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Effect of moisture content, particle size and pressure on some briquetting properties of hazelnut residues

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ABSTRACT
This study examined the utilization of residues from the production of hazelnuts as a source of biofuel. The residues were briquetted using a hydraulic briquetting machine with a horizontal course. Solid cylindrical briquettes were produced with two different compression pressures (P: 80 MPa and 160 MPa), moisture contents (M: 8%-10% and 13%-15%) and particle sizes (PS: 2-5 mm and 7-10 mm). Thermal and physical-mechanical properties (bulk density, tumbler and shatter indexes, water absorption capacity, moisture and equivalent humidity contents, ash content, higher heating value), flue gas emission of the briquettes were measured. It was found that the optimum briquetting pressure was 160 MPa, optimum moisture content was 8%-10%, and optimum particle size was 2-5 mm for hazelnut husk agricultural residues. The study yielded promising results and proved that the idle residue potential in agriculture could be utilized for green energy.

Keywords:
Agricultural waste
Biofuel
Emission
Feedstock
Green energy
Hazelnut

Nem içeriği, parçacık boyutu ve basıncın fındık zurufu atığının bazı briket özellikleri üzerine etkisi

ÖZET
Bu çalışmada, biyoyakıt kaynağı olarak fındık üretiminden kaynaklanan atıkların kullanımı incelenmiştir. Atıklar, yatay bir rotaya sahip bir hidrolik briketleme makinesi kullanılarak briketlenmiştir. Katı silindirik briketler iki farklı sıkıştırma basıncı (P: 80 MPa ve 160 MPa), farklı nem içeriklerinde (M:%8 -%10 ve %13 -%15) ve parçacık boyutları (PS: 2-5 mm ve 7-10 mm) ile üretilmiştir. Briketlerin ısısal ve fiziksel-mekaniksel özellikleri (kütle yoğunluğu, mekanik dayanıklılık ve kırılma indeksleri, su emme kapasitesi, nem ve eşdeğer nem içeriği, kül içeriği ve ısıl değerleri) ve yanma sonrası gaz emisyon değerleri, ölçülmüştür. Çalışma sonucunda fındık zurufu tarımsal atığı için en uygun briketleme basıncı 160 MPa, nem içeriği %8 -%10 ve parçacık boyutu 2-5 mm aralığında bulunmuştur. Çalışma umut verici sonuçlar vermiştir ve tarımdaki atıl atık potansiyelinin yeşil enerji için kullanılabileceğini kanıtlanmıştır.

Anahtar Sözcükler:
Tarımsal atık
Biyoyakıt
Emisyon
Hammadde
Yeşil enerji
Fındık

1. Introduction

Fossil fuels represent the main source of energy in today's world. However, as the demands for energy increase along with increases in world population, fossil-fuel reserves are continually decreasing. Fossil fuels such as petroleum, coal and natural gas satisfy the major fraction of total need of world's energy (Wang and Sarkar, 2018). Given that the main task of the energy sector is to ensure the continual availability of reasonably priced energy for a growing population and developing economy, it is clear that the consumption of fossil-based fuels must be reduced and the search for new sources of renewable energy accelerated (Ültanır, 1996).

Amongst the existing global challenges, indiscriminate burning of fossil fuels and the ensuing climate change impact due to CO_2 emissions are the most serious problems of 21st century. Of the renewable energy sources, bioenergy as sustainable and environmentally friendly alternative to the fossil fuels has stirred substantial research worldwide (Sohni et al., 2018). Biomass conversion processes have emerged as a rapidly growing field of science and technology endeavored to fulfil ever-growing energy deficit as well as reduce CO_2 emissions by 70–90% (Timung et al., 2015; Sohni et al., 2018).

Biomass has received tremendous attention both in developed and developing countries as a renewable energy source (Muazu and Stegemann, 2015). Biomass energy, i.e. energy obtained from plant- and animal-based natural materials composed mainly of carbohydrate compounds (Ölçüm, 2006; Chen et al., 2011; Prakash and Karunanithi, 2008), represents a source of environmentally friendly, inexhaustible renewable energy. Biomass, which includes agricultural residues, accounts for approximately two-thirds of all potential sources of renewable energy in Turkey (Angın and Şensöz, 2006), whose vast areas of agricultural production offer great potential in terms of renewable energy resources.

