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Influence of Conduction Drying on the Physical and Combustion Properties of Hazelnut Shell

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Abstract: Hazelnut fruit samples were collected over 2 years (2020 and 2021) and subjected to four different drying temperatures (100, 120, 140, and 160 °C) and four different drying times of 15, 30, 45, and 60 min using conduction drying. The analyses performed showed that conduction drying at different temperatures and different drying times had a significant effect on the change in the composition of the hazelnut shell fuel and its mass properties. Comparing the untreated samples over two years and the samples after drying, it can be seen that in 2020, the drying treatment causes a decrease in the percentage of C and H, while in 2021, drying at 160 °C and 45 min causes an increase in C and H values. After treatment, the S content decreased on average, while the value of O increased or remained the same. The greatest increase in heating values (HHV and LHV) was observed at temperatures of 140 °C and 120 °C and the duration of 45 min. When drying was applied, a significant difference in mass change was observed at 120 °C, 100 °C, and 140 °C and 30 and 60 min process durations. The change in heating value is significantly affected by the parameters year of sampling, temperature, and time, while the change in mass of the hazelnut shell is most affected by drying time.



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1. Introduction

In recent decades, rising energy prices and increasing fossil fuel consumption have led to negative impacts on the environment and scientific research in the field of renewable energy sources. The European Commission has adopted a number of documents to achieve energy policy goals. In its energy plan, the European Commission proposes to increase the utilization target of the Renewable Energy Directive to 45% by 2030 [1]. At the same time, agriculture is very important for the overall development of individual countries, but it can also have a negative impact on the state of the environment; waste from agriculture is present in large quantities in both the EU and the Republic of Croatia and therefore has the potential to become a source of renewable raw materials [2].

An important branch of agriculture is the cultivation of nuts, of which the hazelnut is the most common. Hazelnuts are an important nut crop in agriculture worldwide [3] and grow in the Mediterranean region, mainly in Turkey, Spain, and Italy [4]. Their yield was more than 528,000 tons in 2019/2020 [5]. Since hazelnut shell accounts for more than 50% of the total weight of the nut, the hazelnut processing industry generates a large amount of shell by-products [3]. Hazelnut shells as agricultural biomass have great potential for use as an energy source, as they are a renewable, sustainable, and low-cost source of supplemental energy [6].

Agricultural biomass is an important source of renewable resources [7] with a large production potential, and the use of biomass as a feedstock is continuously increasing

worldwide [8,9]. In addition, agricultural biomass is a sustainable source of fuels and chemicals [10] and could be fully processed into valuable products [11,12]. A large portion of agricultural biomass is lignocellulosic material, and the main properties of lignocellulosic biomass are very good strength, combustibility, biodegradability, and reactivity. Hazelnut shells have a cellulose content of over 40% [13], abundant hydrocarbon content, low moisture content, and high carbon content, which are suitable for energy production [14]. The combustion behavior of biomass must be studied in order to evaluate the impacts of biomass materials, assess their technical, economic, and environmental benefits, and determine their potential for conversion into secondary solid, liquid, and gas products. Consequently, studies have been conducted on the pyrolysis and gasification of hazelnut shells [15].

Because of the high water content, any hazelnut harvested must be dried so it can be used or stored. The moisture content (MC) of freshly harvested hazelnuts is usually higher than the safe storage level (i.e., <10% (wet basis) for the shells and <6% (wet basis) for the kernels) [16]. Therefore, postharvest drying is critical to ensure the food safety and quality of hazelnuts during long-term storage [17–19]. Drying must be done in such a way that all qualitative and quantitative properties are maintained, i.e., the temperature of the air used for drying and the temperature to which the product is heated should be adapted to the characteristics of the product and its intended use [20–22]. Convection drying with a slow flow of warm air is one of the methods used for drying hazelnuts in shell, but its problem is the long drying process [23–25].

Considering all the above, the goal of this research was to determine the change in mass and fuel properties of hazelnut shells resulting from the application of different conduction drying treatments. Different temperatures were used in the research: 100 °C, 120 °C, 140 °C, and 160 °C drying for 15, 30, 45, and 60 min. Changes in combustion properties and mass after treatment were determined by statistical analysis, as was the influence of the parameters year of sampling, temperature, and duration of the process on the tested biomass, both individually and combined.

2. Materials and Methods

For this study, the hazelnut *Corylus* sp. (Bjelovar-Bilogora county, Daruvar municipality, geographical coordinates of the experimental garden: 45°35′22.84″ N 17°13′10.75″ E) was used. In the optimal ripening period (September 2020 and September 2021), in dry weather, when most of the fruits had already fallen to the ground by themselves, the hazelnut fruits were collected from under each bush studied. The same procedure was repeated for each sample and vegetation year. Harvesting was performed manually to avoid damaging the shell. All collected samples were manually cleaned from remnants of the casings and impurities and prepared for further processing. The combustion properties of the hazelnut shell biomass were determined before and during the thermal treatment of conduction drying at temperatures of 100, 120, 140, and 160 °C for times of 15, 30, 45, and 60 min. The model of this three-factorial experiment was year × toasting temperature × toasting time = 2 × 4 × 4. Combustion analyses of hazelnut shells included the determination of volatile matter content, C, H, N, and S contents, and higher (HHV) and lower (LHV) calorific values. Volatile matter (VM) content was determined by calculation according to the protocol (EN ISO 14198:2009) [26]. The content of carbon (C) and hydrogen (H) was determined according to the protocol (HRN EN ISO 16994:2015) [27] in a CHNS analyzer (Elementar Analyze Systeme GmbH, Langenselbold, Germany), while oxygen (O) was calculated as the rest of elements C, H, N, and S. The heating values, HHV and LHV, were determined according to the protocol (HRN EN 14918:2010) [28] using an IKA C200 oxygen bomb calorimeter (IKA Analysentechnik GmbH, Heitersheim, Germany). The mass ratio of the fruit, kernel, and shell of the hazelnuts was determined using a Mettler Toledo balance, on which the weight of the whole fruit was first weighed. Then, with the help of a device, the shell was separated from the kernels, and then the kernel and the shell of the hazelnuts were weighed.

After determining the dependent and independent variables, statistical analysis was performed using TIBCO STATISTICA 13.3.0 software (StatSoft TIBCO Software Inc., Palo Alto, CA, USA) [29]. The analyzed data are presented in the form of means and standard deviations with respect to the characteristic dependent and independent variables. In order to determine the differences between the observed samples, analysis of variance (ANOVA) and Tukey's post hoc HSD test were used. In addition to the aforementioned statistical analyses, the correlations of the observed variables were analyzed to determine the relationship through the correlation coefficient. A "correlation matrix" plot was created using the R software tool (Rstudio) [30] and associated packages ("corrplot"). Principal component analysis (PCA) was performed to present more data (multidimensionality) for easier interpretation.

