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Qualitative Characterization of the Pellet Obtained from Hazelnut and Olive Tree Pruning

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Abstract: Biomass occupies a very important place among renewable energy sources, and the residual biomass recovery chain represents a sector of fundamental importance. Our work focused on the production of pellets by pruning residues from two of the most important woody crops in Italy: hazelnut and olive groves. We found a higher value of bulk density for the hazelnut pellet (581.30 kg m^{-3} vs. 562.38 kg m^{-3}) and a higher value of length for the olive pellet (16.66 mm vs. 10.47 mm). The percentages of durability were very similar (98%). The low heating value and ash content of hazelnut and olive were 17.21 MJ kg^{-1} and 3.1%, and 16.83 MJ kg^{-1} and 2.5%. A higher concentration of Cu, Pb, and Ni was observed in the hazelnut. The contrary was observed for the concentration of Zn. N content was 0.77% and 1.24% for the hazelnut and the olive, respectively. The concentration of S was 0.00% for both. The quality parameters that do not meet current standards could be improved by mixing these materials with different types of wood.

Keywords: hazelnut grove; olive grove; pruning residues; energy chain; pellet

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1. Introduction

The environmental issues linked to climate change and the decreasing availability of fossil energy sources have determined a greater interest in renewable energies. Within the latter, biomasses can play a fundamental role [1]. The importance of wood as an indispensable resource for limiting climate change and supporting global energy demand is now widely recognized [2–4].

The European Commission has indicated, as part of the 2020 climate/energy package [5], a series of rules aimed at reducing greenhouse gas emissions by 20% (compared to 1990 levels), using 20% energy from renewable sources, and improving 20% in energy efficiency. Nowadays, a new scenario provides for an increase in the contribution of renewables up to 27% in Europe, besides a reduction of 40% in greenhouse gases by 2030 [6]. Moreover, the EU, with the European Renewable Energy Directive (RED II), risks causing indirect land-use change (ILUC) when agricultural land previously destined for food production is converted to biofuel production. Therefore, using residuals as an alternative raw material for bioenergy production is fundamental to support the agro-energy supply chain.

Several studies have shown that the residual biomass represents an important energy resource in terms of available quantity and energy quality [7–11]. In Italy, it is estimated availability of 3.585×10^6 t of pruning residues and 1.50×10^6 t of these are burned in the field [12]. Agricultural pruning residues can be used to guarantee a clear reduction of polluting emissions typical of fossil fuels [13]. Furthermore, using residual biomass instead of fossil fuel for energy production is a means of mitigating global warming [14]. On an industrial level, however, this potential energy resource is still little exploited for several reasons. These include the lack of organized logistics, the concrete knowledge of effective availability over time and space, low mass and energy density, and high costs of transport that characterize the biomass [15–17].

It is possible to overcome the limits caused by low mass density and high transport costs by using densification processes to obtain a biofuel characterized by a greater energy density and easier to use [18–22]. With pelletization, the density of energetic biomass is considerably increased, leading to a significant reduction in transport and storage costs [23].

The energy valorization of residual biomasses for pellets production would offer economic advantages, increasing rural areas' income, and the environment, from reducing environmental impact [24]. Indeed, the use of pellets significantly reduces the formation of fine dust, minimizing the risks for health and the negative impacts during handling [22,25]. Pelletization also allows the thermochemical conversion improvement [26] due to the constant humidity level [27].

The high efficiency of the pellets for heating has increased its use [1]. In 2016, 29.1 million tons of pellets were produced [28], and in the last ten years, the annual production growth was around 20% [29]. This trend is also due to the general attention derived from the policies issued by the EU and the objectives to be achieved using bioenergy [30]. The demand for pellets during the year 2020 was estimated at around 50 million tons [31,32]. The increase in production is linked to the market price of pellets which becomes the key factor for the sector's development [33]. In Italy, using September 2020 data (ENplus A1 pellets), the market price of pellets varied from a minimum of €200 to a maximum of €450 t^{-1} [34].

Our research focused on pellets production using the pruning residues obtained from hazelnut and olive (*Olea europea* L.) groves. Generally, the residual biomass deriving from any type of orchard can be transformed into energy, and the obtained products have similar qualitative characteristics. Furthermore, deriving from less intensive crops that are also characterized by limited chemical inputs, the olive and hazelnut residues could be suitable for direct combustion [35]. Italy is one of the main European consumer countries of pellet [36], with approximately 1.5 million tons at the domestic level and an annual average of 1.4 tons per family [37]. In Italy, there are about 1.1 million hectares cultivated with olive trees [38–41], and the quantity of biomass from pruning potentially obtainable depends on the type of cultivar used, the cultivation system, and the frequency of pruning [10]. According to some research, Spanish and Italian olive trees can supply up to 11 tons of residues per hectare [42–44].

About 70,500 hectares of hazelnut (*Corylus avellana* L.) are planted in Italy [38,45], and 98% of the national production comes from the Lazio Region [46]. The biomass potentially obtainable from the pruning of this last crop is approximately 1.5 t ha^{-1} of dry matter per year [45,47].

In Viterbo province, hazelnut and olive are cultivated on 18,500 and 21,000 hectares, respectively [38,45,48]. Annually, over 60,000 tons of wet biomass can potentially be used for pellets production.

Studies on the densification of pruning residues are still relatively little recognized, and it is difficult to identify a complete picture of the qualitative characteristics of the product obtained.

Several studies have been carried out in Italy relating to the characterization of pellets obtained from poplar plantations, pruning residues of different types of orchards such as hazelnut groves, olive groves, and vineyards, and spent coffee. Each of the studies highlighted both positive and critical aspects of the pellets themselves. The most critical parameters found in these studies were mainly related to the ash and nitrogen content for the vineyard [49,50], spent coffee [51], hazelnut, and olive tree [52,53]. At the same time, for the 3 and 6-year-old poplar pellets, there were problems with bulk density and ash, but not of nitrogen [54].

In this context, our study aimed at enhancing various residual lignocellulosic materials by promoting a demonstration model of small-scale pellet production. Specifically, our objectives were: (i) to assess the amount of produced biomass during pruning, (ii) to evaluate the chemical, physical, and energy characteristics of the pellet obtained. This work contributes to increasing knowledge in the energy use of pellets from pruning residues using raw materials from crops grown organically.

2. Materials and Methods

2.1. Field Activities

Field activities were performed in the Viterbo province (Lazium region, Italy). The olive grove, subjected to biennial pruning, was planted in 1920 with seedlings of the Caninese variety with planting distances of 10 × 10 m (density 100 plants ha^{-1}). The organic hazelnut grove, subjected to annual pruning, was planted in 1989 with two cultivar types, the Tonda Gentile Romana (as pollinator) and the Giffoni, with a planting distance of 5 × 5 m and a density of 400 plants per hectare. Field surveys and sampling only concerned the Giffoni cultivar.

The morphometric surveys of the plants were carried out on 30 sample trees per crop, measuring height and basal diameter for each sample tree—the product released on the ground after pruning was tied in bundles and weighed by a field dynamometer. The residual biomass production was estimated by multiplying the average biomass obtained per plant by the plant density. For the characterization of the pruned material, 10 random branches for each sample tree were selected and measured (300 sub-samples per crop).

2.2. Laboratory Activities by Experimental Procedure

In February, the trees were pruned, and the residues were picked up from the ground at different times. The hazelnut residues were collected few days after the pruning operations, with a moisture content of 46%. At the pruning time, the olive tree residues had a moisture content of 40% (27% at the end of April).

