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Original Article

Relationship between fatty acid composition and biodiesel quality for nine commercial palm oils

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Abstract

Biodiesel is an alternative fuel consisting of alkyl esters of fatty acids from vegetable oils or animal fats. The fatty acid compositions in the oils used as feedstock can influence quality of the biodiesel. In the present study, oil content and fatty acid composition of mesocarp and kernel oil were examined from nine commercial oil palm *Elaeis guineensis* cultivars. Saponification number, iodine value and cetane number were calculated from palm oil fatty acid methyl ester compositions. Fruits of tenera oil palm were collected from a farmer's plantation in Dan Makham Tia District, Kanchanaburi Province in 2009. Variation between cultivars was observed in oil content and fatty acid profile of mesocarp oil rather than kernel oil. The percentage of oil in dry mesocarp ranged from 63.8% to 74.9%. The mesocarp oil composed of 41.5 - 51.6% palmitic acid, 3.58-7.10% stearic acid, 32.8-42.5% oleic acid and 9.3-13.0% linoleic acid. Likewise saponification number, iodine value and cetane number of mesocarp oil fatty acid methyl ester showed more variation among cultivars, ranging from 196.5-198.9, 45.7-54.6 and 61.8-63.6, respectively. While those of kernel oil fatty acid methyl ester showed no different among cultivars, ranging from 229-242, 13.6-16.4 and 65.3-66.5, respectively. The cetane number of fatty acid methyl ester positively correlated with contents of myristic, palmitic and stearic acids in palm oil and saponification number of biodiesel, but negatively correlated with iodine value.

Keywords: Tenera palm oil, fatty acid composition, biodiesel, fatty acid methyl ester, cetane number

1. Introduction

Biodiesel is defined as the fatty acid alkyl monoesters derived from renewable biodiesel sources, such as vegetable oils and animal fats. It is biodegradable, non-toxic with low emission profiles as compared to petroleum diesel (Meher *et al.*, 2006). The edible oils such as soybean oil in U.S.A. and palm oil in Malaysia are being used for biodiesel production (Karaosmanoglu *et al.*, 1996). In Thailand, 90% of palm oil produced is used for food and the remaining 10% for non-food consumption, such as production of liquid fuels and oleo-chemicals. Conversion of palm oil into biodiesel using methanol was reported by Yarmo *et al.* (1992). There were great differences between palm oil and palm kernel oil with respect to their physical and chemical characteristics. Palm oil contains mainly palmitic acid (16:0) and oleic acid (18:1), the two common fatty acids, and about 50% saturated fat, while palm kernel oil contains mainly lauric acid (12:0) and more than 89% saturated fat (Demirbas, 2003a). Studies on physical and chemical properties of palm oil biodiesel are

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rarely based on triglyceride composition. Muniyappa *et al.* (1996) reported on density, viscosity and cloud point of two biodiesels developed from soybean and beef tallow oil. The high cloud point of methyl esters from beef tallow oil was an indicative of a high concentration of saturated fatty acid methyl esters. When liquid biodiesel is cool, the methyl esters of stearic (C18:0) and palmitic (C16:0) acids are the first fraction to precipitate and therefore typically constitute a major share of materials recovered from clogged biodiesel fuel filters (Mittelbach and Remschmidt, 2004). Accordingly, the viscosity of a fatty acid ester increases with increasing chain length and saturation. However, only *cis* double bonds cause a noticeable reduction of viscosity as esters, while *trans* double bonds display viscosity similar to their saturated counterparts (Knothe and Steidley, 2005). Research on influence of fatty acid composition of vegetable oils on quality of biodiesel indicated that low cetane numbers associates with highly unsaturated fatty acid components (C18:2 and C18:3) (Ramos *et al.*, 2009). Pinzi *et al.* (2011) reported that a double bond value of 1.16 in the fatty acid chain appears to be an optimal value to achieve the best compromise between low calorific value (LCV), cetane number (CN), flash point (FP) and cold filter plugging point (CFPP), and an optimal length of chain is provided by an average value of 17 carbon atoms.

