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RESEARCH ARTICLE

VALORIZATION OF TURKISH COFFEE WASTE AS A BIODIESEL FEEDSTOCK

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ABSTRACT

Increasing industrialization and population increase demand to fossil fuels. Fossil fuels are limited all over the world. This causes the supply of these fuels to deplete and at the same time increase greenhouse gas emissions. Biodiesel is a good alternative to fossil fuels. Researchers are looking for products with high oil content as a feedstock for biodiesel production. Since the average oil content of coffee is 15% by weight and the annual coffee consumption in the world is approximately 1.5-2 million tons, it is possible to contribute to the economy by producing biodiesel from the waste coffee oil. Turkish coffee is a special coffee due to its preparation and cooking methods and has an important place in Turkish culture. Its consumption between the other coffee types is above 80% in Turkey, so it should be evaluated differently. In this study, the oil amount of Turkish coffee waste was investigated and it was discussed as a raw material for biodiesel. 16.8% wt. oil was obtained as a result of soxhlet extraction of Turkish coffee waste. This study suggests 8.44 million L of biodiesel production from Turkish coffee waste annually.

Keywords: *Biodiesel, Coffee, Turkish Coffee, Turkish Coffee Waste, Renewable Energy*

1. INTRODUCTION

Energy consumption which is mainly based on fossil fuels increases in parallel with the rapidly increasing population around the world. According to the World Energy Statistics the share of fossil fuels in the global energy supply in 2020 is 78% [1,2]. In Turkey it was determined that fossil fuels had the highest share among the total energy supply sources with a share of 87% and 13% share was created by renewable energy sources. In Turkey, main energy sources in power generation are as follows: coal 37%, natural gas 30%, hydroelectric 19.7%, wind 6.5%, solar 2.6%, geothermal 2.4%, and renewable waste 1.2% in 2018 [3]. Since the dependence on fossil resources in energy continues in the global arena, the tendency to renewable energy is on the rise. Today the policies adopted by the countries for energy saving are seen as an extremely critical area in ensuring energy supply security, reducing foreign dependency, protecting the environment and combating climate change. In particular, the Paris Climate Agreement was accepted as a milestone in the fight against climate change, and in this direction, the European Union Renewable Energy Directive was updated in 2018. According to

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this directive, it is aimed to increase the share of renewable energy sources to 32% and to reduce greenhouse gas emissions by 40% until 2030 [4].

Biodiesel is an alternative fuel produced from renewable resources such as animal and vegetable oils and can be used in diesel engines. It is a sustainable, environmentally friendly, non-toxic alternative fuel. Global biodiesel production is estimated to reach 23 billion liters by 2025. Biodiesel can also reduce CO2 emissions by 50% which is a valuable incentive given the role of the transport sector in increasing greenhouse gases [5-7].

Population growth, urbanization and industrialization led to an increase in the amount of production and consumption on one hand, and on the other hand, it caused an increase in the amount of waste generated. With this increase, there have been many discussions about managing the wastes. Although the removal of wastes from the living area was considered sufficient at first, requirement and finding of new areas for the removal of wastes due to the increasing amount became a big problem. The constant search for new areas for waste and the existence of reusable materials in the resulting solid wastes have caused a radical change in the understanding of waste management. With this change, the management of solid waste, which has a large share in the total amount of waste produced, has also come to the fore, and it has been determined that solid wastes are not items to be disposed of but inputs that can be used in other activities [8-11]. Many environmental and financial benefits can be achieved by recycling wastes. Considering this situation, large amounts of waste cooking oil, used coffee grounds, food wastes and used tea wastes may be recycled which supplied from restaurants, cafes etc. Converting huge amounts of waste into energy and value-added products is one of the effective ways to solve the problems of many countries that struggle to cope with these wastes generated every day [12,13].