After about a month, the raw materials were subjected to a refining process using a BL-100 shredder with a 6 mm grid [55].

The subsequent pelletizing phase was carried out using a Bianco Line pellet machine characterized by a power of 4 kW (Figure 1).

A 3-kW electric motor powers the BL-100 shredder refiner. Refining was made by a single blade rotor and 8 floating hammers. Three blades are mounted on the rear of the rotor, necessary to generate the cyclone for the expulsion of the treated material. The shredder can operate on chipped material and raw product with a maximum diameter of 50–70 mm.

The pellet mill has a 5 mm deep countersink with an angle of 25°. The die channel has a thickness of 23 mm, while the compression channel is 18 mm with a diameter of 6 mm. No wetting system was used. The cooling system consists of a fan placed in front of the pellet expulsion area. A flow regulator allows adjusting the power of the air jet. The cooled material is then dedusted through a vibrating screen with 5 mm diameter holes. A vibrator produces the vibration with a 50 Hz electric motor.

We tried to pelletize biomass with different moisture levels (10–15%), discarding the values that led to a material not properly densified (pellets too short, excessively fractured, etc.). We obtained, therefore, a good final pellet using refined material with a moisture content of 11%.

The biomass characterization was carried out by evaluating the moisture content (5 samples per species), bulk density (10 repetitions per species), pellet dimensions (30 repetitions per species), content and melting point of the ashes, heating value, mechanical durability, content of heavy metals, carbon, hydrogen, nitrogen and sulfur (3 repetitions per species), in accordance with EN ISO 18134-1:2015 [56], 17828:2016 [57], 17829:2016 [58], 18122:2016 [59], 21404:2020 [60], 18125:2018 [61], 17831-1:2016 [62], 16968: 2015 [63], 16948: 2015 [64], 16994:2016 [65], respectively.

Figure 1. Pellet machine utilized for the tests.

For the moisture content (M) on a wet basis, a Memmert UFP800 drying oven was used (105 ± 2 °C). The percentage of moisture content was calculated as the ratio between the weight loss and the weight before the drying process. Subsequently, the same procedure was carried out both on the refined material and on the pellet produced. The biomass after refined was stored in the bins of 0.58 m^3 (inside measures: 1.12 × 0.92 × 0.56 m) until the end of May. To facilitate the dehydration process, we exposed it to the sun twice a week during the last month of storage, turning the biomass into the bins twice a day to ensure uniform dehydration.

The pellet's bulk density (BD) was calculated using a metal cylinder with diameter, height, and volume of 170 mm, 295 mm, and 5 L, weighed by a dynamometer.

The size of the pellets was assessed by measuring their average diameter (D) and length (L).

For the ash content (A), the samples (1 g each) were heated to 250 °C for one hour and to 550 °C for two hours in a Lenton EF11/8B muffle furnace, considering, therefore, consequent variations of the weight of the same. The dried material was subsequently refined for the ash melting point, pressed into a cylindrical shape, and inserted into the Sylab SHV-IF 1500 analyzer identifying using a camera. At that temperature, the deformation of the sample started.

The heating value (Q) was determined according to EN ISO 18125: 2018 [61]. A sample of dried wood chips was first ground by a knife mill Retsch SM 100, and secondly by a centrifuge mill Retsch ZM 200. The higher heating value (HHV) was determined using the calorimeter Anton Paar 6400, while the lower heating value (LHV) was determined using a logarithmic formula. Samples of shredded wood (1 g) were prepared by the pellet mill Pellet Press 2810 to produce tablets. Before every single analysis, the instrument was calibrated with benzoic acid.

The mechanical durability (DU) was evaluated by an Andritz Sprout rotation pellet testing apparatus.

The determination of heavy elements (As, Cd, Cr, Cu, Pb, Ni, Zn) was performed using an Agilent ICP-MS 7700 according to the EN ISO 16968: 2015 [63]. An aliquot of each sample (approximately 500 mg) was transferred to special Teflon containers and subjected to acid attack (HNO_3 and H_2O_2) using a microwave digester (Start D, Milestone). The solutions obtained were diluted and analyzed.

The content of carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) were quantified with an analyzer CHNS-O Costech ECS 4010.

2.3. Data Analysis

Statistical analysis of the data was carried out with the software Statistics and PAST. Normality and homoscedasticity were checked before testing by the Shapiro Wilk W test and Levene test, respectively. Moisture content and Low heating value were examined using the nonparametric Kruskal–Wallis test. The ash melting point was examined by One-Way Anova, and the ash content by the Welch F-test for unequal variances. T-tests were performed for length, diameter, bulk density, and durability, whereas the 50-50 MANOVA was applied for C, H, N, S, and heavy metals. The 50-50 MANOVA is a variant of the MANOVA, which incorporates the Principal Component Analysis into its system. Ranks of the variables observed were analyzed using the rotation test, an application of the 50-50 MANOVA.

3. Results

3.1. Morphological Characteristics of Crops and Pruning

Tables 1 and 2 show the morphological characteristics of the trees and the average dimensions of the pruning residues of the olive and hazelnut, respectively. For the olive trees, the average height and diameter were 4.3 m and 46.62 cm. The length and the diameter of the pruning were 1.27 m and 1.41 cm, respectively. The average amount of pruned biomass per plant was equal to 47.25 kg of fresh matter (28.35 kg of dry matter per plant), corresponding to 2.36 t ha^{-1} year^{-1} (1.42 t of dry matter ha^{-1} year^{-1}).

The average height of the hazelnut plants was 4.25 m, with main and secondary suckers characterizes by different diameters and lengths. The average amount of pruned biomass per plant was 4.17 kg of fresh matter (2.25 kg of dry matter per plant), equal to 1.67 t ha^{-1} year^{-1} (0.90 t of dry matter ha^{-1} year^{-1}).

Table 1. Morphometric values of plants and dimensional characteristics of olive groves pruning.

	Average Values ± St. Dev.	Min. Value	Max. Value
Plant height (m)	4.3 ± 0.22	4	4.6
Plant diameter (cm)	46.62 ± 2.07	44	50
Main branch insertion height (m)	1.01 ± 0.11	0.9	1.15
Diameter of the pruned branches (cm)	1.41 ± 0.6	0.71	3.68
Length of the pruned branches (m)	1.27 ± 0.42	0.30	2
Biomass per plant (kg ha^{-1})	47.25 ± 15.36	26	73
Fresh matter (t ha^{-1} year^{-1})	2.36	1.3	3.65
Post-harvest moisture (%)	27.00 ± 0.86	-	-
Dry matter (t ha^{-1} year^{-1})	1.42	-	-

Table 2. Morphometric values of plants and dimensional characteristics of hazelnut groves pruning (Giffoni cultivar).

	Average Values ± St. Dev.	Min. Value	Max. Value
Plant height (m)	4.25 ± 0.52	2.95	5.3
Diameter of the main sucker (cm)	2.73 ± 0.95	1.5	6.27
Lenght of the main sucker (m)	1.23 ± 0.28	0.67	1.87
Diameter of the secondary suckers (cm)	1.69 ± 0.53	0.79	3.55
Lenght of the secondary suckers (m)	1.04 ± 0.31	0.59	1.77
Diameter of the pruned branches (cm)	1.60 ± 0.72	0.67	3.23
Length of pruned branches (m)	0.51 ± 0.24	0.18	1.16
Biomass per plant (kg)	4.17	3.6	5.5
Fresh matter (t ha^{-1} $year^{-1}$)	1.67	1.44	2.2
Post-harvest moisture (%)	46.15 ± 1.23	-	-
Dry matter (t ha^{-1} $year^{-1}$)	0.90	-	-

3.2. Moisture Content of the Raw Materials and Pellets

After the storage in the bins, the moisture content of the refined raw materials was 11% for hazelnuts and 11.45% for the olive.