3. Results

Carbon (C), sulfur (S), hydrogen (H), oxygen (O), volatile content, higher heating value (HHV) and lower heating value (LHV) are considered as combustion properties. The values obtained for the natural samples are shown in Tables 1 and 2, while Tables 3 and 4 show the values after drying.

Table 1. Content of combustible substances in hazelnut shell in natural samples.

Year	VM (%)	C (%)	S (%)	O (%)	H (%)	HHV (MJ kg ⁻¹)	LHV (MJ kg ⁻¹)
2020	64.72 ± 0.06 ^a	59.99 ± 0.06 ^b	0.11 ± 0.01 ^a	31.82 ± 0.17 ^a	7.71 ± 0.23 ^b	20.87 ± 0.08 ^b	19.19 ± 0.02 ^a
2021	64.15 ± 0.51 ^a	55.11 ± 0.14 ^a	0.34 ± 0.02 ^b	37.71 ± 0.22 ^b	6.52 ± 0.1 ^a	20.43 ± 0.12 ^a	19.01 ± 0.14 ^a
Statistical significance	n.s.	*	*	*	*	*	n.s.

The means in the same column with different lowercase superscripts are statistically different ($p < 0.05$) according to Tukey's HSD test. Statistical significance: * $p \leq 0.01$; n.s.—not significant.

Table 2. Mass of hazelnut samples in two years of sampling.

Year	Fruit Mass (g)	Kernel Mass (g)	Shell Mass (g)
2020	3.85 ± 0.43 ^b	1.77 ± 0.24 ^a	2.08 ± 0.32 ^b
2021	3.52 ± 0.37 ^a	1.69 ± 0.22 ^a	1.83 ± 0.23 ^a
Statistical significance	*	n.s.	*

The means in the same column with different lowercase superscripts are statistically different ($p < 0.05$) according to Tukey's HSD test. Statistical significance: * $p \leq 0.01$; n.s.—not significant.

Table 3. Content of combustible substances in hazelnut shell after conductive drying (2020).

No.	Year	Temp. (C °)	Time (min)	VM (%)	C (%)	S (%)	O (%)	H (%)
1	2020	100	15	69.34 ± 0.02 ^a	54.88 ± 0.91 ^a	0.07 ± 0.01 ^a	37.73 ± 0.98 ^{ab}	7 ± 0.02 ^{efgh}
2			30	70.48 ± 0.04 ^{bcdefg}	54.86 ± 0.51 ^a	0.07 ± 0 ^a	37.98 ± 0.45 ^{ab}	6.7 ± 0.05 ^{bcdefg}
3			45	70.31 ± 0.81 ^{abcdef}	55.21 ± 0.37 ^a	0.07 ± 0 ^a	37.69 ± 0.35 ^{ab}	6.73 ± 0 ^{bcdefg}
4			60	70.98 ± 0.26 ^{defghij}	55.01 ± 0.21 ^a	0.06 ± 0 ^a	38.92 ± 0.19 ^b	5.81 ± 0.05 ^a
5		120	15	70.43 ± 0.99 ^{bcdefg}	55.5 ± 0.23 ^a	0.06 ± 0 ^a	37.92 ± 0.68 ^{ab}	6.29 ± 0.46 ^{ab}
6			30	69.84 ± 0.16 ^{abc}	56.18 ± 0.02 ^a	0.09 ± 0 ^a	36.81 ± 0.08 ^{ab}	6.59 ± 0.03 ^{bcdef}
7			45	70.49 ± 0.31 ^{bcdefg}	56.16 ± 0.19 ^a	0.72 ± 0.09 ^b	36.25 ± 0.3 ^{ab}	6.61 ± 0.01 ^{bcdef}
8			60	70.94 ± 0.36 ^{defghij}	55.76 ± 0.12 ^a	0.07 ± 0 ^a	36.83 ± 0.08 ^{ab}	7.06 ± 0.21 ^{efgh}

Table 3. Cont.

No.	Year	Temp. (C °)	Time (min)	VM (%)	C (%)	S (%)	O (%)	H (%)
9	2020	140	15	70.61 ± 0.19 bcdefgh	55.42 ± 0.01 ^a	0.07 ± 0.01 ^a	37.48 ± 0.02 ^{ab}	6.8 ± 0.02 ^{bcdefg}
10			30	70.84 ± 0.2 bcdefghi	56.47 ± 0.06 ^a	0.07 ± 0 ^a	36.26 ± 0.04 ^{ab}	6.91 ± 0.02 ^{cdefgh}
11			45	70.86 ± 0.02 cdefghi	56.05 ± 0 ^a	0.07 ± 0 ^a	37.1 ± 0.11 ^{ab}	6.45 ± 0.11 ^{bcd}
12			60	71.62 ± 0.36 ^{hij}	56.3 ± 3.13 ^a	0.07 ± 0 ^a	36.74 ± 3.15 ^{ab}	6.55 ± 0.01 ^{bcde}
13		160	15	69.77 ± 0.1 ^{ab}	56.61 ± 0.28 ^a	0.09 ± 0 ^a	36.53 ± 0.28 ^{ab}	6.42 ± 0.01 ^{bc}
14			30	71.36 ± 0.18 ^{fghij}	56.65 ± 0.1 ^a	0.07 ± 0 ^a	36.09 ± 0.1 ^{ab}	6.83 ± 0.01 ^{cdefg}
15			45	71.89 ± 0.28 ^{ij}	57.11 ± 0.12 ^a	0.08 ± 0 ^a	35.33 ± 0.12 ^a	7.07 ± 0.01 ^{fgh}
16			60	71.82 ± 0.33 ^{ij}	56.64 ± 0.01 ^a	0.08 ± 0 ^a	35.88 ± 0.01 ^{ab}	7.06 ± 0 ^{fgh}
Statistical significance				n.s.	*	*	*	*
No.	Year	Temp. (C °)	Time (min)	HHV (MJ kg ^{−1})		LHV (MJ kg ^{−1})		
1	2020	100	15	20.4 ± 0.19 ^{defghi}		18.87 ± 0.18 ^{efghi}		
2			30	20.29 ± 0.02 ^{defg}		18.83 ± 0.01 ^{efgh}		
3			45	20.75 ± 0.01 ^{jklm}		19.28 ± 0.01 ^{lmnopq}		
4			60	20.59 ± 0.02 ^{hijk}		19.33 ± 0.01 ^{mnopq}		
5		120	15	20.36 ± 0.06 ^{defgh}		18.98 ± 0.16 ^{ghijk}		
6			30	20.82 ± 0.06 ^{klmn}		19.38 ± 0.06 ^{nopq}		
7			45	20.57 ± 0.02 ^{hijk}		19.13 ± 0.02 ^{ijklmn}		
8			60	20.75 ± 0.01 ^{jklm}		19.21 ± 0.04 ^{klmnop}		
9		140	15	20.49 ± 0 ^{fghij}		19 ± 0 ^{ghijkl}		
10			30	20.81 ± 0.08 ^{klmn}		19.31 ± 0.07 ^{mnopq}		
11			45	20.88 ± 0.2 ^{lmn}		19.47 ± 0.22 ^{opq}		
12			60	20.47 ± 0.01 ^{fghi}		19.04 ± 0 ^{hijklm}		
13		160	15	19.72 ± 0.09 ^{ab}		18.32 ± 0.09 ^{ab}		
14			30	19.54 ± 0.06 ^a		18.05 ± 0.06 ^a		
15			45	20.13 ± 0.06 ^{cd}		18.59 ± 0.06 ^{bcde}		
16			60	20.18 ± 0.01 ^{cde}		18.64 ± 0.01 ^{cdef}		
Statistical significance				*		n.s.		