Coffee is the most popular and most consumed beverage in the world. It is the second product with the highest trade volume in the world after oil [14]. Approximately 1.6 billion cups of coffee are consumed every day and this large industry produces a large amount of waste with spent coffee grounds. Recycling such wastes into fuels and products through biorefineries is a promising way to solve the waste problem. Coffee waste or spent coffee grounds are among the hopeful raw materials for biodiesel production. It is a high quality raw material with an average oil content of 15% by weight, similar to soybean and palm oil, which are among the first generation raw materials [7,12,15-17]. Different roasting and extraction processes of coffee bring about remarkable biological differences in its structure. Turkish coffee is a blend of moderately roasted and finely ground high quality Arabian-type coffee beans that originating from Brazil and Central America. The way of its making distinguishes Turkish coffee from others. Since new preparation technique was invented by the Turks, it was called Turkish coffee and boiled in copper pots. Unlike the filter coffee, it is extremely finely ground, is prepared by slowly boiling the coffee in water. Turkish coffee is an important part of Turkish culture and is known as one of the traditional drinks. Under this name, it spread to the world and became a part of the cultural and social history and lifestyle of the Turks. It has been determined that Turkish coffee contains biologically active components and caffeine at a higher rate than other coffee types and preparations [18-21].

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In this current study, the potential use of the Turkish coffee waste in biodiesel production was investigated. Although there are many studies about the spent coffee grounds in the production of biodiesel, Turkish coffee waste is not found. Since Turkish coffee plays major role in coffee industry in Turkey, it should be evaluated separately. This work is especially about the Turkish coffee waste and as a case study for Turkey.

2. COFFEE CONSUMPTION IN WORLD AND TURKEY

2.1. World

Coffee is the second product with the largest trade share after oil and has a serious consumer base in the world [14]. Coffee first began to grow on Arabica coffee trees in the Kaffa region in Ethiopia. Although there are various shapes and flavors of coffee beans in the world, there are mainly two groups called Robusta and Arabica. World consumption of Robusta coffee bean is 25 percent, while Arabica coffee bean is around 75 percent. Generally, Arabica coffee is considered superior to robusta due to its delicate aroma, highly acidic nature, and wine like taste [22]. Its acidity is also higher than Robusta. Robusta coffee beans, on the other hand, have stronger aromas and intense flavors compared to Arabica. Robusta beans have a more intense aroma than Arabica beans. At the same time, the caffeine content is twice as high as Arabian. Both varieties have high volatile organic contents. Processing different coffees at different stages causes diversity in spent coffee grounds [8].

The latest data showed that more than 9.98 million tons (166.34 million 60 kg bags) of coffee products were consumed between 2020 and 2021 worldwide. According to the International Coffee Organization (ICO), Europe (33%), Asia and Oceania (22%), and North America (19%) are the main coffee consumers. United States (26.98 million 60 kg bags) and Brazil (22.4 million 60 kg bags) are the main consumers of coffee [23]. Figure 1 shows the consumption of coffee values for the years 2020-2021.

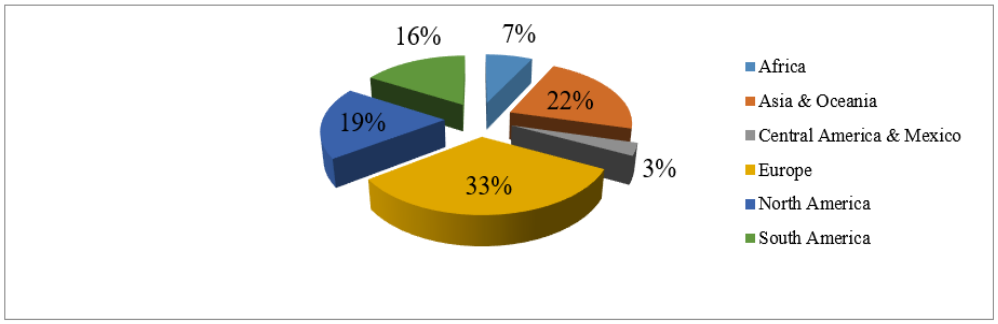

Figure 1. The consumption of coffee in world [23].

