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Magonia pubescens (Sapindaceae) Seed Oil: Physical and Chemical Properties, Fatty Acid Profile and Biodiesel Production

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Abstract

Magonia pubescens is a tree species originally from the Brazilian Cerrado that bears fruit with winged seeds from which fixed oil can be extracted. This study aimed to analyze the physical and chemical properties of the oil extracted from these seeds and the biodiesel produced thereof. Methods from the Adolfo Lutz Institute, American Oil Chemists Society, and American Society for Testing and Materials were used. Seven fatty acids (oleic, arachidic, gadoleic, palmitic, palmitoleic, linoleic, and stearic acids) were found in the oil. Acidity level (1.119 mg $KOH \cdot g^{-1}$), iodine value (77.36 cg $I_2 \cdot g^{-1}$), saponification value (133.36 mg $KOH \cdot g^{-1}$), density (0.8796 $g \cdot cm^{-3}$), and refractive index (1.3348nD) were low when compared to the high peroxide value (26.14 $meq \cdot kg^{-1}$), viscosity (101.46 $mm^2 \cdot s^{-1}$), and moisture (0.88%) of other oils and fats used for biodiesel production. Biodiesel showed density (0.8484 $g \cdot cm^{-3}$), viscosity (29.62 $mm^{-2} \cdot s^{-1}$), acidity level (0.752 mg $KOH \cdot g^{-1}$), and saponification value (148.89 mg $KOH \cdot g^{-1}$).

Keywords: fatty acids, cerrado, winged seeds, oleaginous seeds, Tingui

1. Introduction

Magonia pubescens (Sapindaceae), known as "Tingui", "Timbo", and "Tingui do Cerrado", is a plant originally from the Brazilian Cerrado also found in Bolivia and Paraguay. It is between four and twelve meters tall, and bears large, globular fruit with winged seeds, which germinate easily. This species is used for initial reforestation of degraded lands, its seeds are used to produce soap, and oil can be extracted there of (Coelho et al., 2012).

Biodiesel is a fuel consisting of methyl or ethyl esters obtained by transesterification of different oil sources such as edible and inedible oils, animal fat, algae, and reused oils (Canoira et al., 2010). This type of biofuel production is important, because it can be a substitute for diesel oil, whose reserves have reduced. It is considered a renewable fuel, sinceits oily raw material could be restored by the cultivation of oleaginous plants and/or fat from slaughtered animals. The production of biodiesel can potentially reduce the dependence on oil import to countries with no oil reserves and contribute to local agricultural industries. Moreover, it is miscible in diesel oil in different ratios, causing no damage to engines. It has reduced sulfur content, adequate flash point and lubricity, and shows positive energy balance (Blin et al., 2013; Knothe, 2002; Rakopoulos et al., 2015).

The production of quality biodiesel depends on the correct selection of the oil sources used, since their physical and chemical properties determine biofuel properties. The analysis of inputs should allow selection of the best options and produce a high-quality end product. The properties of the chemical structures of fats and oils that contribute to biodiesel quality are mainly length, degree of unsaturation, and branching chain of their fatty acids.

In this manner, most of the tests used to evaluate the physical and chemical properties in oil and biodiesel are based on indexes determined by the properties above (Martinez et al., 2014).

Seeking new oil sources for biodiesel production is important, since most oils used for its production are also used in foodstuffs. Therefore, low-cost oil sources that are not used as foodstuff, have appropriate physical and chemical properties, and are locally available should be indetified (Martinez et al., 2014). In the Brazilian context, the use of genetic resources of the Cerrado to develop new products contributes to the exploitation and preservation of species and increases the income of local communities. The seed oil from *M. pubescens* may represent an innovative source for biodiesel production, without posing a risk of reducing the supply of oil for food. In this manner, this study aimed principally to analyze the potential use of these seed oils for biodiesel production.

2. Method

The fruits and seeds were collected from July to September 2014 directly from *M. pubescens* trees in the Cerrado biome in the city of Montes Claros, Minas Gerais, Brazil. The species was identified based on a voucher specimen labeled as number 106750 in the Herbarium at the Institute of Biological Sciences, Federal University of Minas Gerais in Belo Horizonte, Minas Gerais.