No.—number; Temp.—temperature; VM—volatile matter; C—carbon; S—sulfur; O—oxygen; H—hydrogen; HHV—higher heating value; LHV—lower heating value. The means in the same column with different lowercase superscripts are statistically different ($p < 0.05$) according to Tukey's HSD test. Statistical significance: * $p \leq 0.01$; n.s.—not significant.

Table 4. Content of combustible substances in hazelnut shell after conductive drying (2021).

No.	Year	Temp. (°C)	Time (min)	VM (%)	C (%)	S (%)	O (%)	H (%)
17	2021	100	15	70.26 ± 0.34 ^{abcde}	55.51 ± 4.43 ^a	0.07 ± 0 ^a	37.1 ± 4.42 ^{ab}	6.9 ± 0.01 ^{cdefgh}
18			30	71.39 ± 0.06 ^{ghij}	55.95 ± 0.02 ^a	0.06 ± 0.01 ^a	37.35 ± 0.49 ^{ab}	6.3 ± 0.54 ^{ab}
19			45	69.99 ± 0.22 ^{abcd}	56.19 ± 0.32 ^a	0.06 ± 0.01 ^a	36.35 ± 0.52 ^{ab}	6.94 ± 0.21 ^{defgh}
20			60	70.43 ± 0.4 ^{bcdefg}	56.87 ± 0.31 ^a	0.07 ± 0 ^a	35.86 ± 0.56 ^{ab}	6.81 ± 0.24 ^{cdefg}
21		120	15	71.99 ± 0.17 ^j	56.1 ± 0.13 ^a	0.06 ± 0 ^a	36.92 ± 0.23 ^{ab}	6.59 ± 0.01 ^{bcdef}
22			30	69.92 ± 0.01 ^{abcd}	56.85 ± 0.07 ^a	0.08 ± 0 ^a	35.17 ± 0.17 ^a	7.36 ± 0.1 ^h
23			45	70.16 ± 0.17 ^{abcd}	56.22 ± 0.17 ^a	0.08 ± 0.01 ^a	36.32 ± 0.17 ^{ab}	6.96 ± 0.01 ^{efgh}
24			60	70.52 ± 0.41 ^{bcdefg}	56.22 ± 0.09 ^a	0.07 ± 0 ^a	35.79 ± 0.16 ^{ab}	7.37 ± 0.07 ^h
25		140	15	70.1 ± 0.45 ^{abcd}	55.98 ± 0.19 ^a	0.07 ± 0 ^a	36.92 ± 0.03 ^{ab}	6.68 ± 0.16 ^{bcdefg}
26			30	70.67 ± 0.03 ^{bcdefgh}	56.45 ± 0.12 ^a	0.07 ± 0 ^a	36.27 ± 0.12 ^{ab}	6.83 ± 0 ^{cdefg}
27			45	71.98 ± 0.33 ^j	56.17 ± 0.21 ^a	0.07 ± 0 ^a	36.72 ± 0.21 ^{ab}	6.69 ± 0 ^{bcdefg}
28			60	70.64 ± 0 ^{bcdefgh}	54.7 ± 0.55 ^a	0.07 ± 0 ^a	38.16 ± 0.69 ^{ab}	6.69 ± 0.13 ^{bcdefg}
29		160	15	70.16 ± 0.44 ^{abcd}	55.38 ± 0.07 ^a	0.07 ± 0 ^a	37.39 ± 0.08 ^{ab}	6.74 ± 0 ^{bcdefg}
30			30	71.32 ± 0.33 ^{efghij}	56.16 ± 0.14 ^a	0.07 ± 0 ^a	37.06 ± 0.14 ^{ab}	6.44 ± 0.01 ^{bcd}
31			45	70.63 ± 0.09 ^{bcdefgh}	57.19 ± 0.09 ^a	0.07 ± 0 ^a	35.19 ± 0.3 ^a	7.13 ± 0.23 ^{gh}
32			60	69.83 ± 0.07 ^{abc}	56.59 ± 0.04 ^a	0.07 ± 0 ^a	36.15 ± 0.02 ^{ab}	6.87 ± 0.05 ^{cdefgh}
Statistical significance				n.s.	*	*	*	

Table 4. Cont.

No	Year	Temp. (°C)	Time (min)	HHV (MJ kg ^{−1})	LHV (MJ kg ^{−1})
17	2021	100	15	20.43 ± 0.14 ^{efghi}	18.92 ± 0.14 ^{fghij}
18			30	20.87 ± 0.02 ^{lmn}	19.5 ± 0.13 ^q
19			45	20.93 ± 0.07 ^{mno}	19.42 ± 0.02 ^{opq}
20			60	21.05 ± 0.1 ^{no}	19.56 ± 0.05 ^q
21		120	15	19.86 ± 0.03 ^b	18.42 ± 0.03 ^{bc}
22			30	20.94 ± 0.09 ^{mno}	19.33 ± 0.11 ^{mnopq}
23			45	21.02 ± 0.11 ^{mno}	19.5 ± 0.11 ^{pq}
24			60	21.16 ± 0.04 ^o	19.56 ± 0.03 ^q
25		140	15	20.54 ± 0.08 ^{ghij}	19.08 ± 0.11 ^{hijklm}
26			30	21 ± 0.02 ^{mno}	19.51 ± 0.02 ^q
27			45	20.19 ± 0.02 ^{cde}	18.73 ± 0.02 ^{defg}
28			60	20.3 ± 0.2 ^{defg}	18.84 ± 0.17 ^{efgh}
29		160	15	19.93 ± 0.1 ^{bc}	18.46 ± 0.1 ^{bcd}
30			30	20.61 ± 0.03 ^{hijkl}	19.2 ± 0.02 ^{klmno}
31			45	20.63 ± 0.06 ^{ijkl}	19.08 ± 0.01 ^{hijklm}
32			60	20.23 ± 0.01 ^{def}	18.73 ± 0.01 ^{defg}
Statistical significance				*	n.s.

