STORAX (*Styrax officinalis* L.) AS A NOVEL NON-EDIBLE OIL RESOURCE FOR BIODIESEL PRODUCTION

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Abstract. Water use and management will be a critical issue in the future due to climate change. Tesbi (*Styrax officinalis* L.), a plant species that can grow in marginal areas, is important for its ability to produce high yields in non-water areas. We compared the physical and chemical characteristics of *Styrax officinalis* L. seeds to those of important oil crops, such as safflower, soybean, canola, and wild mustard. The storax seed oil's fatty acid composition and some of its physico-chemical characteristics were examined to ascertain whether it was suitable for use in the manufacturing of biodiesel. The oil content of storax seed was determined 59.99%. The most dominant fatty acids in this crude oil were linoleic acid (68.95%) and oleic acid (20.01%). The biodiesel properties of tesbi oil were found to be: density (15°C) 905 kg/m^3, color 1.4, pH 7, flash point 176°C, kinematic viscosity (40°C) 5.65, cloud point -9°C, CFPP -2.17°C, pour point -5.93°C, freezing point -0.82°C, water content 520.01 ppm, saponification number 200.77 ml/KOH/g, iodine value 106.23 g iodine/100 g, cetane number 49.58, HHV 39.60 MJ/kg, molecular weight 875.74 g, oxidation stability 3.91 h, carbon 76.57 wt%, hydrogen 11.91 wt%, oxygen 11.47 wt%, and C/H ratio 0.53 wt%. Storax oil biodiesel is a potential alternative fuel.
Keywords: *biodiesel, linoleic acid, oleic acid, oil ratio, storax, Styrax officinalis L.*

Introduction

Using sources of renewable energy is increasing especially in developed countries owing to the decrease in fuels made of fossils and the harmfulness on the environment (Demirbas, 2005; Kumar, 2015; Moustakas and Loizidou, 2023). One of these sources is biodiesel produced from bio-oils.

A short-chain alcohol (methanol or ethanol) and a catalyst react to generate a long-chain fatty acid methyl ester called biodiesel from plant-based oils (Martinez et al., 2014; Fidan and Alkan, 2014; Bolonio et al., 2019).

Although technically made from any type of organic oil, vegetable oils are often used to make biodiesel. Therefore, the supply of raw materials for the sustainable production and consumption of biodiesel is very important. In biodiesel studies, while using edible oils such as soybean, rapeseed, palm, sunflower, recently, non-edible oils have been studied (Cvengros and Povazanec, 1996; Sensöz and Kaynar, 2006; Lovato et al., 2014; Demirbas, 2016; Bolonio et al., 2019; Arumugam and Ponnusami, 2019).

In terms of food safety, using edible oils to make biodiesel is expensive and risky for increasing demand pressure on edible oils (Pinzi et al., 2009). Due to the fact that global hunger and food shortages have been growing daily. It is commonly known that food shortages cause deaths from famine (Rubika et al., 2024). Migrant movement from Asia, Africa, and South America to industrialized nations is no longer reversible. As a result, producing biodiesel from non-edible oils and non-agricultural areas is critical (Mahbub et al., 2011; Musthafa, 2016; Mancini et al., 2019).

Glycerol, which is one of the fat-forming elements, is the same in all oils, but the fatty acids which are the other elements are different in every plant species. This condition

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significantly affects the chemical properties of the oil. The important basic parameters of oil which will use as the raw material in biodiesel production are density, acid value (AV), free fatty acid content (FFA), iodine value (IV), saponification number (SN), cetane number (CN), flash point (FP), calorific value (CV), and pH (Dunn, 2005; Ramos et al., 2009). Again, one of the important parameters that determine the quality of biodiesel is the chemical composition of the oil. In the researches, it is stated that the oils containing long-branched single - double bond fatty acids are the suitable diesel alternative and the increasing degree of unsaturation affects the cetane number negatively (Darnoko and Cheryan, 2000). The high content of oleic and linoleic acids in certain oils makes them preferable for biodiesel production (Acaroğlu and Oğuz, 2002). The chemical composition of tesbi oil is very similar to oils advised for biodiesel production such as safflower, soybean oil, and canola oil. C18:1 and C18:2 ratios of tesbi oil are high as these oils, and linolenic acid is low.

