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Potential of biofuel production from pistachio waste in Iran

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ABSTRACT

Biomass as one of the renewable-energy sources is both sustainable and eco-friendly. Considering the approximately 30% of wastes for agricultural products in Iran as well as the importance of processing industry in reducing wastes, biomass such as pistachio is extremely noteworthy. According to the published statistics, the area under cultivation of pistachio in Iran is currently more than 300,000 ha. Kerman Province with an area of 200,000 ha provides 67% of total Iranian pistachio so that it is the most important area of pistachio cultivation around the world. On average, there are approximately 520,400 tons of pistachio wastes per year in Iran, which is mostly related to peeling of product. Studies indicate that the fermentation and pyrolysis processes of pistachio waste produce valuable fuel. In addition, the biological digestion process can be performed on freshly harvested pistachio wastes. This paper shows that there is a considerable potential for the use of agricultural residues, especially pistachio as fuel in Iran. It was found that the production of biogas from pistachio's soft shell, and pyrolysis of pistachio's hard shell are the most effective ways to dispose of wastes, fuel production, and optimum use of them. It can produce about 256,410, 121,255, and 123,898 tons of bio-oil, char, and gas fuel from pistachio wastes by pyrolysis, respectively. Furthermore, the amount of 103.5 million cubic meters of biogas can be achieved using anaerobic fermentation. The potential of 47.6 million liters ethanol production from total pistachio waste can be predicted. The use of pistachio wastes in addition to economic benefits for investors, will have positive environmental effects.

1. Introduction

Energy sources mostly are classified under two categories of renewable (clean) and non-renewable-energy sources. One of the best, most available and abundant renewable-energy resources is biomass that is also eco-friendly. Biomass energy resources can provide our energy needs in the main form of energy such as electricity or energy carriers like the gases and liquid fuels [1]. Biomass provides more than 11.5% of the world's energy demand and about 79.7% of the consumed energy in the world. In 2014, approximately 316.9 million tons oil equivalent of renewable-energy has consumed around the world, which has grown 12% compared to 2013, and about 0.1 million tons oil equivalent of renewable-energy has used in Iran. In the same year, the production of biofuels has been 70,792 thousand tons oil equivalent in the world, which has grown 7.4% compared to 2013 [2]. A large amount of agricultural wastes are produced annually, which is burned in many rural areas of the developing countries to clean land. This is led to an increase of greenhouse gases and loss of energy sources [3,4]. In many countries, for example, Brazil and the USA, a large volume of biofuels is produced annually [5]. The use of biofuels reduces environmental emissions such as CO and CO_2 [5,6].

Energy supply in Iran is largely dependent upon crude oil and natural-gas resources [7]. Natural-gas and oil separately comprise half of the energy consumption in Iran. Due to the decline of fossil-fuel resources and in order to control and reduce domestic and commercial energy consumption, the use of other types of energy, spatially renewable energies have been highly important during recent years [7,8]. In Iran, many agricultural wastes can be converted into usable biofuels. Annually, Iran produces a large amount of agricultural wastes, which are estimated 17–30% of total agricultural production [9]. Various types of agricultural residues such as wheat straw, rice straw and husks, stalks and ears of corn, stalk and bagasse of sugar cane are disposed.

One of the most important horticultural crops cultivated in Iran is pistachio. Currently, Iran is the largest producer of pistachios in the

Abbreviations: °C, Celsius degree; C, Carbon; cm^3, cubic centimeter; g, gram; hectares, ha; hour, h; H, Hydrogen; kcal, kilocalories; kg, kilogram; kWh, kilowatt per hour; l, liter; m^2, square meter; m^3, cubic meter; min, minute; MJ, mega joules; ml, milliliter; MW, mega watt; N, Nitrogen; O, Oxygen; s, second; VS, volatile solid

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world and annually, disposal of the wastes obtained from cultivation and processing is an important problem. The pistachio is one of the most favorite nuts in the world, and it is widely cultivated in dry and hot areas of the Middle East, the Mediterranean countries, and the United States [10]. The world production of pistachios in 2014 achieved more than 638,000 tons (in shell basis), which is grown 37% compared with that of in 2013, and also 50% rose than in 2004 [11]. The top three producers of pistachio are Iran, the USA, and Turkey with annual production of 230,000, 197,699 and 130,000 tons, respectively in 2014 [11–13].

Biomass containing pistachios can be converted into energy, fuels and chemicals using various methods [14–16]. Biomass can be burned directly or turned into energy in industry. In the indirect method, it can be changed into fuels such as biodiesel, bioethanol, biogas, and bio-oil, [17]. Bioethanol produced from sugar, starch, and cellulose wastes can be used in internal-combustion engines [18]. There are two other common methods for the use of biomass, including biochemical and thermochemical process. Biochemical processes include aerobic and anaerobic digestion and alcoholic fermentation [19–21]. The thermochemical decomposition methods, including pyrolysis and gasification can be used to convert the biomass into energy carriers [22–24].

