorable in oil with elevated water content.

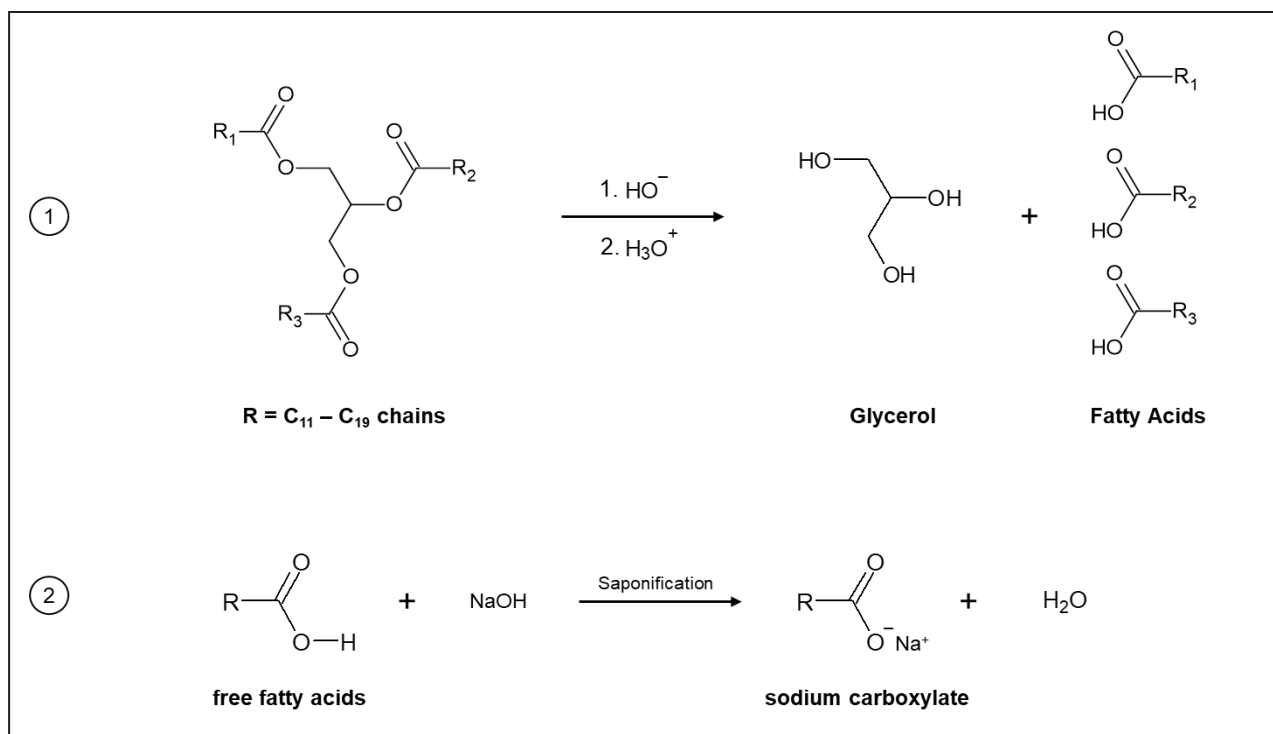


Figure 5. A schematic diagram on the effects of water and free fatty acid on triglycerides. (1) Hydrolysis of triglycerides in the presence of water resulting in the formation of free fatty acids (FFAs) and (2) its subsequent saponification reaction with and alkali base like NaOH resulting to the formation of a surfactant.

The FAME yield in both 1.0% and 2.0% metformin-catalyzed reactions was significantly reduced to $5.5 \pm 0.3\%$ and $2.6 \pm 0.4\%$, respectively (Figure 4B, middle) in the presence of water. This result suggests that metformin is not a suitable catalyst for transesterification reactions where the feedstock and/or alcohol used has elevated levels of moisture. Increasing the amount of metformin did not augment the FAME yield either.

Effect of Water Content of Coconut Oil on the amount FAME of Biodiesel

The water content of feedstock oil is a very important parameter in designing biodiesel production by transesterification of oil with alcohol. In general, the presence of water reduces the conversion of triglycerides to FAME (Atadashi *et al.* 2012). Ma *et al.* (1998) and Demirbas (2006) suggested that during the transesterification reaction, the presence of water poses more negative effects on the FAME yield than the free fatty acid (FFA) content of oil. To study the effects of water content on the transesterification of coconut oil with methanol, the coconut oil was amended with distilled water to make a nominal concentration of 5.0% (w/w) of coconut oil.