To use an oil seed as an energy raw material, the chemical properties, as well as the physical properties, must have the optimum conditions. Because no matter how good the chemical properties of an oil are, if the physical properties such as one thousand grain weight, oil content, inner weight of the seed, shell weight, and shell-inner ratio are not good, its production will not be economical. Therefore, *Styrax officinalis* L. is very important a species in perennial the form of shrub (*Figure 1*). *Styrax* (Styracaceae) has 8genera and about 130 species (Fritch, 1996). The plant, which is found to have about 60% oil in its seeds, is easily grown in arid areas without the need for any agricultural inputs in Southeast Asia, the tropical climates of the American continent, and the Mediterranean biome (Davis, 1972; Sugden, 1986; Fritsch, 1996; Wang et al., 2015). The fact that it can be growing in areas with a shade ratio of 60-70% of forests makes the plant in a very important position (Cesur et al., 2018a). Because the cost of *Styrax officinalis* L. production is going to be lower than the other field crops when it is entered into agricultural production (Mancini et al., 2019). The usage of oil in the seeds (*Figure 1*) as an energy source in the industrial field can reduce the demand pressure on edible oils. At the same time, it can contribute to supplying food security all over the world (Lee et al., 2008; Asif et al., 2017; Sun et al., 2017; Mics and Hufnagel, 2024).

Oflas (1973) reported that 65 storaxes in 150 m² in his preliminary research were observed. According to this calculation, 4300 plants can be grown in 1 ha^{-1} area with a proportional. In a preliminary study, storax seeds were collected 9 kg of storax seeds were harvested in September from the located in altitude of 729 m (02, 95964 east, 41, 16141 north) in the Amanos Mountains within the borders of Nurdağı district of Gaziantep province. According to this refer, 4300 x 9 = 38,700 kg of storax seeds can be obtained from 1 ha^{-1} in forest area. If fruit peel constitutes 30% of the total weight, 25,800 kg of seeds were remain. The seed inner ratio to the total seed is approximately 30% (*Table 1*). This makes 7740 kg. Considering that the seed internal ratio is approximately 47% oil, there is a potential to obtain 3637.8 kg of crude oil. According to these data, the potential oil yield of the storax plant is higher than many cultivated oil plants. In addition, the most powerful feature of the storax plant is that it produces biomass in arid, barren and non-agricultural areas.

In nature, because the plant is under animal and human pressure, it is classified as an endangered species according to IUCN (2018). If its economic importance is recognized and included in the plant production pattern, the population of the plant will increase again. The increase in the population in non-agricultural areas will also make a positive contribution to the fight against global warming and climate change.

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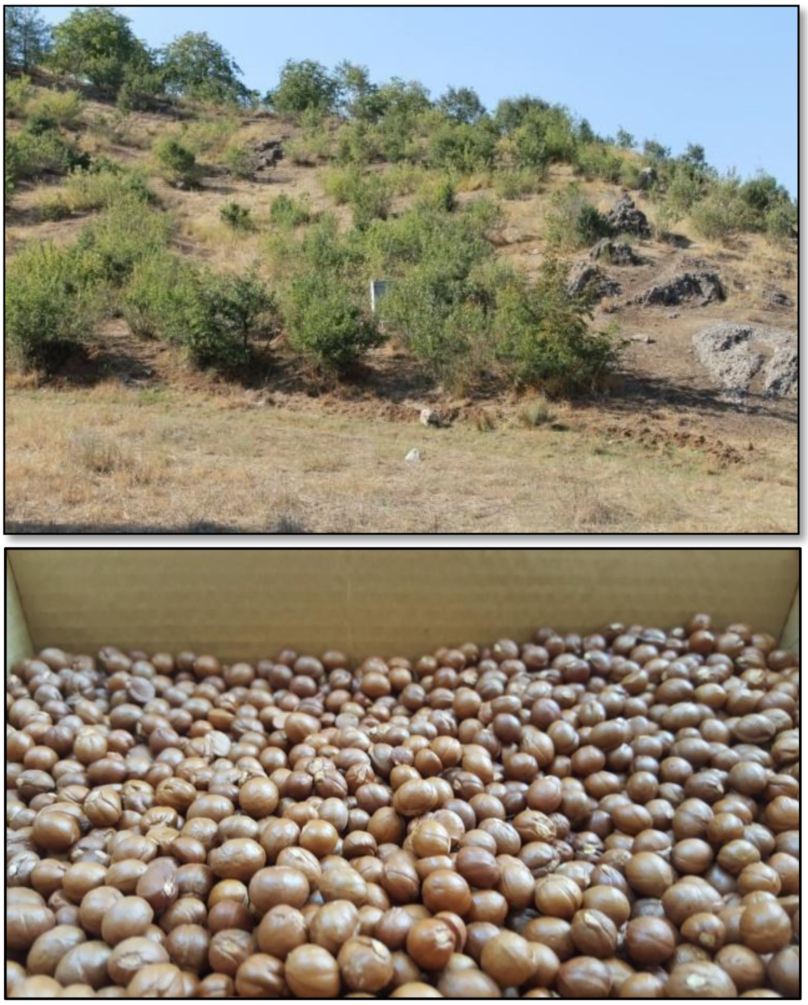