The seeds were first peeled and then dried at 105±2 °C for 24 hours in an oven (Nova Ética, model 400-4ND). The cold-pressed oil was mechanically extracted using a hydraulic press. The extraction yield was calculated as a percentage of the weight of seed used.

2.1 Analysis of Seeds, Oil, and Biodiesel

The moisture content in the seeds was analyzed according to methods provided by the Adolfo Lutz Institute (IAL, 2008). The moisture content, density, ash content, peroxide value, saponification value, viscosity and refraction index of the oil were analyzed according to methods of the American Oil Chemists Society (AOCS). The density analysis and acidity level testing of the biodiesel followed the standards of the American Society for Testing and Materials (ASTM).

2.2 Complementary Analyses of Oil and Biodiesel

Some complementary analyses were carried out using methods different from those provided by the AOCS and ASTM.

2.2.1 Iodine Value (Oil)

The iodine value was calculated based on the composition of fatty acids with unsaturated bonds and their ratio in the oil composition, obtained by gas chromatography analysis, using the Equation 1 (Knothe, 2002).

$$II_{oil} = \Sigma 100 \times \frac{Af \times 253.81 \times db}{MWF} \quad (1)$$

Where,

II = iodine value; *Af* = the percentage of fatty acid in the composition; 253.81 = weight of two iodine atoms that are theoretically added to a double bond; *db* = number of unsaturated bonds of the fatty acid; *MWF* = molecular weight of fatty acid.

2.2.2 Composition of Fatty Acids

The oil composition of fatty acids was analyzed using a gas chromatograph model 7890A GC system (Agilent Technologies, Santa Clara, CA, USA) coupled to a mass spectrometer model 5975C inert XL MSD with triple-axis detector (Agilent Technologies, Santa Clara, CA, USA). The esters were identified by comparing the mass spectrum previously found with the NIST 2.0 library standards Chemstation software (Agilent Technologies, Santa Clara, CA, USA).

Firstly, an oil sample was subjected to derivatization. The process was carried out by adding 20 mg of oil to 5 mL of potassium hydroxide solution at 0.5 $mol \cdot L^{-1}$. The mixture was heated under reflux and stirred constantly for one hour. Subsequently, 2 mL of 4:1 v/v hydrochloric acid/methanol was added and the solution was heated under reflux for another hour. After reaching room temperature, 5 mL of distilled water was added. For extraction, three aliquots of 5 mL of dichloromethane were added to the material obtained from derivatization. The organic phase was collected and then anhydrous sodium sulfate was added to remove water. The resulting mixture was filtered through a round-bottom flask and evaporated in a rotary evaporator at 65 °C. The material was solubilized again using dichloromethane as a solvent and placed in a previously weighed penicillin bottle. After spontaneous evaporation of all dichloromethane in a desiccator at room temperature, the yield was

calculated. For analysis of the chemical composition, 20 µL of the methylated oil was diluted in 980 µL of dichloromethane and then GC-MS analysis was carried out.

The carrier gas used was Helium 6.0; flow rate of 1.8 mL per minute. The sample injection temperature was 220 °C. The split ratio was 1:10. The initial temperature of the column was 160 °C for two minutes, then 200 °C at a rate of 2 °C per minute, then 240 °C at a rate of 10 °C per minute. The total analysis lasted 26 minutes. The interface temperature was 240 °C and the programmed mass/charge ratio was from 30 to 600 (Adams, 2007).

2.3 Biodiesel Production

The biodiesel was produced by single-step transesterification. The molar ratio of the reaction was 1 mol of oil to 6 mol of alcohol (methanol) and 1.5% potassium hydroxide as a catalyst per mass of oil. The reaction was constantly stirred and heated under reflux (40 to 45 °C) for 50 minutes. The biodiesel obtained was washed with distilled water (80 °C) until a neutral pH was achieved and then dried in an oven until all traces of water and turbidity disappeared (Martínez et al., 2014; Mendow et al., 2011; Santos et al., 2013).

3. Results and Discussions

The moisture content foundin cotyledons was 5.48% and in seeds 7.03%. The moisture content in seeds is close to that found in seeds of the same species collected in the Cerrado of the state of Mato Grosso (6.39%) (Coelho et al., 2012). The moisture content was considered suitable for oil extraction for biodiesel production since the moisture content of seeds should beless than 9% for this purpose (Sidibé et al., 2010).