The objective of this work is to study on influence of fatty acid profiles in palm oil on biodiesel quality. The results will benefit palm oil biodiesel producers and oil palm breeding programs for biodiesel purpose.

2. Materials and Methods

2.1 Plant materials and oil extraction

Plant materials were nine commercial oil palm (*Elaeis guineensis*) cultivars from different sources grown in a private farm in Dan Makham Tia District Kanchanaburi Province, western part of Thailand. Not to overemphasize on their origins the plants from Univanich Company, Surat 2, Malaysia, Uti, Ekona, Papua, Avros, Paoronk and Nigeria were renamed as Tenera Oil Palm (TOP) from TOPA, TOPB, …, TOPI, respectively. Bunches of each cultivar were harvested to separate for fruits for oil extraction. Oil from dry mesocarp and kernel were extracted using petroleum ether in soxhlet extractor (Buchi Universal Extraction System B-811) to obtain crude palm oil and palm kernel oil. Then oil percentages in dry mesocarp and kernel were obtained.

2.2 Analysis of fatty acid composition by gas chromatography

Fatty acid compositions were determined in accordance with the AOAC's official method for oil and fats (AOAC, 2000). Extracted lipid was methylated to produce fatty acid methyl esters (FAMEs). The FAMEs were analyzed by a CP9001 gas chromato- graph (GC; Chrompack, Middelburg, The Netherlands) on a WCOT fused silica column (100 m x 0.25 mm, i.d.) coated with CP-SIL 88 (Varian). Helium was used as the carrier gas. Peaks were identified by comparison with relative retention times of the standard FAMEs (Sigma-Aldrich Chemie, Steinheim, Germany). Concentration of each fatty acid was recorded by normalization of peak areas using GC post run analysis software, manual integration and reported as percentage of the particular fatty acid.

2.3 Saponification number, iodine value and cetane number

Saponification number (SN) and iodine value (IV) were calculated from FAMEs composition of oil, using the following Equation (1) and (2), respectively (Kalayasiri *et al.*, 1996):

$$SN = \Sigma\,(560 \times A_i)/MW_i \tag{1}$$

$$IV = \Sigma\,(254 \times D \times A_i)/MW_i \tag{2}$$

where A_i is the percentage, D is the total number of double bonds, and MW_i is the molecular weight of each fatty acid.

Cetane number (CN) and higher heating values (HHVs) of FAMEs were calculated from the following equations by using the estimated saponification number (SN) and iodine value (IV) (Krisnangkura, 1986; Demirbas, 1998a):

$$CN = 46.3 + 5458/SN - 0.225\,(IV) \tag{3}$$

$$HHVs = 49.43 - 0.041(SN) + 0.015\,(IV) \tag{4}$$

2.4 Statistical analysis

Analysis of variance (ANOVA) of fatty acid composition and oil content of palm oil and palm kernel oil were done, using R program (R-Development Core Team, 2008). A least significant difference (LSD) test was employed to compare treatment means using the same program. Correlation coefficients were determined among various traits studied.

3. Results and Discussion

3.1 Oil content and fatty acid composition

Variation in oil content and fatty acid composition in mesocarp and kernel of Tenera oil palm was presented in Table 1. Oil percentage in dry mesocarp was the highest (74.9%) in TOPD and the lowest (63.8%) in TOPH; whereas oil percentage in dry kernel was the lowest (41.8%) in TOPG and the highest (48.2%) in TOPB.

Oil quality and utility are mainly determined by its fatty acid composition. Fatty acid composition in mesocarp oil showed that palmitic and oleic are major fatty acids. The percentages of these two fatty acids in mesocarp oil of nine oil palm cultivars ranged from 41.5 to 51.6% and 32.8 to 42.5% with an average value of 46.6 and 36.6%, respectively.