Turkey is the number-one producer of hazelnuts in the world. In 2012, Turkey produced 660,000 tons of hazelnuts, representing 72.17% of world production, on 422,765 ha, representing 69.11% of the world's hazelnut plantations (FAO, 2018). In Turkey's Black Sea region, hazelnut is the most common and most profitable agricultural product cultivated and results in approximately 200,000 tons of residue annually. However, under current practice, this residue is not used for any purposes. They are left on the fields or burnt to wipe out (Figure 1). Therefore, the present study examined the possible use of residues left after hazelnut harvesting and threshing as solid biofuel. Briquettes produced with two different compression pressures (80 MPa and 160 MPa), moisture contents (8%-10% and 13%-15%) and particle sizes (2-5 mm and 7-10 mm). Thermal, physical-mechanical (bulk density, tumbler and shatter indexes, water-absorption capacity, moisture and equivalent humidity contents, ash content and calorific values), flue-gas emission values measured to determine optimum parameters for the briquetting of hazelnut husk residues.

Figure 1. Random burning of hazelnut husks
Şekil 1. Fındık zuruflarının rastgele yakılması

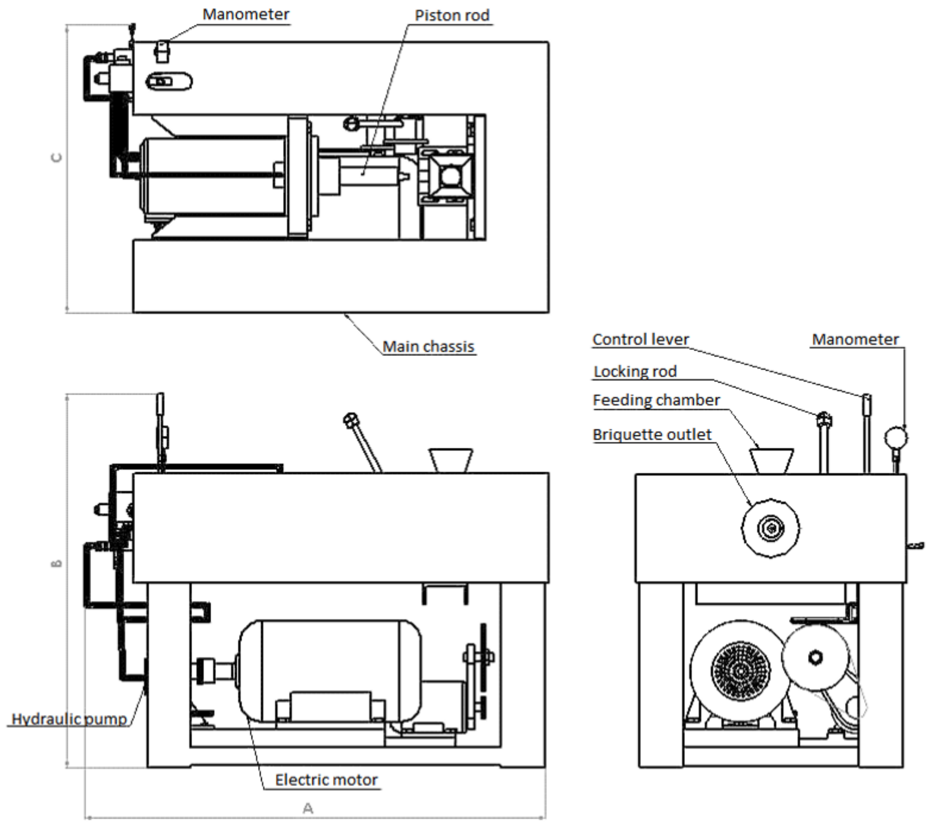


Figure 2. Hydraulic briquetting machine (A: 1280 mm; B: 1155 mm; C: 740 mm)
Şekil 2. Hidrolik briketleme makinası (A: 1280 mm; B: 1155 mm; C: 740 mm)

Table 1. Hazelnut husk briquette treatments
Çizelge 1. Fıdık zurufu brikletleri uygulamaları

Treatment No.	Particle Size (mm)	Moisture Content (%)	Briquetting Pressure (MPa)
T1	2-5	8-10	80
T2	2-5	8-10	160
T3	7-10	8-10	80
T4	7-10	8-10	160
T5	2-5	13-15	80
T6	2-5	13-15	160
T7	7-10	13-15	80
T8	7-10	13-15	160

2. Material and Method

2.1 Briquetting Procedures

This study was conducted using hazelnut husk residue from agricultural production.