2.2. Turkey

Turkish coffee culture started in 1517 and soon after, coffee houses were opened where people came together and drank coffee. In the 17th century, the popularity of Turkish coffee spread to different

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countries. Coffee is not just a consumption item in Turkish cuisine and culture. It has been an effective element of national identity that reflects the history, culture, traditions and cuisine and it differs from modern coffees with its preparation, drinking, presentation and special equipment applied. For Turkish coffee, the highest quality Arabica coffee beans are selected and used. After grounding the beans in a coffee mill and getting the thinnest possible form, coffee is cooked as Turkish coffee by the method prepared in a small boiling pot with a narrow top developed by the Turks [24,25]. Although traditionally "Arabica" type beans are used, different beans can also be used, provided that they are of very high quality. Finely ground Turkish coffee is prepared with water by boiling the coffee slowly. Roasting degree is between the important factors in the taste of Turkish coffee. In order to achieve the characteristic flavor and fine texture of Turkish coffee, the coffee beans must be kept moist after roasting and not be completely dried [20,21]. Turkish coffee is the only type of coffee served with its grounds. It would be unfair to say that the difference of Turkish coffee from other coffees due to its many characteristics is only due to its cooking. Turkish coffee is a value that was included in the Intangible Cultural Heritage List of Humanity by UNESCO in 2013 due to its many features such as the history it gives to the place where it is drunk, being based on a rich cultural foundation, and its place in social life [26,27]. Figure 2 shows the filter coffee and Turkish coffee.

Figure 2. (a) Filter coffee. (b) Turkish coffee.

Turkey is one of the most exciting markets in the world. Turkish coffee itself has a long and deep-rooted tradition. Since 2010, consumption has grown at a steady 15% year-on-year. Coffee consumption in Turkey in 2020/2021 was approximately 106 million kg and is increasing every year which means 1.2 kg of coffee per person per year [23]. In Turkey, Turkish coffee accounts for 40% of outdoor beverage preference whereas this value is around 65% at homes [28]. Table 1 shows the coffee consumption values for last four years for the importing countries. Turkey has the maximum change between these countries.

Table 1. Coffee consumption* of importing countries [23].

Countries	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**Change (%)**
Turkey	1376	1740	1711	1754	8.4

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Russian Federation	4324	4691	4631	4681	2.7
Algeria	1911	2150	2110	2131	3.7
Republic of Korea	2371	2476	2471	2513	2.0
Switzerland	1013	1079	1060	1074	2.0
Australia	1854	1961	1939	1962	1.9
Canada	3829	4020	3929	4011	1.6
USA	26112	27759	26651	26982	1.1
Saudi Arabia	1275	1266	1241	1253	-0.6
Japan	7750	7561	7355	7386	-1.6

* In thousand 60 kg bags

3. VALORIZATION AND POTENTIAL OF COFFEE WASTE

3.1. Filter Coffee

Coffee is one of the most common global beverages, with approximately 10 million tons consumed annually and it produces more than 99% of coffee waste as a by-product after brewing. If not properly managed, high coffee waste production rates cause adverse environmental impacts. Waste coffee grounds have attracted a lot of attention in recent years due to its components such as fiber, amino acids, polyphenols, and saturated fatty acids. The recovery of these organic compounds could be very beneficial. Approximately 650 kg of waste coffee grounds formed from 1 ton of coffee, and this value is about 6 million tons yearly [14,29,30]. According to Brand et al. (2000), only 6% by weight of harvested fresh coffee reaches the consumer as a beverage. Therefore, considering the water from by-product or drying of used coffee grounds, it leaves around 94% waste [31]. This makes it the largest contributor to coffee biowaste, with around six million tonnes produced annually worldwide [32].