Table 1. Oil content and fatty acid composition in oils from mesocarp and kernel of nine oil palm cultivars.

Oil palm cultivar	Oil content (%)		Fatty acid composition (%)[a]													Oleic/linoleic (%)	
	palm oil	palm kernel oil	palm oil					palm kernel oil								palm oil	palm kernel oil
			myristic	palmitic	stearic	oleic	linoleic	caprylic	capric	lauric	myristic	palmitic	stearic	oleic	linoleic		
TOPA	71.8±2.4	43.9±3.5	1.25±0.06	49.8±1.1	5.53±0.20	32.8±1.5	10.3±0.6	4.22±0.50	3.51±0.36	46.4±2.3	14.1±0.2	7.04±0.63	1.60±0.27	14.5±1.5	2.31±0.42	3.20±0.32	6.35±0.58
TOPB	73.6±2.6	48.2±1.2	0.87±0.10	45.3±1.8	3.58±0.52	39.9±1.1	10.4±0.6	4.15±0.72	3.66±0.46	47.8±1.2	15.9±1.2	7.34±0.82	1.77±0.65	14.2±2.5	2.17±0.46	3.85±0.18	6.77±2.00
TOPC	73.5±3.8	46.9±1.0	1.24±0.31	45.9±1.6	4.29±0.16	36.2±1.1	12.1±0.6	4.50±0.55	3.89±0.35	50.4±2.6	15.0±0.8	6.60±0.48	1.54±0.18	11.2±0.9	2.28±0.49	3.00±0.05	5.14±1.28
TOPD	74.9±2.8	42.6±2.0	1.38±1.10	51.6±1.4	3.93±0.50	32.9±1.8	10.1±0.8	4.75±0.38	4.31±0.87	50.6±2.2	14.8±0.6	6.67±0.31	1.53±0.20	12.3±1.0	1.90±0.29	3.27±0.36	6.51±0.47
TOPE	74.6±4.9	45.0±5.2	1.06±0.15	47.5±1.4	4.78±0.82	33.4±2.6	13.0±1.5	4.41±1.36	3.75±0.73	49.6±3.4	15.6±0.8	7.55±1.13	1.95±0.37	13.8±2.7	2.35±0.54	2.62±0.46	5.94±0.39
TOPF	71.2±2.9	46.1±2.4	0.84±0.27	45.8±2.6	4.76±0.97	38.2±3.9	10.3±1.5	4.23±0.85	3.79±0.55	49.5±3.6	15.0±0.6	6.88±0.79	1.98±0.43	12.0±1.4	2.12±0.45	3.82±0.85	5.90±1.43
TOPG	71.2±3.9	41.8±1.7	1.28±0.54	47.5±4.0	4.70±0.98	35.1±2.8	11.2±1.8	4.39±0.80	3.30±0.72	49.4±1.7	15.0±0.6	7.30±0.46	1.82±0.40	13.4±0.9	2.03±0.21	3.19±0.52	6.62±0.72
TOPH	63.8±3.8	46.8±2.1	0.66±0.15	41.5±2.3	4.84±1.07	42.5±4.0	10.6±1.5	4.29±0.88	3.87±0.60	52.0±3.2	14.9±0.6	6.62±0.71	1.68±0.40	11.8±2.1	2.05±0.50	4.12±0.83	5.93±1.02
TOPI	66.3±6.3	45.9±1.7	0.75±0.16	44.0±2.6	7.10±0.63	38.7±4.0	9.3±2.3	3.45±0.81	3.34±0.59	48.0±3.3	16.0±0.7	8.14±0.96	1.82±0.35	13.9±1.4	2.11±0.46	4.52±1.60	6.93±2.22
Mean	71.2	45.3	1.04	46.6	4.83	36.6	10.8	4.27	3.71	49.3	15.2	7.13	1.74	13.0	2.15	3.51	6.23
$LSD_{0.05}$	4.9	3.3	0.34	3.0	0.98	3.8	1.8	1.04	0.73	3.5	0.8	0.93	0.46	2.1	0.53	0.98	1.56
F- test	**	**	**	**	**	**	**	NS	NS	NS	**	**	NS	*	NS	**	NS
CV	5.78	6.05	27.46	5.38	16.57	8.60	14.12	20.68	16.65	5.94	4.55	10.93	21.73	13.39	20.62	23.10	21.04