No.—number; Temp.—temperature; VM—volatile matter; C—carbon; S—sulfur; O—oxygen; H—hydrogen; HHV—higher heating value; LHV—lower heating value. The means in the same column with different lowercase superscripts are statistically different ($p < 0.05$) according to Tukey's HSD test. Statistical significance: * $p \leq 0.01$; n.s.—not significant.

The performed statistical analysis revealed differences in the fuel substance of the samples of hazelnut shells in relation to the year. The average content of VM in 2020 was 64.72%, while in 2021 it was 64.15%. The content of carbon was lower on average in 2020 (59.99%), while in the next year it was 55.11%. The proportion of S was significantly lower in 2020, being 0.11% in 2020 and 0.34% in 2021; in contrast, H had an average value of 7.71% in 2020 and 6.52% in the following year. Mean values of 20.87 MJ kg^{−1} (2020) and 20.43 MJ kg^{−1} were obtained for HHV, while LHV was 19.19 and 19.01 MJ kg^{−1}.

To determine the difference in mass of the hazelnut kernels, the kernel and shell samples were weighed before and after the drying period. Table 2 shows the weight differences of the hazelnut fruit, kernel, and shell in relation to the years of sampling for natural samples, while Table 5 shows the differences in the mass of hazelnut shells after different drying times and different durations of the process.

Table 5. Change in mass of hazelnut samples in relation to years of sampling as a function of applied temperatures and drying time.

Year	Temp. (C °)	Time (min)	Fruit Mass	Kernel Mass	Shell Mass
2020	100	15	3.89 ± 0.33 ^e	1.77 ± 0.19 ^{ghijk}	2.12 ± 0.21 ^{de}
		30	3.88 ± 0.33 ^e	1.74 ± 0.23 ^{fghijk}	2.14 ± 0.26 ^{de}
		45	4.08 ± 0.51 ^e	1.92 ± 0.22 ^k	2.16 ± 0.31 ^{de}
		60	3.84 ± 0.3 ^e	1.73 ± 0.14 ^{efghijk}	2.11 ± 0.2 ^{de}
	120	15	4.1 ± 0.39 ^e	1.83 ± 0.24 ^{ijk}	2.28 ± 0.26 ^e
		30	4.01 ± 0.39 ^e	1.83 ± 0.22 ^{jk}	2.18 ± 0.26 ^{de}
		45	3.91 ± 0.39 ^e	1.8 ± 0.17 ^{hijk}	2.11 ± 0.25 ^{de}
		60	3.16 ± 0.59 ^{abc}	1.55 ± 0.29 ^{bcdefghijk}	1.61 ± 0.32 ^{abc}
	140	15	4.03 ± 0.45 ^e	1.89 ± 0.21 ^k	2.14 ± 0.28 ^{de}
		30	3.84 ± 0.51 ^e	1.75 ± 0.3 ^{ghijk}	2.09 ± 0.24 ^{de}
		45	3.84 ± 0.54 ^e	1.74 ± 0.27 ^{fghijk}	2.1 ± 0.33 ^{de}
		60	3.73 ± 0.5 ^e	1.75 ± 0.26 ^{ghijk}	1.97 ± 0.31 ^{cde}
	160	15	3.7 ± 0.5 ^e	1.68 ± 0.23 ^{efghi}	2.02 ± 0.38 ^{de}
		30	3.78 ± 0.37 ^e	1.7 ± 0.18 ^{efghi}	2.08 ± 0.28 ^{de}
		45	3.8 ± 0.37 ^e	1.75 ± 0.19 ^{hi}	2.05 ± 0.26 ^{de}
		60	3.75 ± 0.37 ^e	1.69 ± 0.21 ^{efghi}	2.05 ± 0.27 ^{de}

Table 5. Cont.

Year	Temp. (C °)	Time (min)	Fruit Mass	Kernel Mass	Shell Mass
2021	100	15	2.94 ± 0.33 ^{abc}	1.41 ± 0.15 ^{abcd}	1.53 ± 0.21 ^{ab}
		30	2.63 ± 0.45 ^a	1.32 ± 0.26 ^{ab}	1.31 ± 0.23 ^a
		45	2.97 ± 0.36 ^{abc}	1.46 ± 0.16 ^{abcdefg}	1.5 ± 0.23 ^{ab}
		60	3.14 ± 0.68 ^{abc}	1.55 ± 0.36 ^{bcdefghijk}	1.59 ± 0.33 ^{abc}
	120	15	3.48 ± 0.35 ^{cde}	1.66 ± 0.15 ^{defghijk}	1.82 ± 0.25 ^{bcd}
		30	2.68 ± 0.47 ^a	1.36 ± 0.22 ^{abcd}	1.33 ± 0.28 ^a
		45	2.87 ± 0.36 ^{abc}	1.44 ± 0.19 ^{abcdef}	1.43 ± 0.19 ^{ab}
		60	2.77 ± 0.39 ^{ab}	1.38 ± 0.18 ^{abcd}	1.39 ± 0.21 ^a
	140	15	2.67 ± 0.45 ^a	1.34 ± 0.23 ^{abc}	1.33 ± 0.25 ^a
		30	2.64 ± 0.35 ^a	1.25 ± 0.14 ^a	1.4 ± 0.26 ^a
		45	2.87 ± 0.36 ^{abc}	1.44 ± 0.19 ^{abcdef}	1.43 ± 0.19 ^{ab}
		60	3.11 ± 0.47 ^{abc}	1.49 ± 0.24 ^{bcdefghi}	1.61 ± 0.26 ^{abc}
	160	15	3.18 ± 0.47 ^{bc}	1.57 ± 0.22 ^{defghi}	1.6 ± 0.28 ^{ab}
		30	3.04 ± 0.42 ^{abc}	1.49 ± 0.22 ^{bcde}	1.55 ± 0.25 ^{ab}
		45	3.3 ± 0.59 ^{cd}	1.58 ± 0.27 ^{defghi}	1.72 ± 0.36 ^{bc}
		60	3.31 ± 0.56 ^{cd}	1.59 ± 0.27 ^{defghi}	1.71 ± 0.33 ^{bc}
Statistical significance			*	*	*

The means in the same column with different lowercase superscripts are statistically different ($p < 0.05$) according to Tukey's HSD test. Statistical significance: * $p \leq 0.01$; n.s.—not significant.

The statistical analysis performed revealed differences in the mass of hazelnut samples in relation to the years of sampling. The average value of fruit mass was 3.85 g in 2020 and 3.52 g in the following year. Kernel mass was 1.77 g in the first year of sampling and averaged 1.69 g in 2021. The shell mass of the observed samples had an average value of 2.08 g in 2020, while it was 1.83 g in 2021.