Figure 1. *(Top) Storax (Styrax officinalis L.) shrubs (Bottom) Storax seeds*

No studies on the physical and chemical characteristics of biodiesel made from *Styrax officinalis* L. seed oil was discovered in the literature review. For this reason, the main objective of this study is to investigate the physical and chemical properties of biodiesel manufactured from *Styrax officinalis* L. seed oil. This research could lead to the development of new renewable and sustainable energy sources.

Material and methods

Seed material

Tesbi seeds used in the study were obtained from an altitude of 865 in Pazarcık (37° 29'25.76”-37° 20'49.63”) district of Kahramanmaraş in Türkiye's eastern Mediterranean region (*Figure 2*). The physical properties of the seeds were determined after the fruit peel was removed. After determining the physical properties of the seeds, tesbi oil was obtained by a screw press. Then, the physical and chemical properties of the oil and its biodiesel were investigated.

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Figure 2. *Distribution map of Styrax officinalis L. in Mediterranean biome. (IUCN, 2018)*

The oil content

Storax seeds, which were separated from their shells, were first milled in a hand mill and then 2 grams of the seeds were mixed homogeneously. The amount of oil in milled seeds was determined by Soxtec 2055 brand in the petroleum-benzene solvent.

Fatty acid composition analysis

Fatty acid methyl esters (FAME) were prepared according to the Association of Official Analytical Collaboration (AOAC) (AOCS, 1997). By using a gas chromatography system from Shimadzu (Kyoto, Japan) with a flame ionization detector (FID) and Rtx-2330 capillary column (60 m x 0.25 m i.d., 0.20 m film thickness), the FAME was detected. The injector and detector were both heated to 250°C and 260°C, respectively. For 20 minutes, the oven's temperature was maintained at 240°C after being raised to that level at a rate of 4°C/min. A flow of 1.0 mL/min of helium was used as the carrier gas. The autosampler used a split mode (split ratio of 1:100) to inject a 1 liter sample. FAME standards were bought from Sigma (Sigma-Aldrich GmbH, Steinheim, Germany).

Biodiesel production process

Biodiesel production of crude seed oil was made by the transesterification method. The method described in detail by Eryılmaz et al. (2014) for the production of biodiesel from tesbi oil was used. Biodiesel production from crude oil was completed by drying the biodiesel at 120 °C for 2 hours.

The saponification number (SN) (Patil and Deng, 2009), iodine value (IV) (Chhetri et al., 2008), cetane number (CN) (Azad et al., 2015), oxidation stability (OS) (Ruhul et al., 2017), kinematic viscosity at 40ºC, and higher heating value (HHV) (Keera et al., 2011) of the *Styrax officinalis* L. seed oil biodiesel can be calculated as given the following formulas:

$$SN = \sum \left(\frac{560\ xA_i}{MW_i} \right) \quad \text{(Eq.1)}$$

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$$IV = \sum(254xDxA_i)/MW_i \quad \text{(Eq.2)}$$

$$CN = 46.3 + \frac{5458}{SN} - 0.225IV \quad \text{(Eq.3)}$$

$$OS = -0.0518(DU) + 11.121 \quad \text{(Eq.4)}$$

DU, the parameter was calculated from monounsaturated and polyunsaturated by using *Eq. (5)* of Kansedo et al. (2009).

$$DU = (Monounsaturated\ Cn{:}\ 1, wt\ \%) + (Polyunsaturated\ Cn{:}\ 2{,}3, wt\ \%) \quad \text{(Eq.5)}$$

$$HHV = 49.43 - [0.041(SN) + 0.015(IV)] \quad \text{(Eq.6)}$$

The proportions of each component in the fatty acids are represented by Ai, and their molecular masses are represented by MWi.