TOPA-TOPI = Tenera oil palm cultivars: TOPA = Univanich, TOPB = Surat 2, TOPC = Malaysia, TOPD = Uti, TOPE = Ekona, TOPF = Papua, TOPG = Avros, TOPH = Paoronk, TOPI = Nigeria;
a = Percentages may not add to 100% due to no inclusion of other constituents;
*, ** = Statistically different at P d" 0.05 and P $\leq$ 0.01, respectively;
NS = not significantly different (P > 0.05).

Among them, TOPD was the richest in palmitic acid (51.6%), while TOPI tenera hybrid was the richest in stearic acid (7.10%) (Table 1).

The major fatty acids in palm kernel oil were lauric acid (C 12:0) (46.4-52.0%), myristic acid (C 14:0) (14.1-16.0%) and oleic acid (C 18:1) (11.2-14.5%) (Table 1). These three fatty acids gave the average values of 49.3, 15.2 and 13.0%, respectively, but lauric acid contents were not different among the cultivars. TOPH hybrid was rich in saturated fatty acids, especially lauric acid, while TOPI hybrid was rich in myristic acid. TOPI and TOPA hybrids showed the highest content of palmitic and oleic acids at 8.14% and 14.5%, respectively.

The ratio of oleic to linoleic acid (O/L) is considered an important criterion to evaluate the mesocarp and kernel oil quality (Kodad and Socias I Company, 2008). Increasing O/L ratio by increasing oleic acid and decreasing linoleic acid contents confers better stability and longer shelf life. In this study, the O/L ratio varied from 2.62 to 4.52 and 5.14 to 6.93 in mesocarp and kernel oils, respectively. However, the cultivars were different only in O/L ratio of palm oil but not palm kernel oil.

3.2 Predicting biodiesel properties by fatty acid methyl esters composition of oil

Fatty acid methyl esters (FAMEs) of seed oils and fats were found suitable for use as biodiesel in diesel engine. FAMEs as biodiesel are environmentally safe, non-toxic and biodegradable. SN, IV, and CN are used to predict the quality of FAMEs for this purpose. SN depends on molecular weight and percentage of fatty acid components. IV depends upon three variables, i.e. percentage of unsaturated fatty acid components, their molecular weight, and the number of double bonds present in them. While CN gives an indication of ignition quality of the fuel, the higher value the better quality (Azam *et al.*, 2005). The values of SN, IV, CN, and HHVs of oils from mesocarp and kernel are shown in Table 2. SN, IV and CN of fatty acid methyl ester of mesocarp oil varied from 196.5-198.9, 45.7-54.6, and 61.8-63.6, respectively, and different among cultivars; while those from kernel oil varied from 229-242, 13.6-16.4 and 65.3-66.5, respectively, but not different among cultivars.

Cetane number is an ability of fuel to ignite quickly after injection; the higher value the better emission of fuel. This is an important parameter considered during selection of FAMEs for use as biodiesel (Jesikha, 2012). CN is included in a fuel quality specification in petroleum diesel standard. A minimum CN of 40 is required in the American Society for Testing and Materials (ASTM) D975-09 as well as in the biodiesel standard. A minimum of 47 prescribed for neat biodiesel in ASTM D6751-09, and a minimum of 51 in German standard E DIN 51606 (Bezaire *et al.*, 2010). In the present study, CN of palm oil and palm kernel oil methyl esters are higher than that of the standard number (>51), because palm oil and palm kernel oil are rich in saturated fatty acids.

Table 2. Biodiesel properties of oils from mesocarp and kernel of nine oil palm cultivars.