Table 3 shows the average values of combustible substances in hazelnut shells after conductive drying in 2020. The lowest average value of VM was obtained for the sample treated at 100 °C for 15 min (69.34%), while the highest average value was obtained for the sample treated at 160 °C for 45 min. The percentage of carbon is the lowest for the treatment at 100 °C and the duration of 30 min and is 54.86%, while the highest percentage is present for the treatment at 160 °C and the duration of 45 min (57.11%). The sulfur content varies between 0.6 and 0.9% in all samples, in contrast to the treatment at 120 °C and 45 min, where it is much higher (0.72%). The highest value of oxygen is present in the sample dried at 100 °C for 60 min (38.92%), while the lowest value is 35.33% (160 °C, 45 min). The average H content is also affected by temperature and duration; the sample dried at 100 °C for 60 min had the lowest value (5.81%), while the highest value was recorded for the sample dried at 160 °C for 45 min (7.07%). HHV and LHV have the lowest values at a temperature of 160 °C for 30 min (19.54 MJ kg^{−1}, 18.05 MJ kg^{−1}), while the highest values were recorded for the treatment of 140 °C and 45 min (20.88 MJ kg^{−1}, 19.47 MJ kg^{−1}).

Table 4 shows the average values of combustible substances in hazelnut shells after conductive drying in 2021. The lowest average value of VM was obtained for the sample treated at 160 °C and 60 min (69.83%), while the highest average value was obtained for the sample treated at 120 °C for 15 min and was 71.99%. The percentage of carbon is the lowest for the treatment at 140 °C and the duration of 60 min and is 54.70%, while the highest percentage is present for the treatment at 160 °C and the duration of 45 min (57.19%). The percentage of sulfur varies between 0.6 and 0.8% in all samples. The lowest value of oxygen is present in the sample dried at 120 °C for 30 min (35.17 %), while the highest value is 36.72% (140 °C, 45 min). The average H content is also affected by temperature and duration; the sample dried at 100 °C for 30 min had the lowest value (6.30%), while the highest value was recorded for the sample dried at 120 °C for 60 min (7.37%). HHV and LHV have the lowest values at a temperature of 120 °C for 15 min (19.86 MJ kg^{−1}, 18.42 MJ kg^{−1}), while the highest values were recorded at 120 °C and 60 min (21.16 MJ kg^{−1}, 19.56 MJ kg^{−1}).

Table 5 shows the differences in the mass of hazelnut shells after different drying times and different durations of the process.

Table 5 shows the change in fruit, kernel, and shell mass with respect to the application of different temperature regimes and the duration of the drying process. The highest average values of fruit mass and kernel mass in 2020 were recorded at a temperature regime of 100 °C and duration of 45 min and were 4.08 g and 1.92 g, respectively, while the lowest average values for the same year were recorded at a temperature regime of 120 °C and duration of 60 min and were 3.16 g and 1.55 g, respectively. In the analyzed shell mass sample, the highest average value (2020) was recorded at 120 °C and a duration of 15 min (2.28 g), while the lowest value was recorded at a temperature regime of 120 °C and a duration of 60 min and was 1.61 g.

When considering the average mass values in 2021, the highest average mass values of the samples were recorded at a temperature of 120 °C and a duration of 15 min (3.48 g, 1.66 g, 1.82 g). For fruit and shell masses, the lowest average values were recorded at a temperature of 100 °C and a process duration of 30 min (2.63 g and 1.31 g), while the lowest value of kernel mass was recorded at a temperature of 140 °C and a duration of 30 min and was 1.25 g.

Figure 1 shows the principal component analysis and the grouping of the samples in the direction of the vector (variables) in relation to the year, the temperature of the process, and the time duration. Samples 14, 15, 16, and 21 have the highest VM values. Samples 15 and 31 have the highest C value, while sample 7 has the highest S value. Sample 4 has the highest value of O, while samples 15, 31, 22, and 24 “move” the most on the vector H. HHV and LHV are highest in samples 11, 24, 20, 26, 23, 19, and 6.

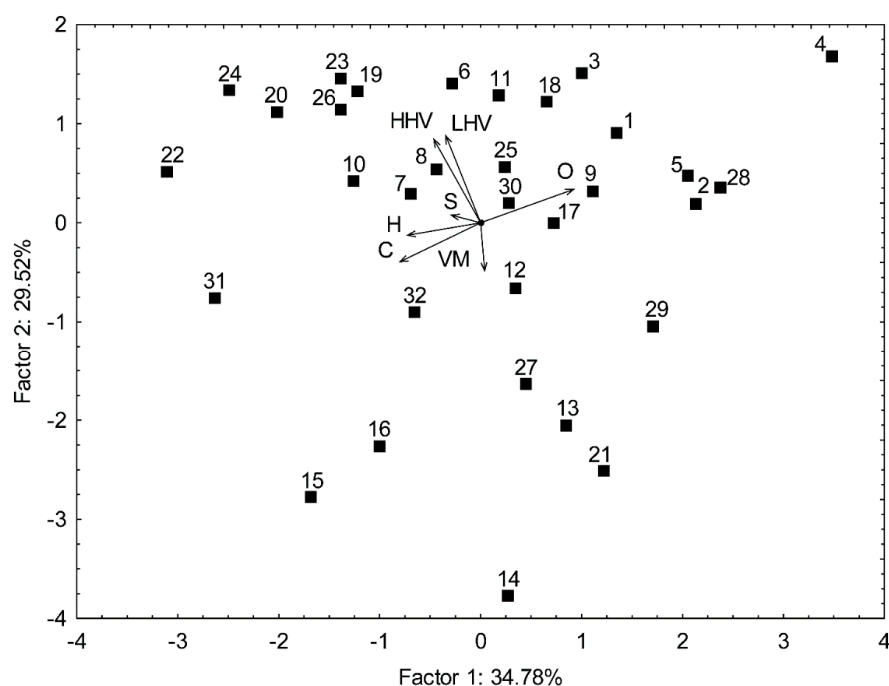


Figure 1. Principal component analysis (PCA) of observed samples depending on the year, drying temperature, and duration.

In the correlation diagram in Figure 2, the correlation coefficients are shown according to the coloring on the scale (values from -1 to 1). The variable VM is positively correlated with C (0.23), while it is negatively correlated with the variables S (-0.07), O (-0.08), H (-0.16), HHV (-0.25), and LHV (-0.23). The correlation coefficients between carbon and variables S, H, HHV, and LHV have positive values, while carbon is negatively correlated with O (-0.91). The value of the correlation coefficient for S is negative for O and H and positive for HHV and LHV, and the variable O is negatively correlated with H (-0.69), HHV (-0.14), and LHV (-0.02). The variable H has a positive correlation value with HHV (0.19) and LHV (0.02).