Figure 6 shows the results obtained in the study of the effects of water on the transesterification of coconut oil with methanol. The presence of water resulted in a significant decrease in the FAME yield of the reaction catalyzed by NaOH, both at 1.0% (Figure 6A, left) and 2.0% (Figure 6B, left) NaOH concentration. This reduction could be because water speeds up the hydrolysis of triglyceride resulting in the production of free fatty acids (Figure 5) (Tomasevic and Siler-Marinkovic, 2003). These free fatty acids, in turn, react with NaOH via saponification forming free fatty acid salts commonly known as soaps (Figure 5).

Formation of soap poses problems in biodiesel production because they act as surfactants forming emulsions of the transesterification products making the separation of the final products tedious, as observed in this experiment (Atadashi *et al.* 2012). For NaOH-catalyzed reactions in the presence of water, suds formed at the end of the reaction. Thus, more washing was required to obtain a clear rinsing. In addition, it was observed that more suds were observed in 2.0% NaOH than in 1.0% NaOH. This result still conforms to the fact that soap formation increases with the increase in NaOH concentration (Vyas *et al.* 2011). Surprisingly, the FAME yield for

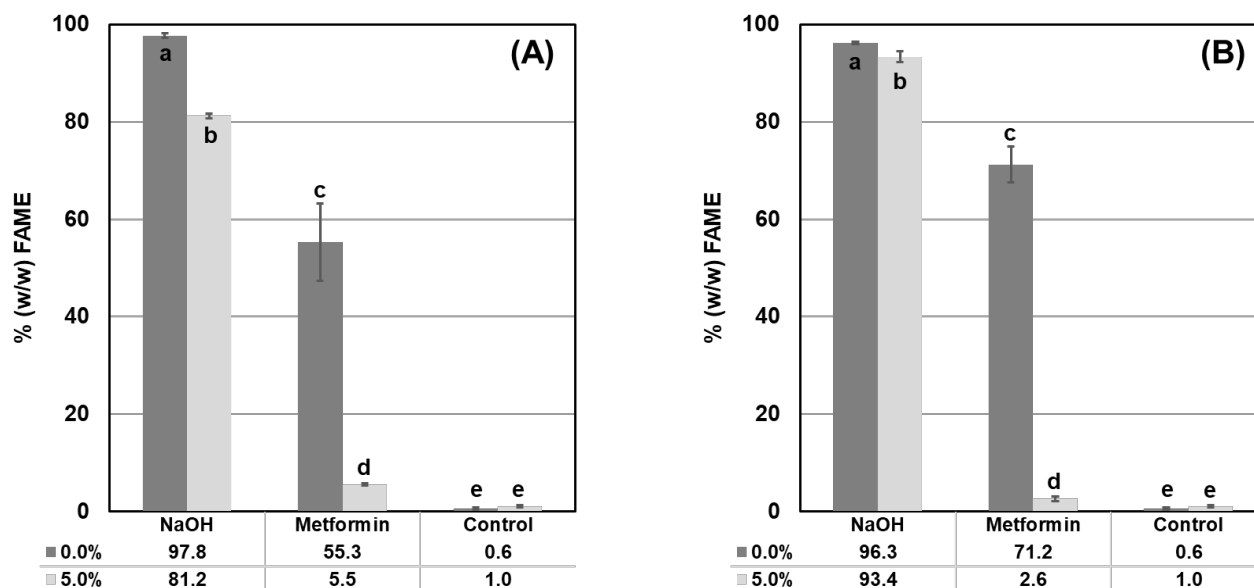


Figure 6. Percent (%) FAME of biodiesel produced from transesterification of coconut oil (0.0% and 5.0% w/w water content of oil) with methanol catalyzed by NaOH and Metformin at A) 1.0% w/w catalyst, and B) 2.0% w/w catalyst. $N = 3$ for each treatment; Values indicated mean \pm standard deviation. Treatments sharing the same letter are not significantly different ($p = 0.05$). Dark gray bars show results for anhydrous (0.0% water) oil, while light gray bars show results for oil containing 5.0% w/w water.