Equation 7 was used to calculate the molecular weight (MW) of the crude oil obtained from *Styrax officinalis* L. seeds (Dharma et al., 2016).

$$MW = 3 * (AMW_{FA}) + weight\ of\ glycerol\ backbone \quad \text{(Eq.7)}$$

where, AMW_{FA} is the average molecular weight of all fatty acids.

Result and discussion

Some the chemical and the physical properties of storax seed and seed oil

Biodiesel is generally producted from vegetable oils (Asfaw et al., 2025). Therefore, the supply of raw materials for the sustainable production and consumption of biodiesel should be economical (Thamsiriroj and Murphy, 2011). Because the cost of oil constitutes 70-85% of the biodiesel expense (Sun et al., 2015). The use of oils consumed as food in biodiesel production is risky in terms of food safety and is also costly (Sharma and Sing, 2017). Therefore, crude oil which can be produced from non-edible oils and non-agricultural areas is very important (Ghazala et al., 2023; Caporusso et al., 2025). *Styrax officinalis* L. is a suitable plant for this properties. When some physical and chemical properties of plant seed (*Table 1*) are examined, it will be seen that it is economically convenient to use it as a biodiesel raw material.

Table 1. *Some the chemical and the physical properties of storax coat and seed*

The physical properties of coat				
Coat height (mm)	Coat width 1 (mm)	Coat width 2 (mm)	Inner height (mm)	Inner width (mm)
11.73±0.96	9.65±0.49	9.23±0.44	9.24±0.92	4.91±0.27
Physical properties of seed				
100 grain weight (g)	Inner weight (g)	Coat weight (g)	Inner rate (%)	
46.96±1.93	13.35±0.70	32.73±1.14	28.45±0.63	
The chemical properties of seed oil				
Oil rate (%)	Molecular weight of oil (MW)	Crude protein rate (%)	Water rate (%)	
59.99± 2.07	877.95 (g/mol)	15.12±0.98	3.26±0.26	

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The most important physical properties of seed in terms of yield were determined as 100 seed weight 46.96±1.93 g, inner weight 13.35±0.70, coat weight 32.73±1.14 g, inner rate 28.45±0.63%. Its chemical properties were determined as oil rate 59.99 ± 2.07%, molecular weight 877.95 g/mol, crude protein content 15.12±0.98% and water ratio 3.26±0.26%, respectively. 100 seed weight and oil ratio of seed which is used in oil produced is very important. It will be seen that these characteristics of the tesbi plant produce very high values when compared to other oilseed plants (*Figure 3*).