The densification phase led to a reduction in the moisture content of the biomass, which went from about 11% of the refined material to about 8% of the pelletized product. Before and after the densification process, the differences in moisture content were statistically significant, with reductions of 21% for the hazelnut and 26% for the olive tree. Statistically, significant differences are also highlighted between the two types of pellets (Figure 2).

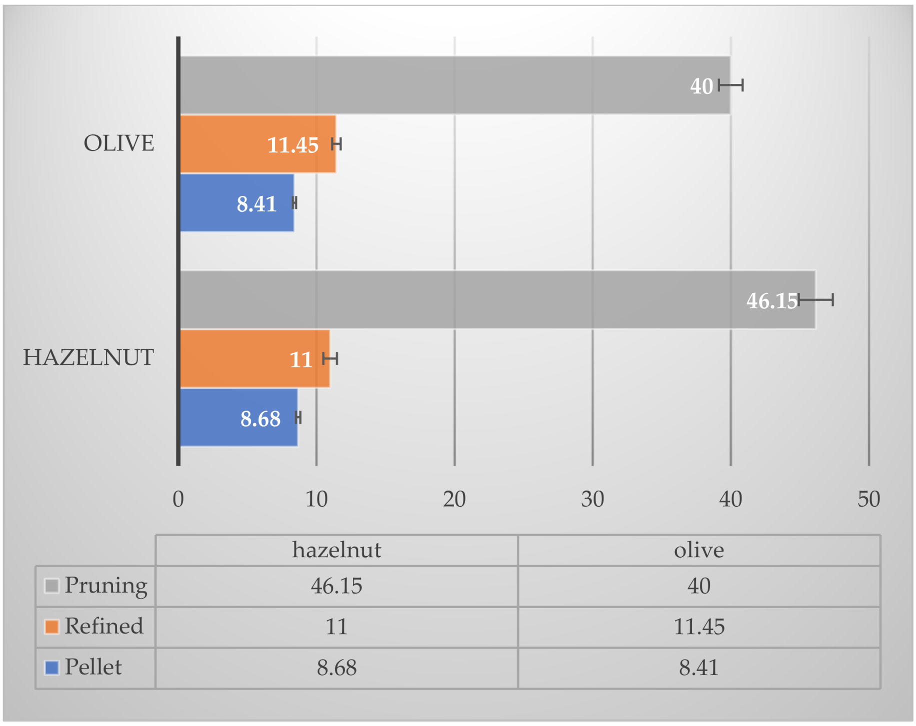

Figure 2. Moisture content (%) of the raw material (chip, refined) and pellet ± St. Dev.

3.3. Dimension, Bulk Density, and Durability of the Pellet

It is possible to notice the different coloring and dimensions of the product obtained (Figure 3). We found a higher value of bulk density for the hazelnut pellet (581.30 kg m^{-3} vs. 562.38 kg m^{-3}) and a higher value of length for the olive pellet (16.66 mm vs. 10.47 mm).

Otherwise, the diameter and the percentage of durability were very similar for both (6 mm and 98% respectively) (Table 3).

The *t*-test revealed significant differences between the two types of pellets regarding the length and the bulk density ($p < 0.05$).

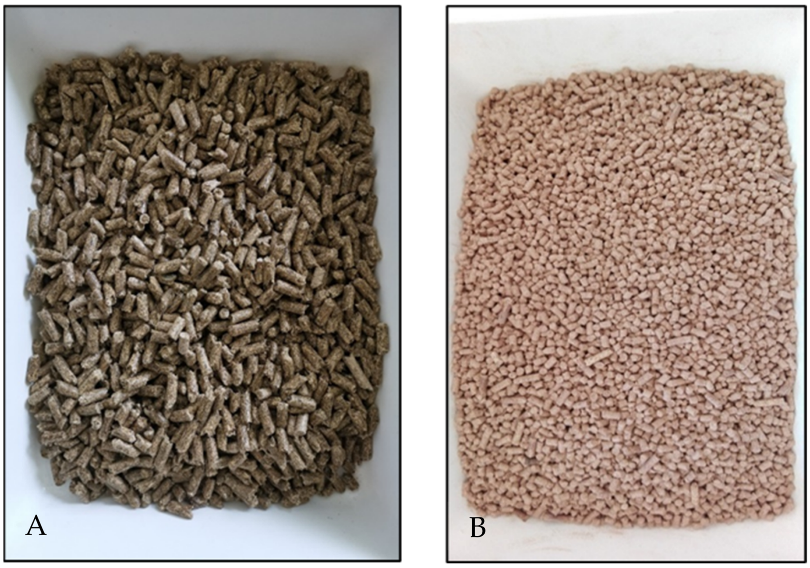

Figure 3. Olive wood (**A**) and hazelnut pellet (**B**) obtained using the 4 kW Bianco Line pelletizer.

Table 3. Length, diameter, bulk density, and durability detected for hazelnut and olive pellets. *t*-test, different letters indicate statistically significant differences ($p < 0.05$).

Pellet	Length (mm)	Diameter (mm)	Bulk Density (kg m^{-3})	Durability (%)
Hazelnut pellet	10.47 ± 2.67 ^{b}	6.20 ± 0.12 ^{a}	581 ± 3 ^{b}	98.0 ± 0.5 ^{a}
Olive pellet	16.66 ± 1.82 ^{a}	6.20 ± 0.10 ^{a}	562 ± 6 ^{a}	98.3 ± 0.6 ^{a}

3.4. Evaluation of Ash Content, Ash Melting Point and Heating Value, of Refined and Pellet

The hazelnut pellet had an ash content of 3.1%, a value higher than the olive pellets (2.5%), while the ash melting point was slightly higher for the olive pellet.

The low heating value of hazelnut and olive pellets was 17.21 MJ kg^{-1} and 16.83 MJ kg^{-1} (Table 4). The refined materials showed similar heating values, about 16 MJ kg^{-1} for both species, but the olive presented a lower ash content (2.8% vs. 3.5%) and a higher ash melting point (1440 °C vs. 1379 °C) (Table 4).

Moreover, an increase of the heating value and ash melting point was observed, in both species, passing from the refined material to the pelletized one (Table 4).

Table 4. Low heating value (Kruskal–Wallis: $p < 0.01$), ash content (Welch F-test: $p < 0.001$) and ash melting point (One-Way Anova: $p < 0.001$) of the material refined constituents for pellet. Numbers followed by different letters are statistically different ($p < 0.05$).

	Low Heating Value (MJ kg^{-1})	Ash (%)	Ash Melting Point (°C)
Pellet of hazelnut	17.21 ± 0.28 ^{b}	3.1 ± 0.6 ^{b}	1.448 ± 2.19 ^{d}
Pellet of olive	16.83 ± 0.02 ^{b}	2.5 ± 0.1 ^{a}	1.462 ± 1.82 ^{c}
Refined of hazelnut	16.18 ± 0.38 ^{a}	3.5 ± 0.1 ^{ab}	1.379 ± 3.05 ^{a}
Refined of olive	16.31 ± 0.29 ^{a}	2.8 ± 0.1 ^{a}	1.440 ± 2.77 ^{b}

3.5. Heavy Metal and C, H, N, S Content

A higher concentration of Cu, Pb, and Ni was observed in the hazelnut. The contrary was observed for the concentration of Zn (Table 5). The heavy metals content of hazelnut pellets is approximately 65% higher than in olive ones. N content was 0.77% and 1.24% for the hazelnut and the olive pellets, respectively. The content of S was 0.00% for both species.

