Characterization and Feasibility of Fruit Tree Pruning for Energy Use

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Abstract. Extremadura region (Spain) produces more than 44,000 hectares of fruit trees. It is the leading autonomous community in plum production and the fourth in peach production. Its cultivation generates significant amounts of pruning that are not used. In this work, a characterization of different types of fruit tree prunings and a study of the necessary pre-treatments for their energy-efficient use are carried out. Samples of four types of fruit tree (plum (*Prunus domestica*), peach (*Prunus persica*), loquat (*Eriobotrya japonica*) and nectarine (*Prunus persica var. nucipersica*)) were subjected to a series of analyses to determine their energy properties as a biofuel. In addition, the different samples were subjected to a series of pre-treatments, such as drying and chipping. The results showed that, in general, pruning residues can be used in the form of chips in medium and large thermal equipment, as their ash content impedes their efficient use in small domestic equipment. Among the samples analyzed, plum tree prunings have slightly better characteristics than the other fruit tree prunings studied.

Keywords: Fruit-tree pruning · Biomass · Thermal use · Characterization

1 Introduction

In Spain, there are extensive agricultural areas in which significant quantities of waste are generated as a result of the normal development of the activity. Although important advances have been made in the management of certain biomass waste, there are no global solutions applicable to all of them and, even today, certain by-products can still generate environmental problems if they are not managed appropriately. This is the case of fruit tree waste.

The Spanish fruit and vegetable sector is of great importance to the country's economy. According to data from the European Statistical Office EUROSTAT, Spain was the country with the largest area of fruit trees in the European Union in 2017. Spain accounted for 33% of a total of 1,409,000 ha of fruit trees in the EU (422,800 ha). At a considerable distance behind were Italy and Poland, with 22 and 13%, respectively.

Specifically, the Autonomous Community of Extremadura has a total of 44,042 ha of cultivated fruit trees. It is the leading Autonomous Community in plum production (78,500 t) and fig production (18,755 t), third in walnut production and fourth in

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peach production. The latter is the most cultivated fruit species in Spain, with a total of 84,000 ha, of which just over 9,000 ha (11%) are in Extremadura and provide an annual production of 146,153 t [1].

In the management of pruning waste, field burning without energy recovery has traditionally been the most widespread procedure. This option causes carbon dioxide emissions into the atmosphere, loss of organic matter in agricultural systems and fire hazards. Another problem is that to carry out controlled burning, the pruning residues must first be accumulated and left to dry for some time on the farm, which leads to the appearance of pests.

As an alternative, revaluation as biofuel can be considered, for which pruning residues are subjected to a series of pre-treatments until they are suitable for energy use.

The use of biofuels in agricultural activities today has many advantages, not least of which is that their use does not imply a reduction in agricultural land [2]. In addition to this, the continuous increase in the use of biofuels to meet energy demand has led biomass companies to start looking for new products, such as residues from agricultural and agro-industrial activities and their combinations [3, 4].

Concerning the use of waste as biomass, although there are numerous references in the field of forestry residues [5, 6], this is not the case for the use of agricultural crop residues in general and fruit pruning residues in particular. In this respect, the results obtained in the EuroPruning and uP_Running projects, coordinated by the Centre for Research on Energy Resources and Consumption (CIRCE), should be highlighted. These projects demonstrated the technical, economic, social and environmental feasibility of using certain agricultural prunings for energy purposes, which is in line with the objectives of this work. The quantification of prunings, as well as collection logistics, have been the main focus of these projects [7].

In this work, an energy characterization of prunings from different fruit trees and a study of several necessary pre-treatments (drying and chipping) are carried out so that they can be used as biofuels in small thermal generation equipment.

2 Materials and Methods

2.1 Biomass Characterization

All samples used were collected from the soil after winter pruning of fruit trees in the area of Badajoz (Spain). The collected samples are composed of fruit tree branches less than 2 cm thick. The varieties analyzed, the most common in the area, were those indicated in Table 1.

Characterization analyses were carried out on all the samples listed in Table 2, according to the corresponding standards.

Fixed carbon is calculated on a dry basis by subtracting volatile matter and ash content from 100.

2.2 Drying Tests

Drying tests for fruit tree pruning were carried out through a convective dryer (CE130, Gunt Hamburg), composed of four removable stainless steel trays, a drying channel (to

Table 1. Types of fruit trees used in the work.

Fruit tree pruning
Plum tree (*Prunus domestica*)
Peach tree (*Prunus persica*)
Nectarine tree (*Prunus persica var. nucipersica*)
Loquat tree (*Eriobotrya japonica*)

Table 2. Standards used in the analyses carried out.