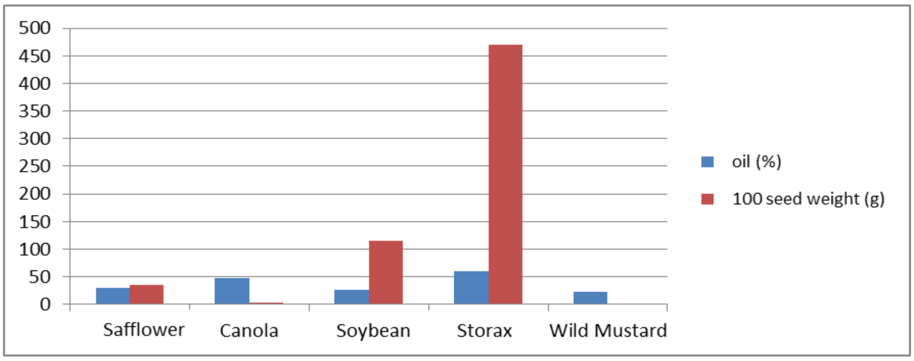

Figure 3. *Comparasion of some the important oil plant with storax plant*

Fatty acid compositions of the storax oil

Fuel use in diesel engines is a complex phenomenon. Because the optimum energy efficiency of the engines depends on the interaction of the physical and chemical properties of the fuel, whether diesel or biodiesel (Tauzia et al., 2006). The combustion characteristics and emissions of the engines vary according to the characteristics of the biodiesel used (Graboski and McCormick, 1998). The properties of biodiesel depend on the properties of vegetable oil used in its production. The hydrogen-carbon ratio of biodiesel is affected by its fatty acids content which causes differences in the injection, combustion, performance and emissions characteristics of the engine. According to Fatty acid compositions of the tesbi oil (*Table 2*), they were determined as ΣMUFA 20.26%, ΣPUFA 69.67% and ΣSFA 10.06%. It is seen that ΣPUFA of the storax oil is the highest value when compared to oils such as Safflower oil, canola oil and soybean oil (*Table 2*). The longer the fatty acid carbon chains in the fatty acid composition and the higher the rate of unsaturated fatty acids, the higher the cetane number (Bajpai and Tyagi, 2006; Lapuerta et al., 2009). According to Knothe et al. (2003), the amount of cetane oil is inversely proportional to linoleic and linolenic acid rates, is proportional to the stearic and palmitic acid rates. The ∑PUFA/(∑SFA+ ∑MUFA) ratio is a potential indicator of the chemical properties of the oils. The ratio close to or less than 1 may indicate that the oil show excellent global properties for biodiesel (Freedman et al., 1984). In addition, the increase of unsaturated fatty acid esters may have a positive effect on the cold flow properties of biodiesel (Sun et al., 2015).

Gas chromatography profiles of the storax biodiesel

Gas chromatography values of Tesbi oil biodiesel are given in *Figure 4*. As can be seen from the figure, the predominant peaks are ($C_{18:1}$), ($C_{18:2}$), ($C_{16:0}$) and ($C_{18:0}$). Other compounds were detected at minör rates. However, it can be said that these few compounds have distinctive features (Malechaux et al., 2020).

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Table 2. *Fatty acid compositions of storax oil, safflower oil, canola oil, and soybean oil (Cesur et al. (2018b); Kaya and Eryiğit (2020))*

No	Fatty acid	Molecular weight	Structure	Systematic name	Formula	Storax oil (this study)	Storax biodiesel (this study)	Safflower oil	Sunflower oil	Canola oil	Soybean oil
1	Myristic	228	$C_{14:0}$	tetradecanoic	$C_{14}H_{28}O_2$	0.03	0.07	0.05	0.045	0	0.1
2	Palmitic	256	$C_{16:0}$	hexadecanoic	$C_{16}H_{32}O_2$	6.29	11.05	5.28	4.68	3.49	11.0
3	Palmitoleic	254	$C_{16:1}$	hexadec-9-enoic	$C_{16}H_{30}O_2$	0.07	0.06	0.05	0.11	0	0.1
4	Margaric	270	$C_{17:0}$	heptadecanoic	C17H33O2	0.06	0.13	-		-	-
5	Margaroleic	268	$C_{17:1}$	Cis-10-heptadecenoic	$C_{17}H_{32}O_2$	0.04	0.09	-		-	-
6	Stearic	284	$C_{18:0}$	octadecanoic	$C_{18}H_{36}O_2$	2.85	3.60	1.79	3.32	0.85	4
7	Oleic asit	282	$C_{18:1}$	cis-9-octadecenoic	$C_{18}H_{34}O_2$	20.01	51.25	29.88	60.08	64.4	23.4
8	Linoleic	280	$C_{18:2}$	cis-9-cis-12 octadecadienoic	$C_{18}H_{32}O_2$	68.95	32.94	62.29	32.44	22.3	53.2
9	Linolenic	278	$C_{18:3}$	cis-9-cis-12 octadecatrienoic	$C_{18}H_{30}O_2$	0.72	-	0.08	0.26	8.23	7.8
10	Araşidonic	312	$C_{20:0}$	eicosanoic	$C_{20}H_{40}O_2$	0.13	0.21	0.40		0	0.3
11	Gadoleic	310	$C_{20:1}$	11eicosenoic	$C_{20}H_{38}O_2$	0.14	-	0.14		0	0
12	Behenic	340	$C_{22:0}$	docosanoic	$C_{22}H_{44}O_2$	0.58	0.09	0	0.002	0	0.1
13	Lignoseric	367	$C_{24:0}$	cis-15-tetracosenoic	C24H46O2	0.12	0.10	0		0	0
			Saturated fatty acids (∑ SFA)			10.06	15.25	7.52		4.34	15.5
			Monounsaturated fatty acids (∑ MUFA)			20.26	51.81	30.07		64,4	23,5
			Polyunsaturated fatty acids (∑ PUFA)			69.67	32.94	62.37		30.53	61.00
			Total			99.99	100	99.96		99.27	100