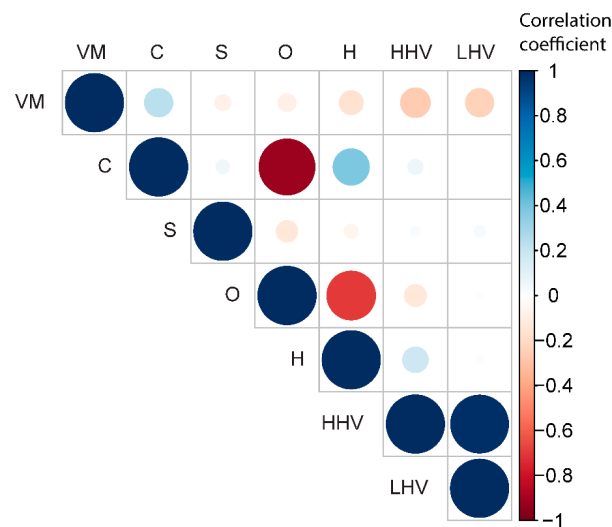


Figure 2. Correlation plot of observed values.

Univariate analysis, shown in Tables 6 and 7, was performed to determine the effect of year, temperature, and time on carbon (C), sulfur (S), hydrogen (H), oxygen (O), volatile content, higher heating value (HHV), lower heating value (LHV), and change in mass of hazelnut samples.

Table 6. Results of the combined univariate analysis of content of combustible substances in hazelnut shell.

	DF	SS						
		VM (%)	C (%)	S (%)	O (%)	H (%)	HHV (MJ kg ⁻¹)	LHV (MJ kg ⁻¹)
Year	1	0.24 n.s.	1.29 n.s.	0.04 *	4.36 **	0.55 *	0.81 *	0.54 *
Temperature	3	4.41 *	11.92 *	0.13 *	19.05 *	0.69 *	5.04 *	5.38 *
Time	3	3.91 *	5.31 n.s.	0.12 *	9.92 **	0.27 **	2.88 *	2.55 *
Year x Temperature	3	3.72 *	9.14 *	0.11 *	14.10*	0.80 *	1.26 *	1.39 *
Year x Time	3	8.12 *	0.16 n.s.	0.12 *	0.31 n.s.	0.39 *	0.92 *	1.06 *
Temperature x Time	9	17.71 *	5.75 n.s.	0.36 *	13.06 n.s.	4.73 *	2.51 *	1.73 *
Year x Temperature x Time	9	7.46 *	6.96 n.s.	0.34 *	12.71 n.s.	2.03 *	1.78 *	1.99 *
Error	64	7.15	63.23	0.02	66.17	1.57	0.44	0.50

C—carbon; S—sulfur; O—oxygen; H—hydrogen; HHV—higher heating value; LHV—lower heating value; DF—degrees of freedom; SS—sum of squares. Statistical significance: * $p \leq 0.01$; ** $p \leq 0.05$; n.s.— not significant.

Table 7. Results of the combined univariate analysis of the change in mass of hazelnut samples with respect to the parameters year, temperature, and duration of the process.

	DF	SS		
		Fruit Mass (g)	Kernel Mass (g)	Shell Mass (g)
Year	1	119.56 *	11.92 *	55.99 *
Temperature	3	1.45 n.s.	0.15 n.s.	0.87 *
Time	3	2.52 *	0.81 *	0.47 **
Year x Temperature	3	0.39 n.s.	0.10 n.s.	0.13 n.s.
Year x Time	3	5.97 *	0.93 *	2.33 n.s.
Temperature x Time	9	8.24 *	1.35 *	3.27 *
Year x Temperature x Time	9	8.92 *	1.02 **	4.05 *
Error	928	199.95	49.52	78.99

DF—degrees of freedom; SS—sum of squares. Statistical significance: * $p \leq 0.01$; ** $p \leq 0.05$; n.s.— not significant.

The variable VM is not significantly affected by parameter year, while the other parameters are significantly affected at $p \leq 0.01$. The C value is significantly influenced by the parameters Temperature and Year x Temperature, while the other parameters have no significant influence. All parameters have a significant influence on the percentage of S in the observed samples ($p \leq 0.01$). The parameters year x time, temperature x time, and Year x Temperature x Time have no significant influence on O, while *year*, *time* ($p \leq 0.05$), *temperature*, and Year x Temperature ($p \leq 0.01$) significantly influence the change in the variable. All parameters have a significant statistical impact on the value of H, with time being significant at a value of $p \leq 0.05$. All observed parameters significantly affect the change in HHV and LHV ($p \leq 0.01$).

Table 7 shows the univariate analysis of the influence of individual and combined parameters *Year*, *Temperature*, and *Time* on the observed variables, namely the changes in hazelnut mass. The changes in fruit and kernel masses are significantly influenced by the parameters Year and Time as well as the interactions Year x Time, Temperature x Time, and Year x Temperature x Time, while the other observed parameters do not have a significant impact on the changes. The parameters *Year*, *Temperature*, *Time*, *Temperature x Time*, and *Year x Temperature x Time* significantly influence the change in shell mass, while other interactions are not statistically significant.

4. Discussion

Biomass from hazelnut shells has a suitable energetic composition. To evaluate the possibility of using raw hazelnut biomass as an energy source, it is necessary to determine its energetic properties [31]. The drying process directly affects the cost price of hazelnut biomass, so it is necessary to conduct research to determine the optimal treatment, which includes the application of different temperatures and durations of the process [32]. The studied samples of hazelnut biomass were collected in two years and subjected to conduction drying treatment at different temperatures and different durations of the process. In order to compare the differences in fuel properties as well as the changes in mass of the studied samples, analyses were performed before and after the treatment. When investigating the fuel properties of natural hazelnut shells collected in 2020 and 2021, the average proportions of VM (64.72 and 64.15%), C (59.99 and 55.11%), S (0.11 and 0.34%), O (31.82 and 37.71%), and H (7.71 and 6.52%) and the heating values HHV (20.87 and 20.43 MJ kg⁻¹) and LHV (19.19 and 19.01 MJ kg⁻¹) were determined. A higher proportion of C and H in the biomass composition increases the heating value of the biofuel [33]. After applying treatments by drying in samples from 2020 and 2021, the highest C content (57.11 and 57.19%) was measured at 160 °C and 45 min. The average H content is also affected by temperature and drying time. For the 2020 samples, the highest value was measured for samples dried at 160 °C for 45 min (7.07%); for the 2021 samples, the highest value was measured for samples dried at 120 °C for 45 min (7.37%). For the 2020 samples, the drying treatment caused a decrease in the percentages of C and H, while in 2021, drying caused an increase in C and H values. After treatment, the S content decreased on average, while the value of O increased or remained the same. Since LHV and HHV are the most important parameters in evaluating the use of certain feedstocks as fuel, they need to be described in more detail. In the first year (2020) of testing natural samples, the mean value of HHV was 20.87 MJ kg⁻¹, and there were significant differences after treatment. The lowest value was 19.54 MJ kg⁻¹ at a higher temperature and longer duration, while the highest value was measured at 140 °C and 45 min duration (20.88 MJ kg⁻¹). In the next year (2021), the mean value of HHV of the natural samples was 20.43 MJ kg⁻¹, and significant differences in the change were again observed with the application of different treatments. The lowest mean value was measured at a temperature of 120 °C for 15 min (19.86 MJ kg⁻¹), while the highest value was 21.16 MJ kg⁻¹ (120 C and 45 min). The differences between the minimum and maximum LHV values changed in parallel with the HHV values. Considering the interactions of year and temperature, and thus the importance of the effect of year and temperature on the increase or decrease in the combustible substances of the