	Standard
Moisture	UNE-EN ISO 18134-2:2017 [8]
Volatile matter	UNE-EN ISO 18123:2016 [9]
Ash	UNE-EN ISO 18122:2016 [10]
Calorific value	UNE-EN ISO 18125:2018 [11]
Bulk density	UNE-EN ISO 17828:2016 [12]
Carbon, hydrogen, nitrogen	UNE-EN ISO 16948:2015 [13]
Sulphur, chlorine	UNE-EN ISO 16994:2017 [14]
Sodium, potassium	UNE-EN ISO 16967:2015 [15]

heat the product and remove moisture), flow control through a heatable fan, and a digital balance to record weight loss.

Around 250 g of waste was spread on each of the four trays (1 kg in total), so that the thickness of the sample on each tray was less than 1 cm. Several tests were carried out, with different drying air velocities (v = 0.8, 1.2 and 1.6 m/s) and temperatures (T = 30, 40 and 50 °C). Tests that were carried out are shown in Table 3.

Table 3. Drying test carried out.

	FTP1	FTP2	FTP3	FTP4	FTP5	FTP6	FTP7	FTP8	FTP9
v (m/s)	0.8	0.8	0.8	1.2	1.2	1.2	1.6	1.6	1.6
T (ºC)	30	40	50	30	40	50	30	40	50

Through experimental tests, the moisture ratio was obtained. Using Fick's diffusion equation for flat geometry, the characteristic dimension and properties of the product, effective diffusivity, and activation energy parameters were calculated.

Effective diffusivity is a fundamental parameter in drying processes. Using experimental tests, it is possible to obtain the moisture ratio, MR, by direct taking. The variation of this ratio is closely associated with Fick's diffusion equation. The analytical solution of Fick's second law for flat geometry and long periods y MR values < 0.6 [16, 17] can be simplified and obtain Eq. 1:

$$MR = \frac{8}{\pi^2} \cdot exp\left(-\frac{\pi^2 D_{eff} t}{L^2}\right) \tag{1}$$

where D_{eff} is the effective diffusivity (m^2/s), L is the characteristic dimension of the "thin layer" product (m), and t is the drying time (s).

To determine the effective diffusivity in the studied byproduct, drying analysis was carried out for various temperatures (30 °C, 40 °C and 50 °C) and different inlet airflow (0.8 m/s, 1.2 m/s and 1.6 m/s) in the convective dryer previously mentioned.

The activation energy, E_a, is the minimum energy required to produce a chemical reaction. In this case, is the minimum energy required to start the drying process. Generally, activation energy and pre-exponential factor are been considered constant. If the values of LN (D_{eff}) versus 1/T (K^{-1}) are represented, it is possible to identify them by a linear relationship in the temperature range selected. The value of the slope of the line represented coincides with the value of E_a/R. So that it can obtain the values of the activation energy of the byproducts studied.

2.3 Chipping Tests

To compare different methods of particle size reduction, several chipping trials were carried out with two different chippers: a blade chipper and a roller mill.

Table 4 shows the characteristics of the equipment used.

Table 4. Characteristics of the chipping equipment used.

	Model	Weight (kg)	Engine	Nominal Power (kW)
Blade chipper	Cip Line B25 E4	170	Three-phase asynchronous	4
Roller mill	GeoTech ESB 2803 Roller	30	Single-phase	2.8

Three types of tests were carried out, one with the blade chipper and two with the roller mill. In the second case, one test was carried out with the minimum aperture and the other with the maximum aperture. A determined amount of sample was manually introduced into the equipment, and the time of the test and the power consumption of the equipment was recorded with a network analyzer.

3 Results and Discussion

3.1 Biomass Characterization

Table 5 shows the results of the proximate analysis of the samples used in this study.

Table 5. Proximate analysis.

Fruit tree pruning	Volatile matter (% db)	Fixed carbon (% db)	Ash (% db)	Moisture (% wb)
Plum tree (*Prunus domestica*)	84.88	11.27	3.85 ± 0.15	29.64 ± 4
Peach tree (*Prunus persica*)	82.48	15.05	2.47 ± 0.4	35.31 ± 0.5
Nectarine tree (*Prunus persica var. nucipersica*)	82.74	13.81	3.45 ± 0.3	45.02 ± 0.6
Loquat tree (*Eriobotrya japonica*)	78.60	17.16	4.24 ± 0.5	53.31 ± 0.5

Moisture varies depending on the time the samples have been collected and the weather conditions. In this case, pruning was carried out in December and all moisture analysis was done two days after collection.