NaOH-catalyzed transesterification in the presence of 5.0% water is much higher compared to previous reports (Table 1). The differences could be due to the different analytical methods used in this study. Refractometry was employed in this study, requiring the samples to be clear for better results. Thus, samples were subjected to more thorough purification process, which could have removed some unreacted oil along with the impurities.

of the catalysts. This could be because NaOH is a much stronger base than metformin ($pK_a = 12.33$). Since metformin is a weaker base, more metformin is needed to neutralize the presence of FFA at equilibrium. Thus, at the same concentration, a smaller amount of metformin is left to catalyze the transesterification of oil. Lastly, no significant amount of FAME was measured in the control treatments (Figure 6A, right), suggesting that coconut oil did not undergo autocatalysis during the experiment.

Table 1. Effects of water on the FAME yields of biodiesel produced from various oil feedstocks using a base catalyst.

Oil Feedstock	Water Content (w/w %)	FAME (w/w %)	Analytical Method	References
Waste Cooking Oil	5.0	79.5	GC-MS	Demirbas, 2006
Waste Cooking Oil	5.3	78.5	GC-MS	Yan <i>et al.</i> , 2008
<i>Capparis deciduas</i> Oil	2.0	65.0	TLC	Dalvi <i>et al.</i> , 2009
<i>Sesbania sesban</i> Oil	2.0	29.0	TLC	Dalvi <i>et al.</i> , 2009
Coconut Oil	5.0	81.24	Refractometry	Present study

For metformin-catalyzed reactions, it is shown in Figure 6 that water completely inhibits its catalytic activity, with about ~90% reduction in the FAME yield for 1.0% catalyst loading (Figure 6A, middle), and a ~96% decrease in the FAME yield for 2.0% catalyst concentration (Figure 6B, middle). In contrast to the NaOH-catalyzed reaction, however, no suds were observed in the metformin-catalyzed reaction, confirming that they do not form soaps with free fatty acids (Schuchardt *et al.* 1998; Sercheli *et al.* 1999). The reduction of its catalytic performance, however, could be due to factors other than the saponification side reaction. One possible explanation is that since water increases the FFA content via hydrolysis (Figure 5), metformin may have been neutralized by the FFA produced (Atadashi *et al.* 2012).

Between NaOH and metformin, it is noticeable in Figure 4 that the effect of water is more pronounced in metformin than in NaOH in both concentrations

CONCLUSION

This study investigated the potential of metformin as a catalyst for the transesterification of coconut oil with methanol. Two variables were considered to study the potential of metformin as a catalyst, (1) water content of oil (0.0% and 5.0% wt. oil), and (2) catalyst concentration (1.0% and 2.0% wt. oil). In the absence of water in coconut oil, metformin showed a relatively high FAME yield at 1.0% metformin concentration, which was further improved with the increase in catalyst concentration to 2.0%. The presence of water (5.0% wt. oil) practically diminished the FAME yield of the metformin-catalyzed reaction. In the presence of water, it was observed that more suds were produced as the concentration of NaOH was increased, making the separation and purification of biodiesel from the by-products more difficult. Interestingly, this was not observed in metformin-catalyzed reactions.

This work shows the ability of a readily-available and cheap organic base, metformin (1,1-dimethylbiguanide) as a catalyst for the transesterification of coconut oil with methanol. However, our results show that metformin does not do well in an elevated amount of water in the oil feedstock, suggesting that water content is an important variable in metformin-catalyzed transesterification. We also cannot rule out the possibility of metformin degradation during the neutralization step with NaOH, and a separate measurement is recommended to resolve this. It is further recommended that the effects of other properties of the oil, such as its free fatty acid content, on the catalytic performance of metformin be investigated. Another limitation of the metformin-catalyzed reaction is its slower kinetics compared to the NaOH-catalyzed reaction, and other organic bases could be considered, preferably stronger organic bases than metformin. Another way to improve the kinetics of the reaction that could be worth looking into is the optimization of reaction parameters such as the catalyst loading, reaction temperature, alcohol-to-oil molar ratio, and mixing rate.

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Authors:

Juvinch R. Vicente, *Department of Chemistry, College of Arts and Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo; email: juvinchvicente05@gmail.com*

Ida G. Pahila, *Biodiesel from Microalgae Project, Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo; email: igpahila@gmail.com*

Mae Grace G. Nillos, *Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao (5023), Iloilo; email: mgnillos@up.edu.ph*