biomass studied, it is clear how important they are. The VM variable was affected by all the individual parameters and their interactions with the change in proportion, except for the year (i.e., in which year the sample was collected). The observed parameters mostly had no significant effect on the change in C, except for the drying time parameter and the interaction of time and year, while all parameters had a significant effect on S, H, HHV, and LHV. For the variable O, the most significant influence was recorded for the parameters year and drying time.

In the two years in which hazelnuts were sampled, fruit mass averaged 3.85 g in 2020 and 3.52 g the following year, kernel mass averaged 1.77 g and 1.69 g, and shell mass averaged 2.08 g in 2020 and 1.83 g the following year. Ferrão et al. (2021) [34] studied the chemical and physical properties of different hazelnut varieties. The weight of the hazelnut fruit ranged from 2.23 to 3.89 g, depending on the variety, while the kernel weight varied from 1.12 to 1.70 g. The weight of the tested samples was within this range. After conduction drying, there were significant changes in the mass of the samples. For the samples collected in 2020, the lowest average values were obtained for the fruit (3.16 g), the kernel (1.55 g), and the peel (1.61 g) after treatment at 120 °C for 60 min. For the 2021 samples, the lowest average values were obtained for the fruit (2.63 g) and the peel (1.31 g) after a treatment at 100 °C for 30 min, and for the core (1.25 g) after a treatment at 140 °C for 30 min. The drying process has a positive effect on improving the properties of the biomass, but it is necessary to take into account the costs caused by energy consumption and determine the most economical option to optimize the process [35]. Over the years, significant efforts have been implemented to diminish the energy expenditure of the energy-intensive drying process [36,37]. The univariate analysis of the variance of the observed variables showed the influence of the parameters year of sampling, drying temperature, and duration on the mass change. Differences in the change in mass of fruit and kernel are most affected the parameters year of sampling and duration of drying, as well as the interactions between the mentioned parameters, while the influence of temperature as a single parameter is not statistically significant. The difference in shell mass is mainly influenced by the duration of the process. For all observed variables, the influence of the interaction between the year of sampling and temperature on the change in mass is not statistically significant. The conducted studies give a good insight into the changes in the fuel properties of hazelnut shell biomass, although the costs incurred during the drying process and the duration of the process itself must also be taken into account. Future plans related to this research include finding an economic and energy-optimal solution for the use of hazelnut shell biomass as a biofuel, with the goal of improving the quality of the feedstock as a potential fuel source.

5. Conclusions

Due to its physicochemical properties and high energy potential, hazelnut shell represents a valuable source of energy. In the studies conducted, the hazelnut biomass was subjected to conduction drying over a period of two years at different temperatures and for different periods of time. The application of conduction drying changed the proportion of combustible materials. Since the quality of the fuel is most affected by the increase in the percentage of carbon and hydrogen, it was found that the greatest increase occurred at a temperature of 160 °C and a duration of 45 min. The highest average heating value (20.88 and 21.16 MJ kg⁻¹) was determined for samples treated at 140 °C for 45 min and 120 °C for 60 min. The lowest masses of the tested samples were measured at 120 °C, 100 °C, and 140 °C and treatment durations of 30 and 60 min. By choosing the optimal drying treatment, the quality of the fuel can be positively influenced, but the energy–economic balance of the application must be taken into account. The aim of future research is to compare the changes in physicochemical and energy properties caused by the conduction drying process in different types and varieties of biomass.