Table 5. Content of C, H, N, S, and heavy metals in the hazelnut and olive pellet.

	C	H	N	S	As	Cd	Cr	Cu	Pb	Ni	Zn
	%				mg kg^{-1}						
Hazelnut Mean	45.07	6.97	0.77	0.00	0.02	0.02	0.21	6.10	0.21	1.21	4.51
St Dev	2.42	0.60	0.21	0.00	0.00	0.00	0.01	0.13	0.01	0.00	0.26
Olive Mean	55.02	5.42	1.24	0.00	0.05	0.00	0.19	2.93	0.00	0.06	4.88
St Dev	2.38	1.32	0.36	0.00	0.00	0.00	0.01	0.07	0.00	0.01	0.10

The 50-50 MANOVA applied to the content of C, H, N, S, and heavy metals assessed significant differences ($p < 0.001$) among the characteristics of hazelnut and olive pellets (Table 6), identifying Ni, Cd, Pb, Cu, and As the variables more significant (Table 7).

Table 6. Results of 50-50 Manova (for each biomass n° = 55). Before the test, percentages were transformed into a square root of the arcsine and data standardized. aDF: Degrees of Freedom; exVarSS: explained variances based on sums of squares; nPC: number of principal components used for testing; nBu: number of principal components used as buffer components; exVarPC: variance explained by nPC components; exVarBU: variance explained by (nPC + nBU) components; *p*-Value: the result from 50-50 MANOVA testing.

Source	*DF* [a]	*exVarSS*	*nPC*	*nBu*	*exVarPC*	*exVarBU*	*p-Value*
Biomass	1	0.803813	2	1	0.886	0.941	0.000000
Error	8	0.196187					

Table 7. Rank of the variables analyzed by rotation simulations test (for each biomass n° = 30). aRankNr: rank of the variables analyzed; pRaw: ordinary univariate *p*-values; pAdjFDR: adjusted *p*-values according to false discovery rates; p99999: adjusted *p*-values according to the familywise error rate.

rankNr[a]	varName	pRaw	pAdjFDR	p99999
1	Ni	0.000000	0.000010	0.000010
2	Cd	0.000000	0.000010	0.000010
3	Pb	0.000000	0.000010	0.000010
4	Cu	0.000000	0.000010	0.000010
5	As	0.000000	0.000012	0.000020
6	Cr	0.000149	0.000280	0.000580
7	C	0.000180	0.000216	0.000620
8–10	Zn, N, H			>0.05

4. Discussion

The number of pruning residuals was similar to the values reported in other studies [17,42–45]. The higher productivity of the olive tree could be related to the greater development of the branches, which generally characterizes this species.

We obtained the final pellet using refined material, with a moisture content of 11%. For an optimal pelletizing process and improved durability of the final pellet, it is desirable to have an average moisture content of 10% of the raw material. Indeed, previous research have established a correlation between moisture content and durability of the pellet [66–68]. The moisture of the final product is crucial because of its strong influence on the stability and final energy efficiency, and it should be less than or equal to 10% (EN ISO 17225-2) [69]

Immediately after the residuals harvesting, the moisture was substantially different between the two species, with similar values to those found in other studies [39,47,70]. The moisture values indicate the different energy costs necessary for the artificial dehydration of the two different materials. However, using the natural drying procedure implemented in the trial, both types of biomass have reached average moisture of 11%, optimal to proceed to the next pelletizing phase.

The higher bulk density found for the hazelnut pellets was probably connected to their shorter length and the different solid densities of the raw materials.

The mechanical durability of the pellets of both species showed values just over 98%, thereby meeting the prerogatives foreseen by the reference legislation (DU $\geq$ 97.5 for A1 and A2 Classes).

The heating value is the most important parameter to consider characterizing a fuel [71,72]. The values recorded for both types of pellets comply with the reference legislation, as already reported by Telmo and Lousada [71].

An excess of ash determines the reduction of the heating value. Moreover, it negatively influences the combustion of the biomass producing waste and incrustations, which cause corrosion of the combustion device. All this leads to lower plant performance and an increase in ash disposal costs [72]. The percentage of ash recorded of pellets of both species did not comply with the threshold of the current legislation, which allows the percentage of ashes up to 2% for class B.

One of the main problems of the ashes is their fusibility, caused by the high temperatures in the combustion chamber. After the melting temperature is reached, the ashes are deformed. When the device is cooled, ashes solidify, producing agglomerates that can block the grid, obstruct the air inlets inside the combustion chamber and cause malfunctions in the devices used for their elimination. Therefore, the use of fuels that have a low ash fusion temperature causes an increase in the grids' incrustation phenomena and the heat exchanger elements. The ash fusibility values of both types of pellets exceed the minimum threshold of 1200 °C, the minimum value required by the regulations.

A minimal amount of metal compounds characterize each type of biomass. The quantification of these has gained increasing attention due to the toxicological effects of the emissions produced during the combustion process on human health and the environment [73,74]. Heavy metals are normally present in biomass in traces or any case with very low concentration values (usually not exceeding 10 mg kg^{-1}). This quantity must remain low considering that the pellet obtained is normally used in reduced power plants without filters useful for reducing dust [75].

The analysis of heavy metals showed higher concentrations in the hazelnut pellet for the following elements Cd, Cr, Cu, Pb, and Ni. Cu (6.10 mg kg^{-1}) high content in the hazelnut pellet could be due to treatments carried out on the hazelnut plants, with cupric products to counteract phyto–parasitic attacks. In the olive pellets Zn and As concentrations were higher. Overall, the heavy metal content values did not exceed the values reported by the current regulations.

In the olive wood pellet, there was also a higher concentration of N. N content allowed in the pellet, according to EN ISO 17225-2 [69], should be at most equal to 0.3% for class A1, 0.5% for class A2, and 1% for class B. The value recorded for the olive pellets suggests minimal and accidental contamination of the product along the production chain, the transport and/or presence of small quantities of biomass derived from other sources [72].

We compared all the parameters analyzed and the EN-ISO references values for both species (Table 8).

The olive wood pellet did not meet three of the 16 parameters analyzed (bulk density, ash, N), while the hazelnut pellet met two (bulk density and ash). However, analyzing the single parameters, the olive wood pellet complied with nine parameters of 16. Furthermore, considering the great quantity of residual biomass from the olive groves, a further advantage is evident for this type of pellets.

During the passage in the rollers–extruder, the biomass residuals were subjected to strong pressure with an effective increase of temperature [76], which resulted in a reduction of the moisture content of the transformed material (Figure 3). Similar results were found in another work regarding the production of pellets from poplar of 3, 6, and 9 years old [54].

Table 8. Compliance of the quality parameters of the pellets produced according to the EN ISO 17225-2 classification: ✓ (complies with legislation), **X** (does not comply with legislation) **A1-A2–B** (quality classes).