Pyrolysis is widely applied for conversion of biomass into economically and useful renewable fuels. In the pyrolysis process, biomass is converted into gases, liquid, and char by heating [25,26]. The fast pyrolysis of ligno-cellulosic agricultural wastes is capable of producing chemical raw materials used in industry, which usually made of fossil oil resources as well as production of energy from renewable sources. The amount of catalysts and pyrolysis temperature plays a significant role in the product distribution and composition of the produced bio-oil. Various studies have been conducted on pyrolysis methods for different biomasses.

In a study, the palm oil of Empty Fruit Bunch (EFB) was pyrolyzed using quartz fluidized-fixed bed reactor. The effect of pyrolysis temperature, particle size and the heat on yields was studied. The products of EFB pyrolysis were bio-oil, char and gas [27]. In another study, the effect of pyrolysis temperature on the yield and composition of gaseous products was investigated. The gaseous products of pyrolysis include high levels of hydrocarbons, especially methane and saturated hydrocarbons [28]. One research was conducted on the fixed-slow pyrolysis of coconut shell to determine the effect of pyrolysis temperature, heating rate and particle size on the yield of pyrolysis. The results were indicated that the interaction effect of pyrolysis temperature and particle size was significantly greater than the interaction effect of temperature and holding time [29]. Several studies also were carried out in the case of the wood pyrolysis in the presence of acid catalyst ($FeCl_3$) [30], tobacco waste pyrolysis [31], castor shell pyrolysis in a fixed bed reactor [32], and fast pyrolysis of corn waste mixed with eucalyptus wood [33].

In terms of food industry, pistachio is a rich source of phenolic compounds and more recently it has been between the 50 first food products with the highest anti-oxidant potential [34]. In the field of energy, a few researches were conducted associated with the fuel production from pistachio's wastes in the world. For example, Faramarzi et al. were done an experimental investigation and mathematical modeling of physical activated carbon preparation from the pistachio shell. The effect of different parameters was studied in the pyrolysis stage and also activation stage of the preparation process for activated carbon [35]. Açikalin et al. were pyrolyzed the pistachio shell in a well-swept fixed bed reactor, and evaluated the effects of pyrolysis conditions and were analyzed the final products. The solid product was a valuable fuel with an energy content higher than that of sub-bituminous coal [10]. Demiral et al. were performed the pyrolysis of soft shell of pistachio in a fixed-bed reactor to produce bio-oil. The chemical characterization was shown that the bio-oil obtained from soft shell of pistachio can be used as a renewable fuel and chemical feedstock [15]. Tonbul was studied the thermal degradation characteristics of different particle sizes of pistachio shell and its kinetics by using a thermogravimetric analyzer [36]. Apaydin-Varol et al. were used the pistachio shell as the biomass sample to investigate the effects of pyrolysis temperature on the product yields and composition. For this, they were applied the slow pyrolysis in a fixed-bed reactor at the atmospheric pressure [37]. Pütün et al. were examined the rapid and slow pyrolysis of pistachio hard shell in a tubular reactor under a nitrogen flow, and studied the effect of pyrolysis conditions on the product yields and characterization of the liquid product. The results showed that using pistachio shell as a renewable source to generate valuable liquid products is applicable via pyrolysis [38]. Okutucu et al. were produced the fungicidal oil and activated carbon from the pistachio shell as a biomass feedstock [39].

As mentioned above, numerous studies have been conducted in the field of chemical-thermal biomass conversions using pyrolysis technology during recent years. This technology has several socio-economic benefits and is an efficient method compared with other methods of chemical-thermal conversion [40].

Pistachio waste can be converted into valuable fuel using the fermentation, digestion, and pyrolysis methods. In this study, the potential for the production of biofuels as well as different methods of waste pyrolysis and fermentation have been investigated in Iran. In addition, the amount of mentioned produced fuels will be estimated. It is emphasized that the biomass for fuel production is only limited to non-food biomass that are not linked with the direct food chain such as first-generation biofuels. Similarly, the interest in pistachio wastes is because they are a free available non-food biomass.

In an overview, the present research will be conducted as follows. First, the main sources of biomass and the biofuel production are introduced in Iran. Then, the most types of pistachio wastes and procedure of fuel production such as pyrolysis, fermentation, and digestion from these wastes are examined. The more emphasis is on pyrolysis of pistachio wastes because of according to different studies, this method is frequently used in distinctive platforms. Finally, the amount of fuels produced from pistachio wastes and economic issues associated with them will be studied in Iran.

2. Biomass resources in Iran

In Iran, due to the extensive facilities, climatic diversity, and production all kinds of crops and products in temperate regions, existence of subtropical and tropical areas, it has become one of the five great countries that produce more than 20 agricultural products out of which about 30% are wasted [41]. Table 1 shows the potential annual production of five major sources of biomass and urban waste in Iran.

Table 1
Potential annual production of five major sources of biomass and urban waste production in Iran [1].

Biomass Resource	Annual Product	Biogas Production Potential (Million cubic meter)	Million barrels of oil equivalent
Agricultural-forestry waste	23,147[a]	5475	74
Urban waste	13,870[b]	1646	15
Urban waste water	25,176[a]	108–245	2
Industrial waste water	36,245[c]	82–280	5.5
Livestock waste	74,946[a]	8668	36

[a] Thousand tons.
[b] Million tons.
[c] Thousand liter.