Hazelnut residues were sun-dried under normal conditions until their moisture content was reduced to either 8%-10% or 13%-15%, as defined by (EN 14774-1, 2009) standards. The dried material was then ground in a 3-kW electric hammer mill consisting of 8 hammers rotating at a speed of 2,850 rpm. Once particles of the required sizes (2-5 mm and 7-10 mm) were obtained, moisture contents were re-measured, and the particles were briquetted using a hydraulic briquetting machine with a briquetting range of 0-320 MPa that was developed as a prototype (Figure 2).

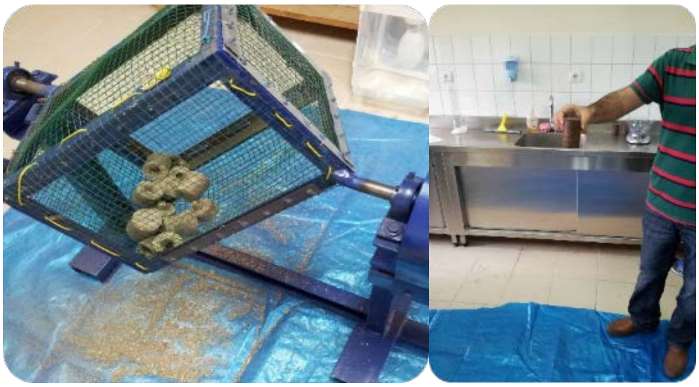
Solid cylindrical briquettes were produced by feeding the prepared residue material into a cylindrical mold with a wall-thickness of 25 mm. Residues were briquetted at either 80 MPa or 160 MPa. In order to avoid blockage during the briquetting process, material was fed into the machine in batches. Cylindrical briquettes of 50 mm diameter and 80-100 mm in length were obtained for 8 treatments (Table 1).

2.2 Thermal, Physical-mechanical Properties of Briquettes

Density of the residue was measured by feeding the chopped, dried material into a constant volume vessel from a height of approximately 4 cm high, weighing the vessel, and calculating the value of the mass of the material divided by the volume of the vessel (kg/m^3). Density of the briquettes was measured by calculating the mass of the briquette divided by its volume.

Water-intake resistance was measured by plunging the briquettes into normal tap water and recording their masses at 30-second intervals for 2 minutes and then calculating percentage increases in mass (Lindley and Vossoughi, 1989; Kaliyan and Morey, 2006). Air-moisture resistance of briquettes was evaluated by storing sample briquettes in a closed environment for 21 days and then calculating the difference in mass before and after storing, which was recorded as equivalent moisture content.

Briquette resistance to breakage by impact (Tumbler index) and after falling (Shatter index) was tested according to (ASAE S269.4, 2000 and ASTM D 440-86, 1998) standards, respectively (Figure 3a and 3b).



a b

Figure 3. a) Tumbler test, b) Shatter test

Şekil 3. a) Mekanik dayanıklılık testi, b) Düşme-kırılma testi

Higher heating values of briquettes were measured using an IKA C200 calorimeter. Testing was performed according to standards (ASTM-D 5865-07A, 2009). Ash contents were determined by a muffle furnace.

2.3 Flue-Gas Emissions

Flue-gas emissions during burning were measured using an Ecom EN2 flue-gas sensor. The probe of the device was installed approximately 1 m above the stove, and all readings were performed from this constant point.

Data analysis was performed using the IBM SPSS Statistics 21 software. The normality analysis was performed with the Kolmogorov-Smirnov single sample test and the variance homogeneity was assessed by the Levene test and the variances were homogeneous ($P > 0.05$), with normal distribution of the data.

3. Results and Discussion

This study analysed the physical-mechanical and thermal properties of briquettes formed from hazelnut harvest residues using two different briquetting pressures (80 MPa, 160 MPa), moisture contents (8%-10%, 13%-15%) and particle sizes (2-5 mm, 7-10 mm) in order to assess their potential as solid biofuel. Pressures were selected based on pre-testing that showed 80 MPa to be sufficient for obtaining briquettes of satisfactory durability and shape and are in line with studies described by Krizan et al. (2015), Zhang and Guo (2014) and Sun et al. (2014).

3.1 Thermal, physical-mechanical properties

Moisture content of briquettes is very important for successful extrusion (Oladeji, 2015; Wachira et al., 2015). Moisture content of the material in the present study was selected based on previous studies, which reported material moisture contents of between 8%-15% to be suitable for briquetting using hydraulic equipment (Zhang and Guo, 2014; Coşereanu et al., 2015; Oladeji, 2015). Some physical-mechanical parameters of hazelnut husk briquettes are given in Table 2.