The yield obtained in the extraction of oil from seeds was 10.36%. The quantity of oil extracted may vary due to the type of press used, moisture content, and prior processes for cleaning and heating the seeds (Sidibé et al., 2010).

The analysis of seed oil using a gas chromatograph coupled to a mass spectrometer (GC-MS) identified seven fatty acids in the seed oil of *M. pubescens* (Figure 1). The fatty acid profile of vegetable oils usually consists of five acids, namely, palmitic, stearic, oleic, linoleic, and linolenic (Knothe et al., 2002). Most of these fatty acids can be found in the seed oil of *M. pubescens* (Table 1).

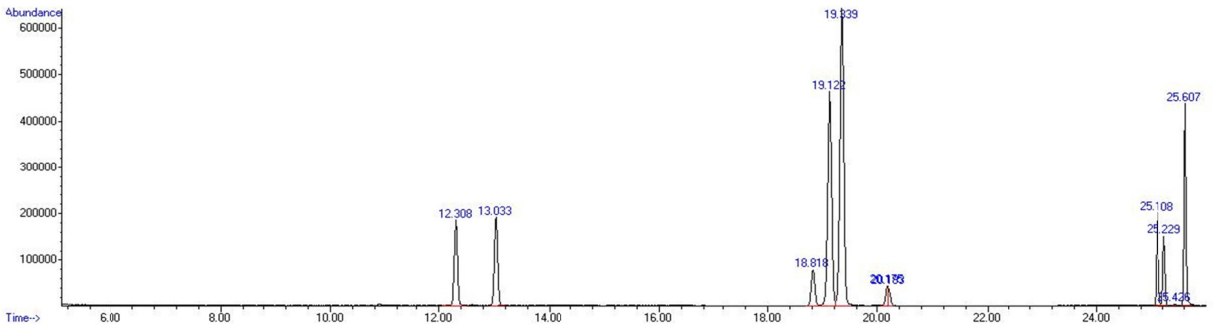

Figure 1. Chromatogram *M. pubescens* seeds oil obtained by GC-MS

Table 1. Fatty acid composition in *M. pubescens* oil and other oils

Source	Fatty acids (%)								Ref.
	Palmitoleic (C16:1)	Palmitic (C16:0)	Linoleic (C18:2)	Oleic (C18:1)	Stearic (C18:0)	Gadoleic (C20:1)	Arachidic (C20:0)	Others	
M. pubescens	8	8.2	3.7	56.9	2.4	9.5	11.3	-	-
Soybean	0.11	10.26	51.04	26.55	3.52	-	0.23	8.29	(1)
	0.2	11.2	55.4	25.2	2.9	0.1	-	5	(2)
	0.11	11.6	52.93	25.09	3.25	-	-	7.02	(3)
	0.10	10.47	53.28	24.96	3.34	-	-	7.85	(4)
Cotton	-	28.7	57.4	13.0	0.9	-	-	-	(4)
Sunflower	0.12	5.33	52.01	37.13	3.45	-	0.16	1.8	(1)
	0.3	6.7	51.3	38.7	2.9	0.1	-	-	(2)
	0.09	6.14	51.17	34.30	4.11	-	0.17	1.02	(5)
Palm	0.4	45.6	10.5	38.5	3.8	-	-	1.2	(2)
	0.19	43.03	10.82	39.47	4.31	-	-	2.18	(4)
Animal fat	3.32	29.06	1.8	35.92	23.82	-	-	6.08	(4)
Beef tallow	2.86	22.99	3.91	41.6	19.44	0.33	0.14	8.73	(6)
Canola	0.27	6.45	29.81	53.36	2.54	-	0.42	7.15	(1)
Jatropha oil	1.07	13.95	33.78	42.71	7.94	-	-	0.55	(3)
Castor oil	-	1.64	6.42	82.88	1.85	-	-	2.18	(7)

Note. References: (1) Atmanli et al. (2015); (2) Esteban et al. (2012); (3) Martínez et al. (2014); (4) Melero et al. (2010); (5) Ghanei et al. (2011); (6) Goodrum et al. (2003); (7) Canoira et al. (2010).