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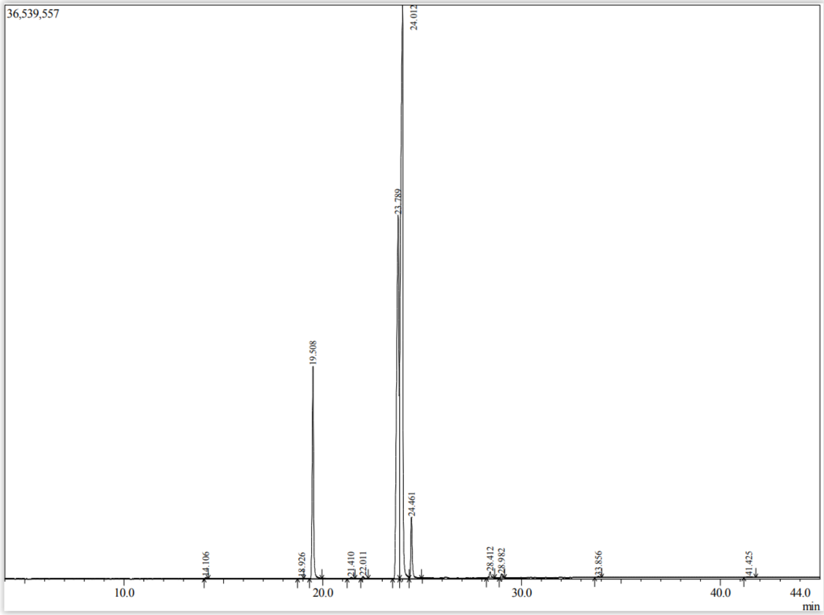

Figure 4. *GC-MS results of storax biodiesel*

Some physicochemical properties of the storax biodiesel

Biodiesel produced from vegetable oils is required to comply with EN14214 and ASTMD 6751 standards for economical use. In *Table 3*, some properties of the tesbi oil biodiesel are compared with EN14214 and ASTM D 6751 standards and its compatibility with the literature is examined. As can be seen in *Table 3*, density (15°C) of the tesbi biodiesel was 905.12. It is important because the density directly affects engine performance. For the production of biodiesel in the European standard EN14214, the biodiesel density limits are between 860.0 and 900.0 (UNE-EN 14214). The pH value of the oil affects the production speed, composition and quality of biodiesel. It is also highly effective on ionization which is an important factor in mechanisms such as binding and interaction of molecules (Çiçek and Yalçın, 2013). In the production of biodiesel, it is said that the most efficient pH value of the biodiesel is 7.5 (Sun et al., 2015). Cetane number, calorific value, flash point and density are the basic parameters in biodiesel efficiency (Demirbaş, 2008; Gülüm and Bilgin, 2017; Razavi et al., 2019). Loss of power occurs in biodiesel with low calorific value (Çanakcı and Özsezen, 2005). Cetane number is an important feature as ignition delay and combustion quality parameter.