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References

1. European Commission. *REPowerEU Plan*; COM (2022) 230 Final; European Commission, 2022. Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131 (accessed on 16 August 2022).
2. Jovičić, N.; Antonović, A.; Matin, A.; Antolović, S.; Kalambura, S.; Krička, T. Biomass Valorization of Walnut Shell for Liquefaction Efficiency. *Energies* **2022**, *15*, 495. [CrossRef]
3. Perez-Armada, L.; Rivas, S.; González, B.; Moure, A. Extraction of phenolic compounds from hazelnut shells by green processes. *J. Food Eng.* **2019**, *255*, 1–8. [CrossRef]
4. Demirkaya, E.; Dal, O.; Yüksel, A. Liquefaction of waste hazelnut shell by using sub-and supercritical solvents as a reaction medium. *J. Supercrit. Fluids* **2019**, *150*, 11–20. [CrossRef]
5. Fuso, A.; Risso, D.; Rosso, G.; Rosso, F.; Manini, F.; Manera, I.; Caligiani, A. Potential valorization of hazelnut shells through extraction, purification and structural characterization of prebiotic compounds: A critical review. *Foods* **2021**, *10*, 1197. [CrossRef]
6. Kocabaş-Ataklı, Z.Ö.; Okyay-Öner, F.; Yürüm, Y. Combustion characteristics of Turkish hazelnut shell biomass, lignite coal, and their respective blends via thermogravimetric analysis. *J. Therm. Anal. Calorim.* **2015**, *119*, 1723–1729. [CrossRef]
7. Hodgson, E.M.; Lister, S.J.; Bridgwater, A.V.; Clifton-Brown, J.; Donnison, I.S. Genotypic and environmentally derived variation in the cell wall composition of *Miscanthus* in relation to its use as a biomass feedstock. *Biomass Bioenergy* **2010**, *34*, 652–660. [CrossRef]
8. Bilandžija, N.; Voca, N.; Jelcic, B.; Jurisic, V.; Matin, A.; Grubor, M.; Krička, T. Evaluation of Croatian agricultural solid biomass energy potential. *Renew. Sustain. Energy Rev.* **2018**, *93*, 225–230. [CrossRef]
9. Krička, T.; Matin, A.; Bilandžija, N.; Jurišić, V.; Antonović, A.; Voća, N.; Grubor, M. Biomass valorization of *Arundo donax* L., *Miscanthus × giganteus* and *Sida hermaphrodita* for biofuel production. *Int. Agrophysic* **2017**, *31*, 575–581. [CrossRef]
10. Patel, A.; Agrawal, B.; Rawal, B.R. Pyrolysis of biomass for efficient extraction of biofuel. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, *42*, 1649–1661. [CrossRef]
11. Kok, M.V.; Özgür, E. Characterization of lignocellulose biomass and model compounds by thermogravimetry. *Energy Sources Part A Recovery Util. Environ. Eff.* **2017**, *39*, 134–139. [CrossRef]
12. Zhao, C.; Liu, X.; Chen, A.; Chen, J.; Lv, W.; Liu, X. Characteristics evaluation of bio-char produced by pyrolysis from waste hazelnut shell at various temperatures. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, 1–11. [CrossRef]
13. Hoşgün, E.Z.; Berikten, D.; Kivanç, M.; Bozan, B. Ethanol production from hazelnut shells through enzymatic saccharification and fermentation by low-temperature alkali pretreatment. *Fuel* **2017**, *196*, 280–287. [CrossRef]
14. Haykiri-Acma, H.; Yaman, S.; Kucukbayrak, S. Combustion characteristics of sodium-free pyrolytic char from hazelnut shell. *Fuel Process. Technol.* **2012**, *96*, 169–174. [CrossRef]
15. Yilgin, M.; Yildirim, S.; Pehlivan, D. Combustion of hazelnut shell-lignite blends in poly-particulate beds. *Biomass Convers. Biorefinery* **2021**, 1–9. [CrossRef]
16. Chen, L.; Subbiah, J.; Jones, D.; Zhao, Y.; Jung, J. Development of effective drying strategy with a combination of radio frequency (RF) and convective hot-air drying for inshell hazelnuts and enhancement of nut quality. *Innov. Food Sci. Emerg. Technol.* **2021**, *67*, 102555. [CrossRef]
17. Haghi, A.K. Effect of drying methods on wood strength. *Monomers Oligomers Polym. Compos. Nanocomposites* **2021**, *2061*, 357–371. [CrossRef]
18. Wang, W.; Jung, J.; McGorin, R.J.; Zhao, Y. Investigation of the mechanisms and strategies for reducing shell cracks of hazelnut (*Corylus avellana* L.) in hot-air drying. *Lwt* **2018**, *98*, 252–259. [CrossRef]
19. Yi, J.; Li, X.; He, J.; Duan, X. Drying efficiency and product quality of biomass drying: A review. *Dry. Technol.* **2020**, *38*, 2039–2054. [CrossRef]
20. Matin, A.; Majdak, T.; Krička, T.; Grubor, M. Valorization of sunflower husk after seeds convection drying for solid fuel production. *J. Cent. Eur. Agric.* **2019**, *20*, 389–401. [CrossRef]
21. Matin, A.; Grubor, M.; Ostroški, N.; Jurišić, V.; Bilandžija, N.; Kontek, M.; Zdunić, Z.; Krička, T. Effect of Hydrothermal Treatment on the Improvement of Wheat and Triticale Grain Properties. *Agric. Conspec. Sci.* **2021**, *86*, 243–250.
22. Qiu, J.; Kloosterboer, K.; Guo, Y.; Boom, R.M.; Schutyser, M.A.I. Conductive thin film drying kinetics relevant to drum drying. *J. Food Eng.* **2019**, *242*, 68–75. [CrossRef]

23. Giraudo, A.; Valentini, N.; Venturello, A.; Savorani, F.; Bertone, E.; Bonazzola, G.; Zeppa, G.; Geobaldo, F. Kinetic modeling of hazelnut drying: Effects of different cultivars and drying parameters. *J. Food Process Eng.* **2018**, *41*, e12632. [[CrossRef](#)]
24. Silva, P.C.; Resende, O.; Ferreira Junior, W.N.; Silva, L.C.D.M.; Quequeto, W.D.; Silva, F.A.S.E. Drying kinetics of Brazil nuts. *Food Sci. Technol.* **2022**, *42*, 1–7. [[CrossRef](#)]
25. Ambros, S.; Mayer, R.; Schumann, B.; Kulozik, U. Microwave-freeze drying of lactic acid bacteria: Influence of process parameters on drying behavior and viability. *Innov. Food Sci. Emerg. Technol.* **2018**, *48*, 90–98. [[CrossRef](#)]
26. HRN EN 15148:2009; Solid Biofuels—Determination of the Content of Volatile Matter. Croatian Standard Institute: Zagreb, Croatia, 2009.
27. HRN EN ISO 16948:2015; Solid Biofuels—Determination of Total Content of Carbon, Hydrogen and Nitrogen. Croatian Standard Institute: Zagreb, Croatia, 2015.
28. HRN EN 14918:2010; Solid Biofuels—Determination of Calorific Value. Croatian Standard Institute: Zagreb, Croatia, 2010.
29. TIBCO Statistica, version 13.3.0; StatSoft TIBCO Software Inc.: Palo Alto, CA, USA, 2013.
30. Rstudio, version 1.4.1564; Poist: Boston, MA, USA, 2022.
31. Gebreegziabher, T.; Oyedun, A.O.; Hui, C.W. Optimum biomass drying for combustion—A modeling approach. *Energy* **2013**, *53*, 67–73. [[CrossRef](#)]
32. Yi, L.; Feng, J.; Qin, Y.H.; Li, W.Y. Prediction of elemental composition of coal using proximate analysis. *Fuel* **2017**, *193*, 315–321. [[CrossRef](#)]
33. Bilandžija, N.; Voća, N.; Leto, J.; Jurišić, V.; Grubor, M.; Matin, A.; Geršić, A.; Krička, T. Yield and Biomass Composition of *Miscanthus x Giganteus* in the Mountain Area of Croatia. *Trans. FAMENA* **2018**, *42*, 51–60. [[CrossRef](#)]
34. Ferrão, A.C.; Guiné, R.P.F.; Ramalhosa, E.; Lopes, A.; Rodrigues, C.; Martins, H.; Gonçalves, R.; Correia, P.M.R. Chemical and physical properties of some hazelnut varieties grown in Portugal. *Agronomy* **2021**, *11*, 1476. [[CrossRef](#)]
35. Myllymaa, T.; Holmberg, H.; Ahtila, P. Techno-economic evaluation of biomass drying in moving beds: The effect of drying kinetics on drying costs. *Drying Technol.* **2019**, *37*, 1201–1214. [[CrossRef](#)]
36. Doder, D.D.; Djaković, D.D. Modeling of intermittent convective drying of walnuts in single layer and its influence on deep bed drying simulation. *Therm. Sci.* **2019**, *23*, 3687–3699. [[CrossRef](#)]
37. Doder, D.D.; Đaković, D.D. Energy savings in convective drying of various materials using variable temperature conditions. *Environ. Prog. Sustain. Energy* **2020**, *39*, 1–11. [[CrossRef](#)]

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