Oil palm cultivar	Palm oil				Palm kernel oil			
	SN	IV	CN	HHV	SN	IV	CN	HHV
TOPA	197.9±0.9	45.9±0.5	63.6±0.2	40.63±0.04	229±3	16.4±2.0	66.5±0.2	39.8±0.1
TOPB	197.6±0.4	52.0±1.8	62.2±0.4	40.55±0.02	237±6	15.9±2.4	65.8±1.1	39.5±0.3
TOPC	197.3±1.0	51.9±1.9	62.3±0.3	40.56±0.02	236±1	13.6±0.3	66.4±1.1	39.6±0.4
TOPD	198.9±0.3	45.7±1.5	63.5±0.3	40.59±0.01	239±11	13.8±1.3	66.0±1.3	39.4±0.5
TOPE	197.5±1.0	51.0±1.1	62.5±0.2	40.57±0.04	242±6	15.9±3.3	65.3±0.4	39.3±0.2
TOPF	197.2±0.8	50.5±1.6	62.6±0.3	40.59±0.03	235±11	13.9±1.7	66.5±1.0	39.6±0.4
TOPG	197.8±1.4	49.4±3.7	62.8±0.7	40.58±0.04	237±4	14.9±0.9	66.0±0.4	39.5±0.2
TOPH	196.6±0.5	54.6±1.3	61.8±0.2	40.55±0.01	240±6	13.7±2.5	66.0±0.4	39.4±0.2
TOPI	196.5±0.4	49.1±2.1	63.0±0.5	40.64±0.02	235±8	15.5±1.6	66.1±0.8	39.6±0.3
Mean	197.5	50.0	62.7	40.58	237	14.8	66.1	39.5
$LSD_{0.05}$	1.0	2.4	0.5	0.03	9	2.4	0.9	0.4
F- test	**	**	**	**	NS	NS	NS	NS
CV	0.43	3.97	0.62	0.07	3.33	13.61	1.20	0.80

TOPA-TOPI = Tenera oil palm cultivars: TOPA = Univanich, TOPB = Surat 2, TOPC = Malaysia, TOPD = Uti, TOPE = Ekona, TOPF = Papua, TOPG = Avros, TOPH = Paoronk, TOPI = Nigeria;
SN = saponification number (mgKOH/g), IV = iodine value (g Iodine/100g oil), CN = cetane number, HHV = higher heating values (MJ/kg);
*,** = statistically different at $P \leq 0.05$ and $P \leq 0.01$, respectively;
NS = not significantly different ($P > 0.05$).

Iodine value is a measurement of unsaturation of fats and oils; higher IV indicates higher unsaturation (Knothe, 2002). A standard minimum IV for biodiesel was 120 for European's EN 14214 specification (Sokoto *et al.*, 2011). IV among the nine hybrid tenera palm oil and palm kernel oil methyl esters were low (<55.0) because the oils were rich in saturated fatty acids such as palmitic (C16:0), stearic (C18:0), lauric (C12:0), and myristic (C14:0) acids which lower the value.

Another important property characterizing a fuel is its energy content. This parameter is called calorific value (CV), or heat of combustion or heating value (HV). HV of a vegetable oil can be calculated by using SN and IV obtained from simple chemical analyses (Demirbas, 1998a). Higher heating values (HHVs) are calculated by using Equation 4 mentioned earlier. HHVs of the mesocarp and kernel oil showed very low variation, ranging from 40.55 to 40.64 MJ/kg and 39.3 to 39.8 MJ/kg, respectively. TOPH hybrid palm oil contained high unsaturated fatty acids (oleic and linoleic) and high IV, thus showing low HHVs. The heating value of a fuel increases with increasing carbon number in fuel molecules, as well as with increasing ratio of carbon and hydrogen to oxygen and nitrogen atoms (Demirbas, 1997).