Table 2. Physical-mechanical parameters for hazelnut husk briquettes

Çizelge 2. Fındık zurufu briketlerinin fiziko-mekanik parametreleri

Treatment No	Briquette volume mass (kg m^{-3})	Tumbler Index (%)	Shatter Index (%)	Water intake capacity (2 min)	Air moisture resistance (%)
T1	1012.79 ± 1.51de	60.18 ± 0.76f	83.04 ± 3.11	37.00 ± 0.57b	5.90 ± 0.10c
T2	1198.56 ± 2.89a	84.88 ± 0.69c	91.65 ± 1.13	27.59 ± 1.09c	7.06 ± 0.22b
T3	962.18 ± 2.20f	44.70 ± 1.00g	76.20 ± 3.80	40.11 ± 0.88b	7.88 ± 0.56a
T4	1159.04 ± 2.91b	83.75 ± 0.59c	95.08 ± 0.91	48.18 ± 1.43a	5.62 ± 0.14c
T5	1025.61 ± 3.60cd	78.65 ± 0.72d	95.19 ± 0.30	15.73 ± 0.65d	-2.04 ± 0.19e
T6	1041.46 ± 6.19c	91.96 ± 0.22a	95.20 ± 0.22	17.02 ± 0.39d	-0.76 ± 0.26d
T7	994.97 ± 3.48e	75.82 ± 0.49e	95.81 ± 0.67	13.69 ± 0.60d	-1.91 ± 0.05e
T8	1031.07 ± 6.25cd	88.65 ± 0.55b	97.58 ± 0.35	12.72 ± 0.32d	-1.93 ± 0.09e
Sig.	<0.01	<0.01	0.181	<0.01	<0.01

*The difference among the values carrying the same letter at each column is insignificant at $P \leq 0.05$

Density

Briquette density was significantly affected by briquetting pressure, moisture content and particle size (P<0.01). The majority of volume mass values ranged between 1000-1400 kg.m^{-3}, which is in line with the literature (Grover and Mishra, 1996; Kaliyan et al., 2009; Tumuluru et al., 2011; Chinyere et al., 2014). The maximum briquette density obtained (1198.56±2.89 kg m-3) was for T2 (160 MPa/8%-10%/2-5 mm). As expected, better impaction was achieved with higher pressure (160 MPa). Compression was also better according to densities for material with lower moisture content than higher moisture content due to the characteristic incompressibility of liquids (Wachira et al., 2015). Furthermore, in line with Grover and Mishra (1996), density was higher for briquettes produced from material with smaller particle sizes. It was found that in addition to particle size being one of the main parameters for briquette density, particle size distribution also had an effect on the surface roughness of briquettes (Bilgin, 2008; Wilaipon, 2009; Oladeji, 2015).

Tumbler Indexes

Tumbler indexes increased with increases in briquetting pressure and moisture content and decreased with increases in particle size; however, the differences were not statistically significant (P<0.01). The highest Tumbler index obtained (91.96±0.22%) was for Treatment 6 (160 MPa/13%-15%/2-5 mm). Kaliyan and Morey (2006) showed that up to a certain limit, increases in moisture content increase briquette durability, and Bazargan et al. (2014) and Wachira et al. (2015) reported tougher briquettes were produced when materials with higher moisture contents were subjected to higher briquetting pressure. Figure 4 shows some images of samples from treatments following Tumbler testing.

Shatter Indexes

Shatter indexes of briquettes increased with increases in briquetting pressure and moisture content and decreased with increases in particle size; however, the differences were not statistically significant (P<0.01). The lowest Shatter index obtained (76.20±3.80 %) was for Treatment 3 (80 MPa/8%-10%/7-10 mm). Figure 5 shows some images of samples from treatments following Shatter testing. The presence of different size particles improves the packing dynamics and also contributes to high static strength (Kaur et al., 2017).

Water-intake capacity

Water-intake capacity was significantly affected by briquetting pressure, moisture content and particle size (P<0.01). Differences were observed between groups after immersion in water for 2 minutes (P<0.01), although all treatment samples were observed to totally dissolve after several minutes in water. Denser briquettes were produced under higher briquetting pressures. This caused less water infiltration into the briquettes.