Parameters	Unit of Measure	EN ISO 17225-2			Hazelnut		Olive	
		A1	A2	B				
Lenght	(mm)		3.15 < L ≤ 40		10.47	✓	16.66	✓
Diameter			6 ± 1		6.20	✓	6.20	✓
Bulk d.	(kg m^{-3})		≥600		581	X	562	X
Durability	(%)	≥97.5		≥96.5	98.05	A1	98.26	A1
LHV	(MJ kg^{-1})		≥16.5		17.21	✓	16.83	✓
Fusibility	(°C)	≥1200	≥1100		1448	A1	1462	A1
Ash	(%)	≤0.7	≤1.2	≤2	3.1	X	2.5	X
N		≤0.3	≤0.5	≤1	0.77	B	1.24	X
S (%)		≤0.04	≤0.05		0.00	A1	0.00	A1
As	(mg kg^{-1})		≤1		0.02	✓	0.05	✓
Cd			≤0.5		0.02	✓	0.00	✓
Cr			≤10		0.21	✓	0.19	✓
Cu			≤10		6.10	✓	2.93	✓
Pb			≤10		0.21	✓	0.00	✓
Ni			≤10		1.21	✓	0.06	✓
Zn			≤100		4.51	✓	4.88	✓

In recent years, numerous scientific works have analyzed the qualitative characteristics of different residual biomasses [77–80]. Table 9 summarizes some of the main chemical and energetic parameters collected in other studies focused on the pruning of vineyards and fruit trees. Comparing these values with those of the hazelnut and the olive tree, it is possible to better understand the potential offered using them to produce pellets.

Table 9. Chemical and energy parameters of pruning of different fruit species.

	Ash	HV	N	S	Cu	Zn	Pb	Ni	As	Cr	Cd
	%	MJ/kg	%	%				mg/kg			
Vineyard	4.8	17.1	0.7	0.034	21.6	31.5	0.59	9.1	<0.010	0.32	0.05
Apple tree	4.2	17.34	0.68	0.03	12.38	9.55	0.37	1.41	<0.010	0.48	0.09
Pear tree	4.3	17.63	0.86	0.026	39.7	16.2	0.49	0.59	<0.010	0.76	0.042
Almond tree	3.41	17.8	0.77	0.035	nd	nd	nd	nd	<0.010	nd	nd
Citrus tree	5.2	14.7	0.52	0.086	nd	nd	nd	nd	<0.010	nd	nd
Apricot	3.06	17.13	0.63	0.16	7.76	12.56	1.09	0.53	<0.010	0.63	0.021
Peach	2.6	17.54	0.97	0.11	156.3	13.37	1.27	0.72	<0.010	0.52	0.086
Cherry tree	2.47	17.9	0.5	<0.010	57.5	4.61	0.41	0.41	<0.010	0.54	0.01
Plum	2.73	17.88	0.67	<0.010	7.44	6.33	0.39	0.8	<0.010	6.16	0.035
Walnut	5.6	17.75	0.57	<0.010	2.65	10.13	0.61	0.67	<0.010	0.43	<0.010

A qualitative classification of each parameter was created, starting from the species with the most satisfactory values (1st) to the less satisfactory one or with data not available (12th) (Table 10).

Table 10. Qualitative classification of the parameters for each species (1st: most satisfactory values; 12th: least satisfactory values). Each species was highlighted by a different color.

	Ash	**HV**	**N**	**S**	**Cu**	**Zn**	**Pb**	**Ni**	**As**	**Cr**	**Cd**
1°	Cherry	Cherry	Cherry	**Hazelnut**	Walnut	**Hazelnut**	**Olive**	**Olive**	Wineyard	**Olive**	**Olive**
2°	**Olive**	Plum	Citrus	**Olive**	**Olive**	Cherry	**Hazelnut**	Cherry	Apple	**Hazelnut**	Cherry
3°	Peach	Almond	Walnut	Pear	**Hazelnut**	**Olive**	Apple	Apricot	Pear	Wineyard	**Hazelnut**
4°	Plum	Walnut	Apricot	Apple	Plum	Plum	Plum	Pear	Almond	Walnut	Apricot
5°	Apricot	Pear	Plum	Wineyard	Apricot	Apple	Cherry	Walnut	Citrus	Apple	Plum
6°	**Hazelnut**	Peach	Apple	Almond	Apple	Walnut	Pear	Peach	Apricot	Peach	Pear
7°	Almond	Apple	Wineyard	Citrus	Wineyard	Apricot	Walnut	Plum	Peach	cherry	Wineyard
8°	Apple	**Hazelnut**	Almond	Peach	Pear	Peach	Apricot	**Hazelnut**	Cherry	Apricot	Peach
9°	Pear	Apricot	**Hazelnut**	Apricot	Cherry	Pear	Peach	Apple	Plum	Pear	Apple
10°	Wineyard	Wineyard	Pear	Cherry	Peach	Wineyard	Wineyard	Wineyard	Walnut	Plum	Walnut
11°	Citrus	**Olive**	Peach	Plum	-	-	-	-	**Hazelnut**	-	-
12°	Walnut	Citrus	**Olive**	Walnut	-	-	-	-	**Olive**	-	-

From the classification, it was possible to deduce that the qualitative characteristics of the residual biomass of olive and hazelnut trees were optimal compared to the other species examined. Indeed, olive and hazelnut occupied the first three positions in eight parameters and six parameters, respectively. The two species were penalized for the content of nitrogen. The ash content was always above the 2% threshold for all the species. Meanwhile, five species were characterized by values between 4.2 and 5.6% and only three species with values below 3%. Instead, the heating value appears to be a limiting factor exclusively for citrus fruits (HV < 16.5 MJ kg^{-1}). Figure 4 shows the dendrogram of the hierarchical clustering analysis obtained by applying the centroid binding method in relation to the different chemical and energy characteristics [81]. The purpose of cluster analysis (Figure 4) is to group the experimental units into classes according to similarity criteria, i.e., to identify a certain number of classes with characteristics as homogeneous as possible within the classes themselves and, at the same time, as inhomogeneous as possible between the different classes. The homogeneity is highlighted in relation to the distance existing between the classes.

The dendrogram identified, at a distance of 10, five clusters:

- C1: Peach
- C2: Vineyard, Apricot, and Apple;
- C3: Cherry and Pear;
- C4: Walnut and Plum;
- C5: Olive and Hazelnut

The olive and hazelnut have a strong similarity in having the highest values in terms of Zn, Pb, S, Cr, and As.

The Apple, Apricot and Vineyard class has similar content of Cu and N, calorific value, placing itself in an intermediate position of values. The peach class is very different from the other classes, as it has high values of N, S, and Pb, but the Cu content represents the most dissimilar value.