3.3 Correlation between biodiesel properties and fatty acid composition in palm oil and palm kernel oil

Correlations between palm oil biodiesel properties and fatty acid methyl ester of mesocarp and kernel oil are shown in Table 3 and 4. Oleic acid in mesocarp oil was negatively correlated with myristic and palmitic acid, while myristic acid content showed positive correlation with palmitic acids (Table 3). The negative correlation reveals that when the amount of oleic acid increased, the amounts of myristic and palmitic acids decreased. These results agreed with the previous report in oils extracted from oil palm germplasm by Chaves-Salas and Sterling-Rodriguez (1991). Oleic acid also showed negative correlation with linoleic acid. Similar results were observed in the seed oil of other oilseed crops such as soybean (Rebetzke *et al.*, 1996). One reason for the inverse relationship between these fatty acids could be environmental dependent on where the genotypes were grown (Fernandez-Martinez *et al.*, 1993). In kernel oil, caprylic acid was positively correlated with capric acid but negatively correlated with palmitic and oleic acids, while oleic acid content had a positive correlation with palmitic acid (Table 4).

Cetane number was positively correlated with methyl ester of palmitic acid from mesocarp oil, but negatively correlated with methyl ester of oleic and linoleic fatty acids (Table 3). Similar result was reported by Gopinath *et al.* (2010) that CN was positively correlated with methyl esters of lauric, myristic, palmitic, and stearic fatty acids, but negatively correlated with those of oleic, linoleic, and linolenic fatty acids.

From the correlation analysis, it can be observed that both palmitic and myristic acids from mesocarp oil had negative correlation with iodine value (Table 3). For saponi-

Table 3. Correlations between oil content, fatty acid profile and biodiesel traits in mesocarp of nine oil palm cultivars.

Component	Myristic	Palmitic	Stearic	Oleic	Linoleic	O/L	IV	SN	CN	TSFA	TUSFA	SR	HHV
Oil	0.72*	0.76*	-0.59	-0.71*	0.46	-0.76*	-0.41	0.77	0.32	0.61	-0.60	0.58	-0.16
Myristic		0.87**	-0.34	-0.87**	0.33	-0.78*	-0.66	0.84**	0.59	0.82**	-0.81**	0.82**	0.10
Palmitic			-0.26	-0.92**	0.09	-0.64	-0.86**	0.93**	0.80**	0.96**	-0.95**	0.95**	0.31
Stearic				0.06	-0.38	0.45	-0.19	-0.55	0.31	0.04	-0.07	0.04	0.79*
Oleic					-0.34	0.78*	0.78*	-0.75*	-0.73*	-0.94**	0.94**	-0.93**	-0.36
Linoleic						-0.81**	0.33	0.09	-0.38	0.00	-0.01	-0.01	-0.54
O/L							0.24	-0.59	-0.17	-0.55	0.55	-0.54	0.24
IV								-0.69*	-0.99**	-0.94**	0.94**	-0.95**	-0.73*
SN									0.60	0.79*	-0.77*	0.79*	0.01
CN										0.91**	-0.91**	0.91**	0.81**
TSFA											-1.00**	1.00**	0.56
TUSFA												-1.00**	-0.58
SR													0.56

Correlation shown in bold face type are significant at 5% (*) and 1% (**) levels of probability (df = 7); O/L = Oleic acid/linoleic acid; TSFA = total saturated fatty aicd; TUSFA = total unsaturated fatty acid; SR = saturation ratio (TSFA/TUSFA); SN = saponification number; IV = iodine value; CN = cetane number; HHV = higher heating values.

fication number showed a positive correlation with palmitic and myristic acids but negative with oleic acid.