Given the results shown in Table 5, it can be seen that the ash percentage of the samples is slightly high in all cases. This situation will harm the use of these by-products in small thermal equipment with a minimum ash collection capacity. In this sense, it is recommended to use them in higher power equipment in the tertiary or industrial sector, with an acceptable capacity to be able to manage the ash adequately. In addition, the ash percentage data are very close to those shown for other species used for thermal use, such as miscanthus or switchgrass [18, 19]. However, the pruning of plum trees with larger branches has a lower percentage of ash, as it has a lower proportion of bark in its composition. In this respect, it would be recommended for thermal use compared to other options.

Both volatile matter and fixed carbon values are similar to each other and very similar to other similar by-products.

Table 6 shows the results of the elemental analysis performed on the samples. No significant variations from typical lignocellulosic biomass pruning values are observed.

Table 7 compiles the values of bulk density and high heating values for all samples.

Taking into account the bulk density, if the effect of moisture weight is eliminated, it can be indicated that plum prunings have the highest bulk density (dry basis), reaching approximately 141 kg/m^3, as opposed to loquat (dry basis) with 119 kg/m^3.

The high heating values indicate the similarity between them, as all samples are made up of small fruit tree branch prunings. There are slight variations between the different types, but these are not significant. This fact leads to the conclusion that the calorific value of the samples analyzed is not a differentiating factor in favor of one of the options.

Table 6. Ultimate analysis.

Fruit tree pruning	C (% db)	H (% db)	N (% db)	S (% db)	Na (% db)	K (% db)	Cl (% db)
Plum tree (*Prunus domestica*)	44.51	7.01	0.28	0.03	0.028	0.082	0.039
Peach tree (*Prunus persica*)	45.82	7.14	0.45	0.02	0.005	0.233	0.096
Nectarine tree (*Prunus persica var. nucipersica*)	45.82	7.14	0.45	0.02	0.005	0.274	0.015
Loquat tree (*Eriobotrya japonica*)	45.06	7.01	1.31	0.05	0.005	0.219	0.130

Table 7. Bulk density and High Heating Value.

Fruit tree pruning	Bulk density (% ar)	HHV (kcal/kg)
Plum tree (*Prunus domestica*)	194.50 ± 30	4217
Peach tree (*Prunus persica*)	201.11 ± 30	4223
Nectarine tree (*Prunus persica var. nucipersica*)	231.02 ± 30	4260
Loquat tree (*Eriobotrya japonica*)	255.83 ± 30	4252

3.2 Drying Tests

Due to the similarity of characteristics between the different samples, it was decided to carry out the drying tests (as well as the chipping tests) using only plum prunings. The pruning of this fruit tree was considered to be the most representative, since there are larger quantities available, as it is the most widespread crop of this type in the Autonomous Community of Extremadura. In addition, it is the type of fruit tree that is maintained in the area, as the other varieties are disappearing because the plum is a fruit that is less dependent on seasonality, being more interesting to produce than the others.

Figure 1 shows the moisture ratio concerning drying time for each of the temperatures and air flows studied.

As expected, drying of fruit tree pruning (FTP) is produced in a shorter period of time the higher the temperature of the experiment is. For the same temperature, the drying process is slower the lower the airflow is. In this way the highest speed in the decrease in moisture ratio is achieved in the FTP9 test, obtaining the lowest value in the FTP1 test.

The values of D_{eff} and LN (D_{eff})are shown in Table 8. Comparing D_{eff} values obtained in this work with those suggested by other authors for other agricultural by-products

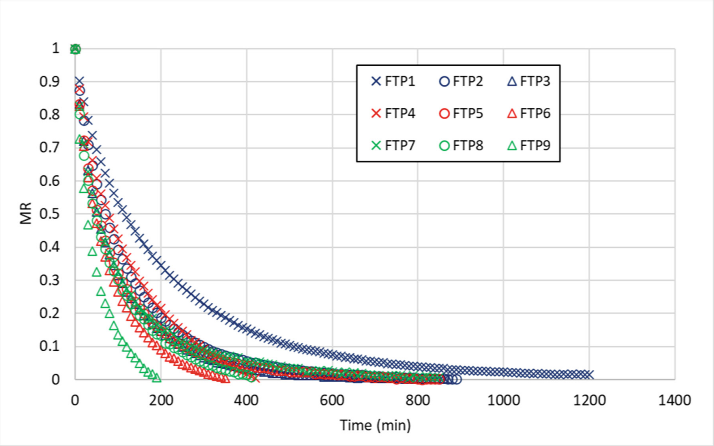

Fig. 1. Moisture ratio MR vs drying time.