Coffee grounds contain C (59.5%), H (7.3%), N (2.5%) and O (30.7%). Mussatto (2011) stated that the grounds are rich in semi-cellulosic and cellulose polymerized sugar (from hemicelluloses; mannose, galactose, arabinose and celluloses; glucose), while galactan and mannan are the main sugars in the grounds. Its chemical composition and the minerals in the coffee structure can take the values in Table 2 [33,34].

Table 2. Chemical composition and minerals of coffee grounds.

Components	**Dry weight (g/100 g)**	**Minerals**	**mg/kg**
Cellulose	8.6	Potassium	3549
Hemicellulose	36.7	Phosphorus	1475.1
Arabinan	1.7	Magnesium	1293.3
Galactan	13.8	Calcium	777.4
Mannan	21.2	Aluminum	279.3
Proteins	13.6	Iron	118.7

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Acetyl groups	2.2	Manganese	40.1
Ashes	1.6	Copper	32.3
		Zinc	15.1

There are many studies that have focused on the production of biodiesel from used coffee grounds. Visak (2017) investigated the kinetics of oil extraction from used coffee grounds using n-hexane as solvent. They found that oil extraction can be carried out in 10 minutes because of the higher diffusion coefficients of oils from used coffee grounds. For the first time, successful in situ transesterification of spent coffee grounds was demonstrated using sodium hydroxide as catalyst at different methanol/oil molar ratios [35]. In addition, Uddin (2019) used waste coffee grounds and the oil was obtained from waste coffee grounds using n-hexane in extraction. Since the crude oil has higher acidity, a two-stage acid-base catalyst transesterification process was used to produce biodiesel. They produced biodiesel within the limit of standards [36]. Nguyen (2020) studied used coffee grounds for biodiesel synthesis using 1,8-diazabicyclodec-7-ene as both a green solvent and catalyst. They found optimal reaction conditions using the response surface methodology. They found the maximum biodiesel yield 97.18% [29]. Rocha (2014) studied the production of biodiesel and ethanol from used coffee grounds. They studied ultrasound-assisted extraction of fat from spent coffee ground. They produced biodiesel with a yield of 97% into fatty acid methyl esters [37]. The conversion of a binary mixture of waste cooking oil and used coffee grounds oil (50/50% by volume) into biodiesel was investigated by Atabani (2019). This study reinforces that the blending of waste cooking oil and spent coffee ground oil improves biodiesel properties and contributes to its economy. Atabani (2018) studied the recycling of used coffee grounds as a potential raw material for alternative fuel production [12,13,38].

3.2. Turkish Coffee

In case for Turkey, Turkish coffee is the most consumed coffee type in cafes and homes. Considering that Turkish coffee is consumed with its grounds, it can be thought that it is more than enough to be evaluated as waste, since it will be for each cup. Considering the average Turkish coffee consumption is around 84% of the total coffee consumed in Turkey, Turkish coffee waste generated annually is around 57 million kg [39-42].

In order to obtain the potential of Turkish coffee waste potential, spent Turkish coffee waste grounds were collected from the cafes. Its brand was Kurukahveci Mehmet Efendi which uses Arabica beans. Approximately 1 kg of waste was used as a sample. The grounds were dried at 105°C to remove moisture. The oil was then extracted by using a Soxhlet process which brand is Gerhardt Analytical Systems. The extraction process was carried out at Tubitak BUTAL (Bursa Test and Analysis Laboratory) in Bursa, Turkey. Ether was used as an organic solvent. The Soxhlet temperature was maintained at 65-70 °C. Rotary vacuum evaporator was applied to separate oil from the organic solvent. The yield was calculated on dry weight basis. The oil amount of coffee grounds is found as 16.8±0.1% (on a dry weight basis). Table 3 shows the oil percentage amounts of the spent coffee grounds found in literature.

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Table 3. Oil yields on a dry weight basis in literature and this study.