Iodine value showed negative correlation with (HHVs) (Table 3). An increasing in IV resulted in decreasing in heat content of the oil. Demirbas *et al.* (1998b) reported that HHVs are related with structural properties of the oil. They increase with increasing chain length and decrease with increasing in number of double bonds. An increase in heat content is a result of increasing in number of carbons and hydrogens, and vice versa. From the correlation analysis, IV showed negative correlations with SN and CN, while SN has a positive correlation with CN. Correlation between CN and percentage of unsaturation was negative in mesocarp oil but not significant in kernel oil. These are in line with the results reported by Bangboye and Hansen (2008) who verified that CN follows the same trend in composition of the FAME compounds in the feedstocks used. A feedstock high in saturated fatty esters has higher CN. The IV observed in this study exhibited a negative correlation with CN and showed positive correlation with percentage of unsaturation. Rao *et al.* (2010) reported that biodiesel made from vegetable oils with high amount of saturates (low IV) have a higher CN than those with high amount of unsaturates (high IV). Knoth (2005) found that CN increases with increasing chain length, decreasing branching and unsaturation. These chemical structures increase the HV and thus slow a tendency for CN to increase together with viscosity and HV (Demirbas, 2003b). The correlation between CN and HHVs can be clearly observed in mesocarp oil (Table 3).

4. Conclusions

Palm oils in this study are rich in saturated fatty acids such as lauric, myristic and palmitic acids with predicted CN of 61.78-63.55 and IV of 45.71-54.63. The standard of biodiesel in Thailand requires that CN of the fuel should be over 51 (ASTM D 613) and IV should be no less than 120 (EN 14111), thus this oils can be used as a good feedstock of biodiesel. Cetane number of palm oil biodiesel showed positive correlation with saturated fatty acids but negative with unsaturated fatty acids and IV.

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Table 4 Correlations between oil content, fatty acid profile and biodiesel traits in kernel of nine oil palm cultivars.

Component	caprylic	capric	lauric	Myristic	Palmitic	Stearic	Oleic	Linoleic	O/L	IV	SN	CN	TSFA	TUSFA	SR	HHV
Oil	-0.36	0.06	0.04	0.49	0.01	0.12	-0.16	0.34	-0.29	-0.06	0.06	-0.01	0.14	-0.11	0.19	-0.07
Caprylic		0.69*	0.49	-0.53	-0.77*	-0.38	-0.45	-0.13	-0.47	-0.44	0.34	-0.05	0.32	-0.45	0.45	-0.30
Capric			0.60	-0.25	-0.70*	-0.43	-0.62	-0.29	-0.42	-0.63	0.44	-0.01	0.51	-0.63	0.66	-0.39
Lauric				-0.05	-0.55	-0.12	-0.83**	-0.42	-0.51	-0.84**	0.75*	-0.19	0.90**	-0.84**	0.94**	-0.68*
Myristic					0.69*	0.48	0.25	0.03	0.32	0.23	0.43	-0.59	0.35	0.24	-0.11	-0.47
Palmitic						0.56	0.73*	0.20	0.62	0.70*	-0.05	-0.42	-0.21	0.72*	-0.65	-0.02
Stearic							0.28	0.17	0.16	0.29	0.21	-0.39	0.14	0.28	-0.16	-0.25
Oleic								0.32	0.70*	0.98**	-0.33	-0.33	-0.62	0.99**	-0.96**	0.23
Linoleic									-0.43	0.51	-0.26	-0.08	-0.37	0.42	-0.36	0.21
O/L										0.54	-0.16	-0.21	-0.32	0.62	-0.64	0.10
IV											-0.35	-0.32	-0.64	0.99**	-0.95**	0.26
SN												-0.78*	0.93**	-0.34	0.56	-0.99**
CN													-0.51	-0.32	0.07	0.84**
TSFA														-0.64	0.80*	-0.89**
TUSFA															-0.96**	0.25
SR																-0.48

Correlation shown in bold face type are significant at 5% (*) and 1% (**) levels of probability (df=7); O/L = Oleic acid/linoleic acid; TSFA = total saturated fatty aicd; TUSFA = total unsaturated fatty acid; SR = saturation ratio (TSFA/TUSFA); SN = saponification number; IV = iodine value; CN = cetane number; HHV = higher heating values.

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