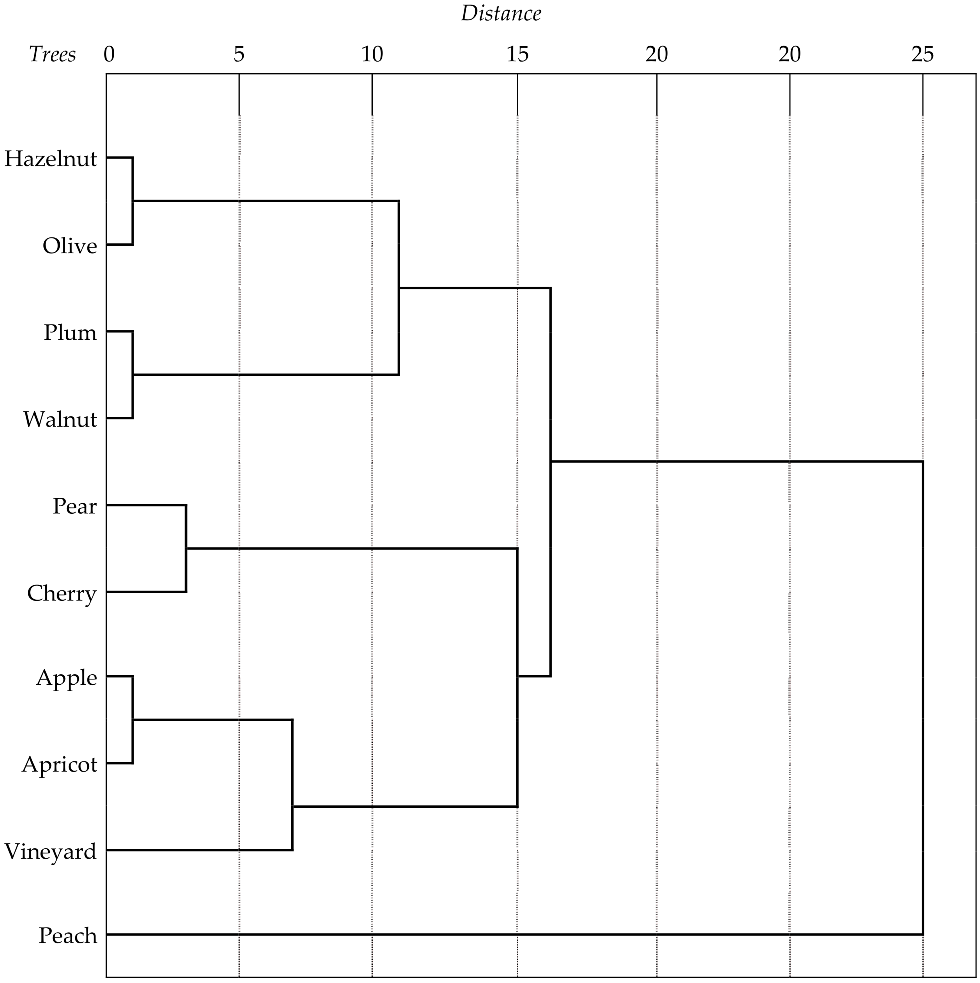

Figure 4. Dendrogram of the chemical and energy characteristics of the different types of pruning.

5. Conclusions

Our results show that it would be possible to obtain good quality pellets using hazelnut and olive tree pruning as raw material and regarding achievable profitability and potential energy. The analyzed pellets satisfy the indications provided for class A1 for diameter and length, moisture content, fusibility of the ashes and heating value, and heavy metals, the S content, and durability. Instead, regarding the ash content, nitrogen (only for olive pellets), and bulk density, the measured values do not comply with legislative directions for residential and industrial use.

The most critical parameters are the bulk density and the ash content. However, the bulk density values are not very far from the minimum threshold of 600 kg m^{-3} and, presumably, by using more performing pellet mills, this criticality could be overcome. The ash content remains the most critical issue as the measured values are very high.

However, the critical issues highlighted above could be bypassed considering the possibility of mixing this material with woods of other species to reach the quality classes A1 and A2 [82–84] and using an industrial-scale device to mill the residues [52,53]. If the mixing of materials allows compliance with the standard requirements, pellets of hazelnut and olives could be a good choice for entering the biofuel market for companies located in important production areas.

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References

1. Padilla-Rivera, A.; Barrette, J.; Blanchet, P.; Thiffault, E. Environmental Performance of Eastern Canadian Wood Pellets as Measured Through Life Cycle Assessment. *Forests* **2017**, *8*, 352. [CrossRef]
2. IPCC Climate Change. *Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2007.
3. IEA (International Energy Agency). *Energy Technology Perspectives*; International Energy Agency: Paris, France, 2010.
4. Barbosa, A.; Brusca, I. Governance structures and their impact on tariff levels of Brazilian water and sanitation corporations. *Util. Policy* **2015**, *34*, 94–105. [CrossRef]
5. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF (accessed on 10 December 2020).
6. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources. 2030 Climate and Energy Frameworks. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=fr (accessed on 15 December 2020).
7. Di Blasi, C.; Tanzi, V.; Lanzetta, M. A study on the production of agricultural residues in Italy. *Biomass Bioenergy* **1997**, *12*, 321–331. [CrossRef]
8. Bernetti, I.; Fagarazzi, C.; Fratini, R. A methodology to anaylse the potential development of biomass-energy sector: An application in Tuscany. *For. Policy Econ.* **2004**, *6*, 415–432. [CrossRef]
9. Beccali, M.; Columba, P.; D'Alberti, V.; Franzitta, V. Assessment of bioenergy potential in Sicily: A GIS-based support methodology. *Biomass Bioenergy* **2009**, *33*, 79–87. [CrossRef]
10. Velázquez-Martí, B.; Fernández-González, E.; López-Cortés, I.; Salazar-Hernández, D.M. Quantification of the residual biomass obtained from pruning of trees in Mediterranean olive groves. *Biomass Bioenergy* **2011**, *35*, 3208–3217. [CrossRef]
11. Scarlat, N.; Blujdea, V.; Dallemand, J.-F. Assessment of the availability of agricultural and forest residues for bioenergy production in Romania. *Biomass Bioenergy* **2011**, *35*, 1995–2005. [CrossRef]
12. Moliner, C.; Arato, E.; Marchelli, F. Current Status of Energy Production from Solid Biomass in Southern Italy. *Energies* **2021**, *14*, 2576. [CrossRef]
13. Jones, G.; Loeffler, D.; Calkin, D.; Chung, W. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. *Biomass Bioenergy* **2010**, *34*, 737–746. [CrossRef]
14. Tziolas, E.; Manos, B.; Bournaris, T. Planning of agro-energy districts for optimum farm income and biomass energy from crops residues. *Oper. Res.* **2016**, *17*, 535–546. [CrossRef]
15. Velázquez-Martí, B.; Fernández-González, E. Analysis of the process of biomass harvesting with collecting-chippers fed by pick up headers in plantations of olive trees. *Biosyst. Eng.* **2009**, *104*, 184–190. [CrossRef]
16. Tumuluru, J.S. Effect of process variables on the density and durability of the pellets made from high moisture corn stover. *Biosyst. Eng.* **2014**, *119*, 44–57. [CrossRef]
17. Sperandio, G.; Acampora, A.; Civitarese, V.; Bajocco, S.; Bascietto, M. Transport Cost Estimation Model of the Agroforestry Biomass in a Small-Scale Energy Chain. *Forests* **2021**, *12*, 158. [CrossRef]
18. Tumuluru, J.S.; Wright, C.T.; Hess, J.R.; Kenney, K.L. A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. *Biofuels Bioprod. Biorefining* **2011**, *5*, 683–707. [CrossRef]
19. Sánchez, J.; Curt, M.D.; Sanz, M.; Fernández, J. A proposal for pellet production from residual woody biomass in the island of Majorca (Spain). *AIMS Energy* **2015**, *3*, 480–504. [CrossRef]
20. Liu, Z.; Mi, B.; Jiang, Z.; Fei, B.; Cai, Z. Improved bulk density of bamboo pellets as biomass for energy production. *Renew. Energy* **2016**, *86*, 1–7. [CrossRef]
21. Shone, C.M.; Jothi, T.J.S. Preparation of gasification feedstock from leafy biomass. *Environ. Sci. Pollut. Res.* **2015**, *23*, 9364–9372. [CrossRef]
22. Purohit, P.; Chaturvedi, V. Biomass pellets for power generation in India: A techno-economic evaluation. *Environ. Sci. Pollut. Res.* **2018**, *25*, 29614–29632. [CrossRef]
23. Cao, L.; Yuan, X.; Li, H.; Li, C.; Xiao, Z.; Jiang, L.; Huang, B.; Xiao, Z.; Chen, X.; Wang, H.; et al. Complementary effects of torrefaction and co-pelletization: Energy consumption and characteristics of pellets. *Bioresour. Technol.* **2015**, *185*, 254–262. [CrossRef]