Resistance to moisture-humidity

Briquettes with higher moisture contents released moisture into the environment whereas those with lower moisture contents absorbed moisture from the environment. The humidity level of the environment in which briquettes are stored is known to directly affect their ability to resist humidity. An environment with a relative humidity of between 40%-70% reported to be the most suitable in terms of air-moisture resistance (Vyas et al., 2015).

a b

Figure 4. Hazelnut husk briquettes after Tumbler testing (a: T1, b: T7)

Şekil 4. Mekanik dayanıklılık testinden sonra fındık zurufu briketleri (a: T1, b: T7)

a b

Figure 5. Hazelnut husk briquettes after Shatter testing (a: T2, b: T6)

Şekil 5. Düşme-kırılma testinden sonra fındık zurufu briketleri (a: T2, b: T6)

Higher heating values and ash contents of the briquettes are given in Table 3. The maximum higher heating value was found to be 18.49 MJ/kg. This value was higher than the higher heating value of wood (15.91 MJ/kg), indicating fuel briquettes produced from hazelnut husk agricultural residue to be a better source of heat energy than wood.

This is also in line with the findings of previous studies (Niedziołka et al., 2015; Olugbade and Mohammed, 2015; Shuma et al., 2015). Briquettes with 8%-10% moisture content were also found to have lower ash contents when burnt. High water and ash contents remaining after burning a material are known to have a negative effect on the material's burning quality. Besides, chemical analysis of the material is important, too. Besides, chemical analysis of the material is important, too. This is given in Table 4. It's seen from the table that the crucial element like Cl in the material has slightly passed over the limits (0.06 %) than the limit given in standards (EN 14961-3, 2011) and in (EN ISO 17225-3, 2015).

Flue gas emissions

Many countries are known to suffer from air pollution caused by burning coal for heating purposes, and burning petroleum-based fuels are known to have high levels of SO_x, NO_x and CO_2 emissions (Ross et al., 2002). Reductions in emissions can be achieved by using biofuel briquettes made from agricultural residues such as hazelnut husks in combustion chambers in place of coal. The flue-gas emission values of the hazelnut husk briquettes produced in the present study indicate their use as solid fuel to be environmentally appropriate. Table 5 shows the maximum flue-gas emission values for the hazelnut-husk briquettes used in the present study. Table shows that briquettes obtained from high compression pressures cause more CO_2 emissions. Therefore, it would be more appropriate to produce briquettes at lower pressures in terms of both energy consumption and CO_2 emissions. As the tables indicate, flue-gas emission values for all treatments in this study fall within the limits of legal Regulations for Air Pollution Control for Heating (IKHKKY) in Turkey.

In line with Kristensen and Kristensen (2004), Dias et al. (2004) and Fournel et al. (2015), the present study found briquette CO emissions increased with increases in moisture content, while SO_2 emissions were negligible. These findings are also similar to those of Roy and Corscadden (2012), who measured flue-gas emissions from biomass briquettes produced from various residues burnt in a domestic wood stove.

Table 3. Heating value and ash contents

Çizelge 3. Briketlerin ısıl değeri ve kül içerikleri

Higher heating value (MJ kg^{-1})	Ash content (%)	
	T1 – T4	T5 – T8
18.49	8.47	10.72

Table 4. Chemical analysis for hazelnut husk

Çizelge 4. Fındık zurufu için kimyasal analiz değerleri

Water (% mass)	8.37
Volatile flammability (% mass)	61.41
Nonvolatile flammability (% mass)	22.80
C (% mass)	40.75
H (% mass)	5.73
N (% mass)	0.78
S (% mass)	0.14
O (% mass)	36.75
Cl (% mass)	0.06

Table 5. Maximum measured flue-gas emissions for briquettes

Çizelge 5. Briketler için ölçülen en yüksek baca gazı emisyonları

Treatments	T1	T2	T3	T4	T5	T6	T7	T8
O_2 (%)	12.8	9.4	11.8	10.7	12.7	13.1	11.9	8.8
CO_2 (%)	4.8	5.7	4.9	5.1	3.4	3.9	3.9	6.1
CO (mg Nm^{-3})	3,429	2,079	2,334	2,244	3,811	3,682	3,211	3,800
NOx (mg Nm^{-3})	173	218	229	219	218	145	197	178

4. Conclusion

The present study used a hydraulic briquetting machine to produce cylindrical briquettes with varying parameters in order to determine the most suitable configuration for converting hazelnut residue into solid biofuel based on physical-mechanical and thermal parameters. The study found an optimum briquetting pressure of 160 MPa, optimum moisture content of 8%-10%, and optimum particle size of 2-5 mm. The briquetting of unused agricultural residues for use as solid biofuel could be useful in meeting today’s energy deficits and reducing global warming. In addition, the use of agricultural residues as an alternative energy source can contribute to employment in agricultural regions by promoting the establishment of new, agricultural-based industries. Additional research is important not only for enhancing the quality and quantity of scientific data, but also as a means of focusing public attention on the energy potential of agricultural residues.

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Kaynaklar

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