On comparing *M. pubescens* oil with other oily inputs used for biodiesel production (Table 1), it is possible to observe that oleic acid is the main acid found in this oil (56.9%), and is the second most frequently found in soybean oil (25.09% to 26.55%). Arachidic acid (11.3%) and gadoleic acid (9.5%) are, respectively, the second and third most prevalent in *M. pubescens* oil, although they represent less than 1% of fatty acids in soybean oil. On the other hand, linoleic acid, whose content in soybean oil is higher, ranging from 51.04% to 55.4%, is lower in *M. pubescens* oil (3.7%).

The palmitic acid found in *M. pubescens* oil (8.2%) is also found in palm oil, although at higher levels (43.03% and 45.6%) in the latter. Oleic acid is abundantly found in *M. pubescens* oil (56.9%), while it is the second most commonly found (38.5% to 39.47%) in palm oil. The linoleic acid found in *M. pubescens* oil (3.7%) is the main fatty acid in sunflower oil (51.17% to 52.01%). Cotton seed oil also has a great quantity of this fatty acid (57.4%).

Oleic acid is a major component in *M. pubescens* oil (56.9%), castor oil (82.88%), canola oil (53.36%), jatropha oil (42.71%), and animal fat (35 92% to 41.6%). The latter also has considerable amounts of palmitic acid (22.99% to 29.06%) and stearic acid (19.44% to 23.82%), which are also found in *M. pubescens* oil, but in smaller quantities, 8.2% and 2.4%, respectively (Table 1).

3.1 Physical and Chemical Properties of M. pubescens Oil

Physical and chemical properties of oils are determined by their conservation status, chain length, and degree of unsaturation of their fatty acids. Some properties are related to only one of these properties, *e.g.*, the iodine number, which depends on the degree of unsaturation and the saponification value, which is determined by the carbon chain length. The combination of degree of unsaturation and chain length is critical for density, viscosity, and refraction. The oil conservation status can be assessed by tests such as acidity value and peroxide value.

3.1.1 Saponification and Iodine Value

M. pubescens oil has a lower saponification value (133.36 mg $KOH \cdot g^{-1}$) compared with other oils used as raw materials for biodiesel production, such as soybean (190.1 to 194.2 mg $KOH \cdot g^{-1}$), animal fat (196.3 to 195.7 mg $KOH \cdot g^{-1}$), palm (199.1 to 200.1 mg $KOH \cdot g^{-1}$), canola (184.0 to 191.0 mg $KOH \cdot g^{-1}$), and sunflower (187.7 to 195.3 mg $KOH \cdot g^{-1}$), and is also lower than linseed (179.4 mg $KOH \cdot g^{-1}$) and acai (189.1 mg $KOH \cdot g^{-1}$), as shown in Table 2.

Table 2. Saponification and iodine index *M. pubescens* oil and other oils

Source	Saponification index (mg KOH·g^{-1})	Iodine index (cg I_2·g^{-1})
M. pubescens	133.36 (±0.2406)	77.36
Soybean	193.2 [(1)]; 194.2 [a (2)]; 190.1 [b (2)]	119.8 [(1)]; 119.6 [a (2)]; 123.7 [b (2)]; 120.52 [(6)]; 120-143 [(7)]
Palm	200.1 [a (2)]; 199.1 [b (2)]	52.5 [a (2)]; 47.8 [b (2)]
Beef tallow	196.3 [(2)]	40.6 [(8)]; 42.2 [(2)]; 45.3 [(9)]
Pork fat	195.7 [(2)]	44.8 [(2)]; 77.9 [(9)]
Castor oil	181.85 [(3)]	83.51 [(3)]
Canola	184.0 [(1)]; 191.0 [(2)]	111.7 [(2)]; 101.1 [(1)]
Sunflower	187.7 [(1)]; 193.5 [(2)]; 195.3 [(4)]	93.5 [(1)]; 111.2 [(2)]
Linssed	179.4 [(5)]	180.1 [(5)]
Açaí	189.1 [(5)]	61.8 [(5)]

Note. [a] Unrefined; [b] Refined. References: [(1)] Martínez et al. (2014); [(2)] Toscano et al. (2012); [(3)] Canoira et al. (2010); [(4)] Ghanei et al. (2011); [(5)] Pantoja et al. (2013); [(6)] Gopinath et al. (2009); [(7)] Knothe (2002);[(8)] Melero et al. (2010); [(9)] Mata et al. (2011).