24. Nishiguchi, S.; Tabata, T. Assessment of social, economic, and environmental aspects of woody biomass energy utilization: Direct burning and wood pellets. *Renew. Sustain. Energy Rev.* **2016**, *57*, 1279–1286. [CrossRef]
25. Djatkov, D.; Martinov, M.; Kaltschmitt, M. Influencing parameters on mechanical–physical properties of pellet fuel made from corn harvest residues. *Biomass Bioenergy* **2018**, *119*, 418–428. [CrossRef]
26. Widjaya, E.R.; Chen, G.; Bowtell, L.; Hills, C. Gasification of non-woody biomass: A literature review. *Renew. Sustain. Energy Rev.* **2018**, *89*, 184–193. [CrossRef]
27. Muth, D.J.; Langholtz, M.H.; Tan, E.C.; Jacobson, J.J.; Schwab, A.; Wu, M.M.; Argo, A.; Brandt, C.C.; Cafferty, K.G.; Chiu, Y.-W.; et al. Investigation of thermochemical biorefinery sizing and environmental sustainability impacts for conventional supply system and distributed pre-processing supply system designs. *Biofuels Bioprod. Biorefining* **2014**, *8*, 545–567. [CrossRef]
28. Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 27 February 2021).
29. WBA. *Pellets: A Fast Growing Energy Carrier*; World Bioenergy Association (WBA): Stockholm, Sweden, 2014.
30. Dwivedi, P.; Khanna, M.; Bailis, R.; Ghilardi, A. Potential greenhouse gas benefits of transatlantic wood pellet trade. *Environ. Res. Lett.* **2014**, *9*, 024007. [CrossRef]
31. Taylor, R.E.; Butzelaar, P.; Leeuwen, G.V.; Palmer, A.; Keyes, J.; Gimenez, C.; MacDonald, B. Wood Pellet Market Outlook. In *Wood Market International Monthly Report 2013*; FEA: Littleton, MA, USA; Volume 18, Available online: www.woodmarkets.com (accessed on 20 October 2020).
32. Harun, N.Y.; Afzal, M.T. Effect of Particle Size on Mechanical Properties of Pellets Made from Biomass Blends. *Procedia Eng.* **2016**, *148*, 93–99. [CrossRef]
33. Gravelsins, A.; Muižniece, I.; Blumberga, A.; Blumberga, D. Economic sustainability of pellet production in Latvia. *Energy Procedia* **2017**, *142*, 531–537. [CrossRef]
34. Agriforenergy. Energia rinnovabile dall'agricoltura e dalle foreste. Mercati & prezzi. Anno XVI n. 3/Ottobre 2020. Available online: https://www.aielenergia.it/public/pubblicazioni/193_M_P_3-2020%20(2).pdf (accessed on 20 October 2020).
35. Magagnotti, N.; Pari, L.; Picchi, G.; Spinelli, R. Technology alternatives for tapping the pruning residue resource. *Bioresour. Technol.* **2013**, *128*, 697–702. [CrossRef]
36. Acda, M.N.; Jara, A.A.; Daracan, V.C.; Devera, E.E. Opportunities and Barriers to Wood Pellet Trade in the Philippines. *Ecosyst. Dev. J.* **2016**, *6*, 27–31.
37. GSE (Energy Services Manager). Energia da Fonti Rinnovabili. Rapporto Statistico. 2015. Available online: https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20statistico%20GSE%20-%202015.pdf (accessed on 15 June 2020).
38. Istat, V. Censimento Generale Dell'agricoltura; Roma, Italy, 2001. Available online: http://dati.istat.it/viewhtml.aspx?il=blank&vh=0000&vf=0&vcq=1100&graph=0&view-metadata=1&lang=it&QueryId=33654&metadata=DCSP_COLTIVAZIONI (accessed on 15 June 2020).
39. Acampora, A.; Croce, S.; Assirelli, A.; Del Giudice, A.; Spinelli, R.; Suardi, A.; Pari, L. Product contamination and harvesting losses from mechanized recovery of olive tree pruning residues for energy use. *Renew. Energy* **2013**, *53*, 350–353. [CrossRef]
40. Istat. Principali Coltivazioni Legnose Agrarie. 2015. Available online: https://www.regione.toscana.it/-/agricoltura-in-toscana-dati-sintetici-2015-2017 (accessed on 22 May 2020).
41. Sperandio, G.; Biocca, M.; Fedrizzi, M.; Toscano, P. Economic and technical features of different levels of mechanization in olive harvesting. *Chem. Eng. Trans.* **2017**, *58*, 853–858. [CrossRef]
42. Spinelli, R.; Picchi, G. Industrial harvesting of olive tree pruning residue for energy biomass. *Bioresour. Technol.* **2010**, *101*, 730–735. [CrossRef]
43. Romero-García, J.; Niño, L.; Martínez-Patiño, C.; Álvarez, C.; Castro, E.; Negro, M. Biorefinery based on olive biomass. State of the art and future trends. *Bioresour. Technol.* **2014**, *159*, 421–432. [CrossRef] [PubMed]
44. Secades, P.M.; Ramos, E.R.; Perdices, M.B.; Negro, M.J.; Gallego, F.J.; Linares, J.C.L.; Galiano, E.C. Residual biomass potential in olive tree cultivation and olive oil industry in Spain: Valorization proposal in a biorefinery context. *Span. J. Agric. Res.* **2017**, *15*, 6. [CrossRef]
45. Di Giacinto, S.; Longo, L.; Menghini, G.; Delfanti, L.M.P.; Egidi, G.; De Benedictis, L.; Simone, R.; Salvati, L. Model for estimating pruned biomass obtained from *Corylus avellana* L. *Appl. Math. Sci.* **2014**, *8*, 6555–6564. [CrossRef]
46. Petriccione, M.; Ciarmiello, L.F.; Boccacci, P.; De Luca, A.; Piccirillo, P. Evaluation of 'Tonda di Giffoni' hazelnut (*Corylus avellana* L.) clones. *Sci. Hortic.* **2010**, *124*, 153–158. [CrossRef]
47. Colorio, G.; Tomasone, R.; Pagano, M.; Cedrola, C.; Sperandio, G. Residui di potatura di nocciolo raccolti con Comby TR 160. *Suppl. L'Informatore Agrar.* **2009**, *33*, 28–30.
48. Monarca, D.; Cecchini, M.; Colantoni, A. Plant for the Production of Chips and Pellet: Technical and Economic Aspects of an Case Study in the Central Italy. *Comput. Sci. Appl.* **2011**, *6785*, 296–306. [CrossRef]
49. Toscano, G.; Alfano, V.; Scarfone, A.; Pari, L. Pelleting Vineyard Pruning at Low Cost with a Mobile Technology. *Energies* **2018**, *11*, 2477. [CrossRef]
50. Ilari, A.; Toscano, G.; Foppa Pedretti, E.; Fabrizi, S.; Duca, D. Environmental Sustainability of Heating Systems Based on Pellets Produced in Mobile and Stationary Plants from Vineyard Pruning Residues. *Resources* **2020**, *9*, 94. [CrossRef]