High cetane number usually causes shortening of ignition delay (Keskin, 2013). Biodiesel cetane number is higher than petroleum-derived diesel. The US and Brazil (ASTM D 6751) have set the cetane number to 40, but the US has updated it to 47. The cetane number is min. 51 for EU (EN14214). Brazil has not made any changes (Anonymous, 2007). Kinematic viscosity is an important measure of the flow properties of biodiesel (Demirbas, 2016). Physical properties such as density and viscosity affect the engine's combustion characteristics, performance and exhaust emissions (Samavi et al., 2016). An increase in viscosity causes a reduction in the atomization quality of the injected fuel (Al-Hassan and Al-Odat, 2011; Shahabuddin et al., 2013). In this study, iodine value was determined as 106.23. Although the Iodine value limit is set to max. 120 according to EN14214 standard, Spain has set these limits as 120–140 (Ramos et al., 2009). Water content of the storax oil biodiesel was found to be at 520.01 ppm. Since the

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amount of water in biodiesel adversely affects the transesterification process, it is desirable to have less than 0.06% (Demirbas, 2016). As water causes partial change of reaction, it increases saponification. This leads to the catalyst being spent on soap production and thus to a reduction in catalytic efficiency (Çanakçı and Özsezen, 2005). In this study, the content of water in the fat was found to be 0.05% (*Table 3*). One of the important properties in the production of biodiesel is saponification number. Saponification is an undesirable situation in the transesterification process, since leads to much more catalyst demand, longer reaction time and inefficiency than normal reaction (Çanakçı and Özsezen, 2005). Calorific value is one of the most important features of a fuel. The calculation of this value can also be estimated by saponification number and iodine value (Demirbaş, 2008). In this study, saponification number of storax oil biodiesel was found to be 200.77. According to Gopinath et al. (2009), The saponification values are inversely proportional to unsaturated fatty acid ratios. Although the heating value of biodiesel is 12% lower than diesel, this can be improved by techniques such as viscosity reduction additive, water emulsion, exhaust gas recirculation (EGR) and low heat rejection (LHR) (Lee et al., 2005; Çanakçı, 2007). As the saturated fatty acid level increases, the cetane number is increasing, but in this case the biodiesel is affected negatively by the cold flow properties (cloud point, CFPP, freezing point) (Al-Hassan and Al-Odat, 2011; Sun et al., 2015). Molecular weight of tesbi oil biodiesel was found 875.74 g/mol (*Table 3*).

Table 3. *Fuel properties of the storax oil biodiesel in comparison with EN 14214 and ASTM D6751 biodiesel standards*

Fuel properties	Unit	Storax Biodiesel	ASTMD 6751	EN 14214
Density (15ºC)	kg/m^3	905.12	880	860-900
Colour	-	1.4	-	-
pH	-	7	-	-
Flash point	°C	176	93	120 min.
Kinematic viscosity 40 °C 70 °C 100 °C	m^2/s	 5.65 2.01 1.90	1.9-6.0	3.5-5.0
Cloud point	°C	0.82	-3 to -12	-
Cold filter plugging point (CFPP)	°C	-2.17	5 max	-5 min.
Pour point	°C	-5.93	-5 to -16	-
Freezing point	°C	-17		-
Water content	ppm	520.01		500 max.
Saponification number	ml/KOH/g	200.77	370 max	-
Iodine value	g iodine/100 g	106.23	-	120 max.
Cetan number	-	49.58	47 min	51 min.
Higher heating value (HHV)	MJ/kg	39.60	-	-
Molecular weight	g/mol	875.74		-
Oxidation stability	h	3.91	3 min	Min 8
Carbon ©	wt. %	76.57	-	76.91
Hydrogen (H)	wt. %	11.91	-	11.65
Oxygen (O)	wt. %	11.47	-	11.44
Carbon/Hydrogen	wt. %	0.53	-	-

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The findings showed that most of the physicochemical properties of methyl ester of storax oil biodiesel satisfied the standardsand thereby it could be a prospective candidate to the petroleum-based diesel fuel for the diesel engine application.

Conclusion

The physical characteristics of the seeds of the tesbi plants grown in the non-agricultural areas were found to have much more economic characteristics than many oil seeds. At the same time, although it can grow in arid, barren and non-agricultural areas, its potential to produce 40.0 tons of biomass per hectare indicates that research on the plant should be intensified. Chemical properties were also suitable for biodiesel production. The tesbi biodiesel has not been used until this time. therefore, its effects on motor and environment should be investigated. There are no studies on this subject in the literature. This study will contribute to the formation of literature about the tesbi biodiesel. It will also form a preliminary study for future studies.

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