M. pubescens oil consists of 20.8% fatty acids such as gadoleic and arachidic containing 20 carbon atoms. The presence of long chain fatty acids justifiesa lower saponification value when compared with soybean, canola, sunflower, and animal fats that have fewer long chain fatty acids (Table 1).

The iodine value of *M. pubescens* oil (77.36 I_2·g^{-1}) is lower than those found in the literature for soybean (119.6 to 143 I_2·g^{-1}), canola (101, 1 to 111.7 I_2·g^{-1}), sunflower (93.5 to 111.2 I2·g^{-1}), and linseed oils (180.1 I_2·g^{-1}). However, it is higher than those found in beef tallow (40.6 to 45.3 I_2·g^{-1}), pork lard (44.8 to 77.9 I_2·g^{-1}), palm oil (47.8 to 52.5 I_2·g^{-1}), and acai oil (61.8 I_2·g^{-1}) (Table 2).

Table 1 shows that *M. pubescens* oil has seven fatty acids and four of them are slightly unsaturated (palmitoleic, linoleic, oleic, and gadoleic). However, only linoleic acid has two double bonds and represents only 3.7% of the fatty acids. The remaining three fatty acids have only one degree of unsaturation. When compared with other oils, the fatty acid composition may have contributed to alower iodine value, as linoleic acid, which is unsaturated, is abundantly found in soybean (51.04% to 55, 4%) and sunflower oil (51.17% to 52.01%), which presented higher iodine indexes than *M. pubescens* oil.

3.1.2 Acidity Level, Peroxide Value, and Moisture Content

The acidity level of *M. pubescens* oil (1.119 mg KOH·g^{-1}) is suitable for biodiesel production. Although there are no official regulations for properties of oils used as raw material for biodiesel production, the acidity level is expected to be below 2 mg KOH·g^{-1} (Kwiecien et al., 2009).

Table 3 shows that the acidity level of *M. pubescens* oil is higher than soybean (0.069 to 0.39 mg KOH·g^{-1}), castor (0.56 mg KOH·g^{-1}), and canola oils (0.71 to 0.89 mg KOH·g^{-1}). However, its acidity level is lower than sunflower oil (1.90 mg KOH·g^{-1}), palm oil (11.6 mg KOH·g^{-1}), and animal fat (2.56 to 7.0 mg KOH·g^{-1}).

Table 3. Acidity index, humidity and peroxide index *M. pubescens* oil and others oils

Source	Acidity index (mg KOH·g^{-1})	Humidity (%)	Peroxide index (meq·Kg^{-1})
M. pubescens	1.119 (±0.1933)	0.88 (±0.0560)	26.14 (±5.9967)
Soybean	0.069 [(1)]; 0.099 [(2)]; 0.039 [(3)]	0.07 [(5)]	0 [(9)]; 0.01 [(9)]; 3.21 [(10)]
Fat	2.56 [(1)]; 7.0 [(4)]	-	-
Palm	11.6 [(1)]	-	0.6-2.19 [a (11)]
Sunflower	1.90 [(5)]	0.07 [(8)]; 0.06 [(5)]	0.99 [(10)]
Castor oil	0.56 [(6)]	-	-
Canola	0.71 [(5)]; 0.89 [(7)]	-	-
Rapeseed	-	0.06 [(5)]	-
Jatropha oil	-	0.1 [(5)]	-
Corn	-	-	1.0 [(10)]
Linseed	-	-	10 [(12)]; 5.2 [(13)]
Acai	-	-	177.1 [(12)]

Note. References: [(1)] Oliveira et al. (2013); [(2)] Santos et al. (2013); [(3)]Atmanli et al. (2015); [(4)] Melero et al. (2010); [(5)] Martínez et al. (2014); [(6)] Canoira et al. (2010); [(7)] Kwiecien et al. (2009); [(8)] Ghanei et al. (2011); [(9)] Castro et al. (2006); [(10)] Jorge et al. (2005); [(11)] Almeida et al. (2013); [(12)] Pantoja et al. (2013); [(13)] Bera et al. (2006). [a] Varies according origin and extraction method.

The moisture content found in *M. Pubescens* oil is 0.88%. It is high when compared to those found in soybean (0.07%), sunflower (0.06 to 0.07%), rapeseed (0.06%), and jatropha oil (0.1%) (Table 3). High moisture content can contribute to an increased acidity level, as it facilitates the hydrolysis of triglycerides and, consequently, the formation of free fatty acids, which can result in oil degradation (Almeida et al., 2013; Blin et al., 2013).