51. Colantoni, A.; Paris, E.; Bianchini, L.; Ferri, S.; Marcantonio, V.; Carnevale, M.; Palma, A.; Civitarese, V.; Gallucci, F. Spent coffee ground characterization, pelletization test and emissions assessment in the combustion process. *Sci. Rep.* **2021**, *11*, 1–14. [CrossRef]
52. Costa, P.; Dell'Omo, P.P.; La Froscia, S. Multistage milling and classification for improving both pellet quality and biogas production from hazelnut and olive pruning. *Ann. Chim. Sci. Matériaux* **2018**, *42*, 471–487. [CrossRef]
53. Bianchini, L.; Costa, P.; Dell'Omo, P.; Colantoni, A.; Cecchini, M.; Monarca, D. An Industrial Scale, Mechanical Process for Improving Pellet Quality and Biogas Production from Hazelnut and Olive Pruning. *Energies* **2021**, *14*, 1600. [CrossRef]
54. Civitarese, V.; Acampora, A.; Sperandio, G.; Assirelli, A.; Picchio, R. Production of Wood Pellets from Poplar Trees Managed as Coppices with Different Harvesting Cycles. *Energies* **2019**, *12*, 2973. [CrossRef]
55. Bergström, D.; Israelsson, S.; Öhman, M.; Dahlqvist, S.-A.; Gref, R.; Boman, C.; Wästerlund, I. Effects of raw material particle size distribution on the characteristics of Scots pine sawdust fuel pellets. *Fuel Process. Technol.* **2008**, *89*, 1324–1329. [CrossRef]
56. *EN ISO 18134-1: Solid Biofuels–Determination of Moisture Content–Oven Dry Method*; ISO: Geneva, Switzerland, 2015.
57. *EN ISO 17828: Solid Biofuels–Determination of Bulk Density*; ISO: Geneva, Switzerland, 2016.
58. *EN ISO 17829: Solid Biofuels–Determination of Length and Diameter of Pellets*; ISO: Geneva, Switzerland, 2016.
59. *EN ISO 18122: Solid Biofuels–Determination of Ash Content*; ISO: Geneva, Switzerland, 2016.
60. *EN ISO 21404: Solid Biofuels–Determination of Ash Melting Behaviour*; ISO: Geneva, Switzerland, 2020.
61. *EN ISO 18125: Solid Biofuels–Determination of Heating Value*; ISO: Geneva, Switzerland, 2018.
62. *EN ISO 17831–1: Solid Biofuels–Determination of Mechanical Durability of Pellets and Briquettes. Part 1: Pellets*; ISO: Geneva, Switzerland, 2016.
63. *EN ISO 16968: Solid Biofuels–Determination of Minor Elements*; ISO: Geneva, Switzerland, 2015.
64. *EN ISO 16948: Solid Biofuels–Determination of Total Content of Carbon. Hydrogen and Nitrogen*; ISO: Geneva, Switzerland, 2015.
65. *EN ISO 16994: Solid Biofuels–Determination of Total Content of Sulfur and Chlorine*; ISO: Geneva, Switzerland, 2016.
66. Samuelsson, R.; Thyrel, M.; Sjöström, M.; Lestander, T.A. Effect of biomaterial characteristics on pelletizing properties and biofuel pellet quality. *Fuel Process. Technol.* **2009**, *90*, 1129–1134. [CrossRef]
67. Filbakk, T.; Skjevrak, G.; Høibø, O.; Dibdiakova, J.; Jirjis, R. The influence of storage and drying methods for Scots pine raw material on mechanical pellet properties and production parameters. *Fuel Process. Technol.* **2011**, *92*, 871–878. [CrossRef]
68. Whittaker, C.; Shield, I. Factors affecting wood energy grass and straw pellet durability—A review. *Renew. Sustain. Energy Rev.* **2017**, *71*, 1–11. [CrossRef]
69. *EN ISO 17225–2: Solid Biofuels–Fuel Specifications and Classes–Part 2: Graded Wood Pellets*; ISO: Geneva, Switzerland, 2016.
70. Acampora, A.; Croce, S.; Gallo, P.; Assirelli, A.; Pari, L. Comby TR200 alla prova su residui di potatura di nocciolo. *Suppl. L'Informatore Agrar.* **2013**, *43*, 27–30.
71. Telmo, C.; Lousada, J. Heating values of wood pellets from different species. *Biomass Bioenergy* **2011**, *35*, 2634–2639. [CrossRef]
72. Toscano, G.; Riva, G.; Pedretti, E.F.; Corinaldesi, F.; Mengarelli, C.; Duca, D. Investigation on wood pellet quality and relationship between ash content and the most important chemical elements. *Biomass Bioenergy* **2013**, *56*, 317–322. [CrossRef]
73. Ružinská, E.; Štollmann, V.; Hagara, V.; Jabło´nski, M. Analysis of selected heavy metals in biomass for preparation of biofuels—Part I. Toxicological effects of heavy metals. *Ann. Wars. Univ. Life Sci. SGGW For. Wood Technol.* **2015**, *92*, 383–389.
74. Kovacs, H.; Szemmelveisz, K. Heavy metal contaminated biomass combustion as treatment after phytoremediation—A review. *Mater. Sci. Eng.* **2016**, *41*, 69–78.
75. Obernberger, I.; Thek, G. Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass Bioenergy* **2004**, *27*, 653–669. [CrossRef]
76. Castellano, J.M.; Gomez, M.; Fernández, M.; Esteban, L.S.; Carrasco, J.E. Study on the effects of raw materials composition and pelletization conditions on the quality and properties of pellets obtained from different woody and non woody biomasses. *Fuel* **2015**, *139*, 629–636. [CrossRef]
77. Cichy, W.; Witczak, M.; Walkowiak, M. Fuel Properties of Woody Biomass from Pruning Operations in Fruit Orchards. *Bioresources* **2017**, *12*, 6458–6470. [CrossRef]
78. Winzer, F.; Kraska, T.; Elsenberger, C.; Kötter, T.; Pude, R. Biomass from fruit trees for combined energy and food production. *Biomass Bioenergy* **2017**, *107*, 279–286. [CrossRef]
79. Mondragón-Valero, A.; Velázquez-Martí, B.; Salazar, D.M.; Lopéz-Cortés, I. Influence of Fertilization and Rootstocks in the Biomass Energy Characterization of Prunus dulcis (Miller). *Energies* **2018**, *11*, 1189. [CrossRef]
80. Picchi, G.; Lombardini, C.; Pari, L.; Spinelli, R. Physical and chemical characteristics of renewable fuel obtained from pruning residues. *J. Clean. Prod.* **2018**, *171*, 457–463. [CrossRef]
81. Johnson, S.C. Hierarchical clustering schemes. *Psychometrika* **1967**, *32*, 241–254. [CrossRef] [PubMed]
82. Lajili, M.; Limousy, L.; Jeguirim, M. Physico-chemical properties and thermal degradation characteristics of agropellets from olive mill by-products/sawdust blends. *Fuel Process. Technol.* **2014**, *126*, 215–221. [CrossRef]
83. Lajili, M.; Jeguirim, M.; Kraiem, N.; Limousy, L. Performance of a household boiler fed with agropellets blended from olive mill solid waste and pine sawdust. *Fuel* **2015**, *153*, 431–436. [CrossRef]
84. Barbanera, M.; Lascaro, E.; Stanzione, V.; Esposito, A.; Altieri, R.; Bufacchi, M. Characterization of pellets from mixing olive pomace and olive tree pruning. *Renew. Energy* **2016**, *88*, 185–191. [CrossRef]