[20, 21], the olive mill by-products, for example, present values, in natural convection at 40 °C, about $2.1 \cdot 10^{-10}$ for olive pomace, about $1.1 \cdot 10^{-10}$ for olive sludge and about $4.1 \cdot 10^{-10}$ for olive mill wastewater [20, 21].

Table 8. Effective diffusivity and its LN.

	D_{eff}	LN (D_{eff})
FTP1	2.82955E-09	−19.683149
FTP2	6.34411E-09	−18.87574
FTP3	5.71668E-09	−18.979878
FTP4	9.01462E-09	−18.524418
FTP5	6.23831E-09	−18.892556
FTP6	1.37035E-08	−18.105612
FTP7	4.85644E-09	−19.142959
FTP8	8.62744E-09	−18.568318
FTP9	1.8065E-08	−7.829288

The value of the slope of the line represented by LN (D_{eff}) and 1/T (K^{-1}) coincides with the value of E_a/R. Thus, it is possible to obtain the values of the activation energy of the byproduct studied. These values are shown in Table 9.

E_a values obtained by other authors for agricultural by-products are, in kJ/mol: olive pomace 91.35 [20], olive sludge 14.04 [20], olive mill wastewater 77.15 [20] or vegetable waste 19.82 [17], for example.

Table 9. Activation energy (kJ/mol).

For 0.8 m/s	For 1.2 m/s	For 1.6 m/s
29.0250054	16.549017	13.4074732

3.3 Chipping Tests

Figure 2 shows the results for the different chipping operations carried out.

Fig. 2. Resulting product. Blade chipper (left), roller mill: minimum aperture (centre), maximum aperture (right).

The chips resulting from the blade chipper have a smaller and more homogeneous grain size than the others. It can be considered the sample that achieved the highest quality considering its size and particle size distribution.

From the tests carried out with the roller mill, the particle size was approximately the same in both cases, but with greater heterogeneity and a greater presence of large particles in the test carried out with the maximum roller aperture. As the aperture was

Table 10. Results of the chipping tests.

Fruit tree pruning	Average power output (kW)	Testing time (s)	Consumed energy (kWh)	Chipped weight (kg)	Bulk density (kg/m^3)	Efficiency (kWh/kg)
Blade chipper	1.778	366	0.181	10.750	198.8	0.017
Roller mill (minimum aperture)	0.724	770	0.155	5.308	233.47	0.029
Roller mill (maximum aperture)	0.623	642	0.121	5.110	175.33	0.024

so large, on numerous occasions, the prunings passed through the rollers without the rollers exerting any action against the branches.

Table 10 shows the results of the chipping tests.

The most relevant result is that the highest efficiency is achieved with the roller mill (minimum aperture) with a value of 0.029 kWh/kg, almost double the efficiency obtained by the blade chipper.

Figure 3 shows the instantaneous power values over the elapsed time of each test. It can be seen that the values of the two roller mill tests are practically the same, while the blade chipper values are much higher.

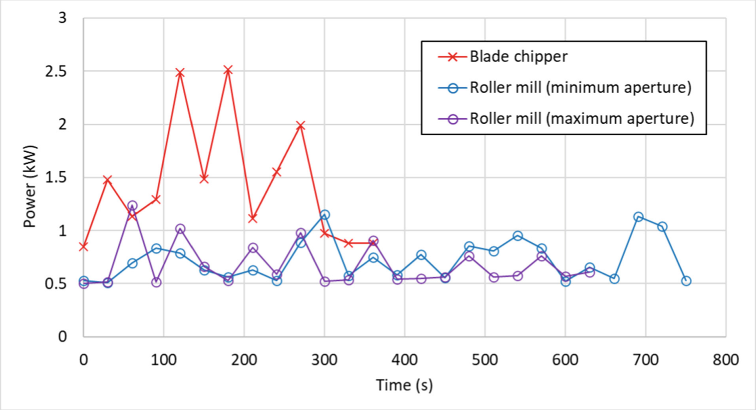

Fig. 3. Instantaneous power values from chipping tests.

It is difficult to compare the chipping results of such small electric chippers as they are not found in the literature. On the other hand, there are studies on the chipping of small Power-Take-Off driven chippers [22].

4 Conclusions

Fruit tree prunings can be used as biofuel in medium-sized domestic heating equipment. The ash percentage is somewhat high for use in smaller equipment. However, they have optimal thermal properties, like HHV.

In order to be used in domestic thermal equipment, it is necessary to undergo a series of pre-treatments, mainly drying and chipping.

Given the results obtained in tests of drying, from the point of view of heat utilization, the drying could be a solution for further use as a biofuel.

The most efficient chipping test of those carried out in this study was achieved with the blade chipper. The chipping of prunings improves logistics and adds value to the waste to be used as biofuel.

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