The peroxide value found in *M. pubescens* oil (26.139 meq·kg^{-1}) was higher than that found in the literature for soybean (0 to 3.21 meq·kg^{-1}) and palm oils (0.6 to 2.19 meq·kg^{-1}), which are raw materials considered of great importance for biodiesel production. The only oil that showed a peroxide value greater than that of *M. pubescens* was acai (177.1 meq·kg^{-1}) (Table 3). The peroxide value is related to storage time, temperature, exposure to light, foreign materials, the extraction process used to extract the oil, and may also vary depending on the origin of seeds used in the extraction process (Almeida et al., 2013; Mata et al., 2011; Pantoja et al., 2013; Sidibé et al., 2010).

Analyses were carried out immediately after oil extraction, so the high peroxide value found is not related to storage time, but may be related to the extraction process employed. In this manner, it is important to carry out studies for the evaluation of other extraction processes, in order to obtain oils with lower peroxide values.

3.1.3 Viscosity Index, Density, Refractive Index, and Ash Content

The viscosity index at 20 °C of *M. pubescens* oil was 101.46 mm^2·s^{-1}. This index is higher than those found in the literature for soybean (67.12 mm^2·s^{-1}), cotton (34.0 mm^2·s^{-1}), palm (79.7 mm^2·s^{-1}), rapeseed (74.19 mm^2·s^{-1}), sunflower (64.4 to 73.45 mm^2·s^{-1}), corn (70.29 mm^2·s^{-1}), acai (50.1 mm^2·s^{-1}), and linseed oils (26.7 mm^2·s^{-1}). However, it may be considered lower than that of beef tallow, whichis solid up to 40 °C (Table 4).

Table 4. Viscosity 20 °C, specific mass 20 °C and refractive index *M. pubescens* oil and others oils

Source	Viscosity ($mm^2 \cdot s^{-1}$)	Specific mass ($g \cdot cm^{-3}$)	Refractive index (nD)
M. pubescens	101.46 (±0.0002)	0.8796 (±0.00015)	1.3348 (±0.00028)
Soybean	60.5 [(1)]; 67.12 [(2)]	0.9185 [(2)]; 0.920 [(7)]; 0.9237 [(8)]; 0.931 [(3)]	1.4671 [(9, 10)]; 1.4680 [(11)]
Sunflower	64.4 [(1)]; 73.45 [(2)]	0.9169 [(2)]; 0.932 [(3)]	1.4668 [(12)]; 1.4679 [(10)]
Palm	79.70 [(3)]	0.917 [(3)]; 0.928 [(7)]	-
Fat	Solid [(4)]	0.909 [(7)]; ±0. 91 [a (4)]	-
Cotton	30.4 [(5)]	0.910 [(5)]	-
Rapeseed	74.19 [(2)]	0.9145 [(2)]	-
Canola	-	0.917 [(3)]	-
Corn	70.29 [(2)]	0.9167 [(2)]	1.4657 [(10)]
Acai	50.1 [(6)]	-	-
Linseed	26.7 [(6)]	-	1.2 [(13)]
Castor oil	-	1.4792 [(14)]	-

Note. References: [(1)] Quinchia et al. (2010); [(2)] Esteban et al. (2012); [(3)] Siddique et al. (2010); [(4)] Goodrum et al. (2003); [(5)] Rakopoulos et al. (2015); [(6)] Pantoja et al. (2013); [(7)] Melero et al. (2010); [(8)] Santos et al. (2013); [(9)] Moradi et al. (2012); [(10)] Jorge et al. (2005); [(11)] Santos et al. (2013); [(12)] Ghanei et al. (2011); [(13)] Bera et al. (2006); [(14)] Canoira et al. (2010). [a] Measured at 40 °C as it is solid at that temperature.

The viscosity index increases when the chain length of fatty acids increases and decreases when the number of unsaturated bonds increases (Esteban et al., 2012; Siddique et al., 2010; Toscano et al., 2012). Thus, the viscosity index found in *M. pubescens* oil is due to the amount of gadoleic acid (9.5%) and arachidic acid (11.3%), which contain 20 carbons. Other oils used for biodiesel production have a low percentage of acids with similar chains and thus show lower viscosity index. Furthermore, *M. pubescens* oil has a few fatty acids with two degrees of unsaturation, such as linoleic acid (3.7%), which is abundant in soybean (51.04% to 55.4%) and sunflower oils (51.17% to 52.01%) (Table 1).