Study	Oil yield (w/w %)	Coffee type
Efthymiopoulos et al., 2019 [43]	13.4-14.8	Spent coffee grounds
Haile, 2014 [44]	15.6	Spent coffee grounds
Deligiannis, 2011 [45]	10-15	Spent coffee grounds
Al-Hamamre, 2013 [46]	15.3	Spent coffee grounds
Atabani, 2017 [38]	13	Spent coffee grounds
Ahangari and Sargolzaei, 2013 [47]	16.7	Spent coffee grounds
This study	16.8	Turkish coffee waste

4. RESULTS AND DISCUSSION

Coffee, which has been an inevitable part of daily life and culture for centuries and consumed heavily by all segments of society, has an important place in both commercial and social life.

Every year millions of tonnes of coffee waste are generated in the food and beverage market all over the world. The massive amount of coffee waste generated daily could result a significant part of biodiesel production. Coffee consumption in the world has been estimated as 9.98 million tonnes in 2021. Its 65% can be assumed as waste. When the average oil content is assumed as 15% and the specific gravity is assumed as 0.92, 1057 million L of coffee oil can be obtained from waste coffee per year [44,46,48]. If the biodiesel conversion efficiency is approximately 85%, approximately 900 million L of waste coffee biodiesel can be produced annually in the world.

In Turkey, increasing the number of branches in the market and facilitating accessibility through the creation of new local and boutique coffee brands are one of the real indicators of the growth of the coffee sector. While per capita coffee consumption per capita was 200 grams in 2002, it has increased to over 1.1 kilogram today. Growth is noticeably higher than other countries on an annual basis. As it is previously highlighted, Turkish coffee is the most consumed coffee in Turkey. When coffee consumption value in Turkey, which is 106 million kg is taken into account, 84% which means 89 million kg is used by Turkish coffee yearly. If 65% is assumed as coffee waste, Turkish coffee waste value becomes 57 million kg. If the oil content of Turkish coffee waste is taken as 16.8% and specific gravity is assumed as 0.92; 10.4 million L of coffee oil may be obtained. As a result, 8.44 million L of biodiesel could be produced from Turkish coffee waste annually.

5. CONCLUSION

Global biodiesel production is expected to reach 39.3 billion liters by 2027, an increase of 9% from the 2017 level. In particular, it is predicted that the European Union will be the largest biodiesel producer. Undoubtedly, the development direction of the biofuels market will be determined by macroeconomic indicators, nationally adopted policies and crude oil prices. When an examination was made according to the types of raw materials used in the production of the biodiesel sector, it was determined that 30% of the waste vegetable oil and 70% of the vegetable oil seeds were used.

Using coffee waste as a raw material for biodiesel production seems like a perfect solution. Because it's free waste and high quality. Coffee residues contain between 11% and 20% by weight oil as much as traditional biodiesel raw materials such as soybean, rapeseed and palm oil.

Although Turkish coffee is not a type of coffee it is a method of a preparation, it should be assessed separately from the other coffee types in Turkey. It has been determined that Turkish coffee contains caffeine and biologically active components at higher rates than other coffee types and preparation methods [49]. As it is seen on Table 3, the oil content of the Turkish coffee waste is also higher than the other coffee waste oil results. This shows the importance of the Turkish coffee waste in Turkey. The main disadvantage of Turkish coffee waste with respect to filter coffee waste is, it should be taken from each cup. It may take time and may be tiring.

When it comes the negative effect of coffee waste on environment, the amount of coffee waste sent to landfills can be 43,000 tons per day (15.7 million tons per year). Disposal of one ton of used coffee grounds produces 682 kg of CO_2 per year, equivalent to 28.64 million tons of CO_2. Therefore, the CO_2 from the disposal of used coffee grounds is equal to that from burning 10.7 million L of diesel fuel per year. With this viewpoint, 39.42 million kg of CO_2 is being generated by Turkish coffee waste.

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