The density of *M. pubescens* oil (0.8796 $g \cdot cm^{-3}$) was lower than that found in the literature for soybean (0.9185 to 0.931 $g \cdot cm^{-3}$), rapeseed (0.9145 $g \cdot cm^{-3}$), sunflower (0.9169 to 0.932 $g \cdot cm^{-3}$), palm (0.917 to 0,928$g \cdot cm^{-3}$), cotton (0.910 to 0.9148 $g \cdot cm^{-3}$), corn (0, 9167$g \cdot cm^{-3}$), and canola oils (0.917 $g \cdot cm^{-3}$), and animal fats (0.909 to 0.91 $g \cdot cm^{-3}$) (Table 4). The density is influenced by the carbon chain length, number of unsaturated bonds in the fatty acids present in the oil, and also the temperature (Esteban et al., 2012; Martinez et al., 2014).

The refractive index of *M. pubescens* oil (1.3348 nD) is lower than that reported in the literature for soybean (1.4671 and 1.4680 nD), sunflower (1.4668 and 1.4679 nD), corn (1.4657 nD), and castor oils (1.4792 nD), and higher than that of linseed oil (1.2 nD) (Table 4). The refractive index depends on the degree of unsaturation of the fatty acids of the oil, the oxidized compounds and polymers present, and also varies according to the heat treatment the oil undergoes. Each type of oil, therefore, shows a different refractive index (Ghanei et al., 2011; Jorge et al., 2005; Moradi et al., 2012; Santos et al., 2013).

The ash content found in *M. pubescens* oil was 0.012%, which is similar to that reported in the literature for palm (0.01%) and souari nut oils (0.01%), and less than that found in babassu oil (0.03%) (Costa Neto et al., 2000).

3.2 Transesterification and Biodiesel Properties

The transesterification reaction reduced the viscosity index of the oil. The index measured in the biodiesel produced (29.62 $mm^2 \cdot s^{-1}$) was lower than that in the oil (101.46 $mm^2 \cdot s^{-1}$). However, the viscosity index is still higher than that determined by the ANP and ASTM D6751. It is also higher than that found in biodiesel produced from other sources such as soybean (3.97 and 4.04 $mm^2 \cdot s^{-1}$), sunflower (4.03 and 4.55 $mm^2 \cdot s^{-1}$), castor (15.3 $mm^2 \cdot s^{-1}$), animal fat (4.65 $mm^2 \cdot s^{-1}$), canola (4.34 and 4.41 $mm^2 \cdot s^{-1}$), and cotton oils (4.0 and 4.06) (Table 5).

Table 5. Characterization of biodiesel *M. pubescens* and comparison with others sources

Biodiesel	Viscosity 40 °C ($mm^2 \cdot s^{-1}$)	Specific mass 20 °C ($g \cdot cm^{-3}$)	Acidity index (mg $KOH \cdot g^{-1}$)	Saponification (mg $KOH \cdot g^{-1}$)
M. pubescens	29.62 (±0.142)	0.8484 (±0.015)	0.752 (±0.151)	148.89 (±3.567)
Standard ANP	3.0-6.0 (1)	0.850-0.900 (1)	0.5 (max) (1)	-
ASTM D6751	1.9-6.0 (10)	-	0.5 (max) (10)	-
Diesel oil	-	0.838 (7)	-	-
Soybean	4.04 (2); 3.97 (3)	0.8845 (3)	0.16 (3); 0.24 (2)	190.7 (2); 194.61 (9)
Palm	4.28 (3)	0.8746 (3)	0.13 (3)	205.0 (9)
Cotton	4.0 (6); 4.06 (3)	0.885 (6); 0.883 (3)	0.09 (3)	-
Sunflower	4.55 (2); 4.03 (3)	0.8840 (3)	0.14 (3); 0.34 (2)	186.0 (2); 190.23 (9)
Castor oil	15.3 (5)	0.925 (5)	1.03 [a]; 1.60 [a] (5)	-
Reused oil	-	-	3.3 [a]; 15.7 [a] (8)	-
Beef tallow	4.65 (4)	-	-	-
Canola	4.34 (3); 4.41 (4)	0.8828 (3)	0.16 (3); 0.32 (2)	-
Rapeseed	-	-	-	185.0 (2); 197.07 (9)

Note. References: (1) ANP 45/2014; (2) Martínez et al. (2014); (3) Alptekin and Canakci (2008); (4) Farahani et al. (2011); (5) Canoira et al. (2010); (6) Rakopoulos et al. (2015); (7) Pereira et al. (2012); (8) Jacobson et al. (2008); (9) Gopinath et al. (2009); (10) ASTM D6751. [a] Varies according changes of temperature conditions and quantities of catalyst and alcohol.

Some methods, however, may reduce the viscosity index of biodiesel, such as an admixture of different raw materials in its production, as well as admixture of ready-to-use biodiesel with diesel fuel in suitable ratios and fuel pre-heating prior to using it. (Atmanli et al., 2015; Blin et al., 2013; Mata et al., 2011; Rakopoulos et al., 2015).

The transesterification also reduced the density of *M. pubescens* oil from 0.8796 $g \cdot cm^{-3}$ to 0.8484 $g \cdot cm^{-3}$ in biodiesel. In spite of being a value higher than that found in mineral diesel (0.838 $g \cdot cm^{-3}$), it is lower than that determined by the ANP and suggested for biodiesel from other sources (Table 5).

The biodiesel acidity level (0.752 mg $KOH \cdot g^{-1}$) was higher than the limit established by the ANP and the ASTM D6751, which suggesta maximum of 0.5 mg $KOH \cdot g^{-1}$. The level found is also higher compared with biodiesel produced from other sources, such as soybean (0.16 and 0.24 mg $KOH \cdot g^{-1}$), canola (0.16 to 0.32 mg $KOH \cdot g^{-1}$), cotton (0.09 mg $KOH \cdot g^{-1}$), and sunflower oils (0.14 and 0.34 mg $KOH \cdot g^{-1}$). However, it was lower than that found in biodiesel produced from reused oil (3.3 to 15.7 mg $KOH \cdot g^{-1}$) and castor oil (1.03 to 1.60 mg $KOH \cdot g^{-1}$) (Table 5). The acidity level of biodiesel is related to the biodiesel production process. Transesterification using oils from the same source, but modification of reaction conditions such as temperature, stirring, molar ratio between catalyst and alcohol, results in biodiesel with different acidity levels (Canoira et al., 2010; Jacobson et al., 2008; Martinez et al., 2014).

There are no official regulations for saponification values in biodiesel. The saponification value of biodiesel from *M. pubescens* oil was 148.89 mg $KOH \cdot g^{-1}$, which is below the saponification values reported in biodiesel produced from different sources of oil such as soybean (190.7 mg $KOH \cdot g^{-1}$), rapeseed (185.0 and 197.07 mg $KOH \cdot g^{-1}$), sunflower (186.0 and 190.23 mg $KOH \cdot g^{-1}$), and palm oil (205.0 mg $KOH \cdot g^{-1}$) (Table 5).

In Brazil, it is tried to diversify the oil sources for the fabrication of biodiesel through the Brazilian National Program of Production and Use of Biodiesel, which also encourages the inclusion of family farming in the cultivation of these inputs with the goal of promoting social development. However, due to the variation in price and low availability of other raw materials, soybean oil remained the main source used in recent years (Santos Alves et al., 2017; César & Batalha, 2010; Zonin et al., 2014). It is also necessary to consider that soy is an important foodstuffs, so it is imperative to find new oil plants with potential for biodiesel production and that do not represent sources of food, as the M. pubescens (No, 2011; Suarez et al., 2009).

Other studies must be carried out in order to verify the possibility of cultivation, economic and productive variables such as productivity per hectar and oil content per hectar, since these conditions have not yet been evaluated and this work verified that *M. pubescens* oil has physical and chemical properties appropriate for biodiesel production, with the exception of the peroxide value. Therefore, further studies too should be carried

out to evaluate other extraction processes to achieve suitable peroxide values and allow for a better use of seeds. Chromatographic analysis showed that the qualitative composition of fatty acids in the oil is similar to that of other oils used for biodiesel production. *M. pubescens* oil is suitable for producing biodiesel, however, transesterification conditions should be evaluated to obtain biodiesel with more suitable physical and chemical properties.

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