

Article

# Control of Invasive Forest Species through the Creation of a Value Chain: *Acacia dealbata* Biomass Recovery

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**Abstract:** In Portugal, some species are now considered invasive by law and have proliferated in recent years. Among these, *Acacia dealbata* stands out. This work investigated the behavior of this species, in order to characterize and evaluate its potential as raw material for biomass pellets production, while controlling its proliferation. It was found that *A. dealbata* has a large capacity for raw material supply, as cutting 2 ha resulted in about 140 tons of biomass. Thus, the attribution of a market value for this material could result in a reduction in the area occupied by the invasive species, once the demand for it increases, causing a pressure over the resource. This pressure on the species must be duly followed by other control measures, such as reducing the population and mitigating its proliferation. Laboratory tests have shown that both the raw material and the finished product are similar to those obtained with other species normally used for biomass pellet production, such as *Pinus pinaster* and *Eucalyptus globulus*. Thus, it can be concluded that there is a high potential for this species in the production of biomass pellets for energy, and that this may be an important contribution to controlling the proliferation of this invasive species.

**Keywords:** *Acacia dealbata*; biomass energy; biomass pellets; invasive species; value chain

## 1. Introduction

Actually, the current situation created by the climate change scenario enhanced a set of phenomena that, somehow, affect the normal development of the natural environment, altering it, and conditioning its evolution [1–3]. In this way, these changes, which directly influence meteorological variables associated with climate, such as rainfall or insolation, will contribute to the alteration of the growth profiles of native species, harming them in detriment of others, exotic, that eventually can be more adapted to the new situation, and, for this reason, more able to react quickly, occupying the habitats [4–6]. The development of these alien species has a highly negative impact on biodiversity, jeopardizing the evolution of ecosystems in a natural way, enhancing the substitution of native species, often with a monoculture trend, reducing the number of species present in a given habitat [7–9].

Some species have the ability to adapt to new edaphoclimatic conditions and to acquire invasive behavior [10–12]. However, in the majority of the cases regarding the introduction of invasive species, the aim was to achieve some sort of commercial purpose, such as the massive production of a certain raw material, rather than through the mere ignorance of those who introduced them inadvertently [13–15]. This is often supported by a purely economic view of the forest, or the use of species to fulfill

some indirect objective, such as the stabilization of roads and highway slopes or the lowering of groundwater levels, where attention is only paid to the intended remedy, not to the ecological and biological components of the method used [16–18]. In this perspective, *Acacia dealbata* presents itself as a problem in several regions of the planet, as shown by Nentwig et al. (2018) [19]. In Portugal there are also many references that can be found about the invasion by this species, where the dispersion processes, the effects on biodiversity, the impacts on the soil, or the behavior facing fire are reported [20–23].

It is also possible to find in the literature many examples of how the introduction of species occurred, such as the several situations described in the works presented by Lorenzo et al. (2010), Lorenzo et al. (2017), Lazzaro et al. (2014), or Lorenzo et al. (2012) with *A. dealbata* [24–27]. Another example that can be described, occurred in Portugal during the 1980s, when a rumor that an industrial unit for tannin extraction and concentration would be set up in Palmela, located near Setúbal, in southern Portugal, most likely to supply the growing wine industry of that time. With this information, many landowners in the nearby regions rushed to start planting *A. dealbata*, especially on the Pegões floodplains region. Over time and due to the failure of the industrial project, the population of *A. dealbata* grew and even began to expand to neighboring areas, creating a large area of monoculture that occupied thousands of hectares, as no other species was able to survive with such a high density of *A. dealbata* [18,28].

Almost 40 years later, and with the need to return the occupied land to other crops, notably for the cultivation of orchards, vineyards, and stone pine forests, landowners began a campaign for the eradication of *A. dealbata*. On a specific site, in a property called “Herdade de Santo Isidro”, where a company occupies an area of approximately 40 ha, and which operates a forest species production garden, a project has been developed for the cutting and grubbing up from the roots the entire area. Taking advantage of this project, the available biomass per hectare was quantified, as well as its characterization for potential use as an energy resource, specifically for its viability for the production of biomass pellets.

There are already some works on the dispersion processes of *A. dealbata*, such as the works presented by Rodriguez et al. (2017), or the work presented by Lada et al. (2019) on the influence of climatic factors on growth and capacity to sequester CO<sub>2</sub>, where *A. dealbata* is also analyzed. However, no specific growth model was found for *A. dealbata* populations outside the original habitats [29,30]. In this way, the present study appears as innovative, since it presents, although still in a preliminary way, an evaluation of the growth rates and the potential of generation of biomass of the species, since it allows the quantification of the potential of space occupation outside the habitats where the species originated. Similar studies have been carried out and presented previously, but always referring to the territories of origin, in Australia, where they frequently relate the growth and dispersion of acacias and their relationship with other species, namely their impact on animal communities, such as in the work presented by Trouvé et al. (2019) [31]. On the other hand, a study presented by Aguilera et al. (2015), deals with the shade tolerance of *A. dealbata* in Mediterranean forest ecosystems of South America, but only addresses the relationship between luminosity and species growth after germination [32]. In fact, the question of the cutting of acacias can, itself, contribute to the spread of the invasion, as described by Lorenzo et al. (2010), where cutting can boost regrowth, increasing the number of growing specimens that will, in the future, be responsible for the production of seeds [24]. This large number of seeds, which have the capacity to resist for long periods of time until conditions allow the germination, has been pointed out, for example in the work by Passos et al. (2017), as one of the main causes for being so difficult to control this species [33].

The objective of the present work was to characterize the exotic species *A. dealbata*, considered invasive in Portugal, regarding its potential as a raw material for the production of biomass pellets for energy. This characterization comprised four stages, distributed as follows:

- 1st Stage—laboratory characterization of the raw material;
- 2nd Stage—production of biomass pellets on a laboratory scale;
- 3rd Stage—production of biomass pellets on an industrial scale;
- 4th Stage—combustion tests.

## 2. Materials and Methods

### 2.1. Collection and Preparation of the Samples

For the realization of this study, 2 ha occupied exclusively by *A. dealbata* were selected, delimited, and cut. This delimitation was intended to quantify the total existing biomass per hectare. All the biomass was cut, baled, and then sent by truck (as shown in Figure 1) to an experimental wood pellets production unit located in the municipality of Oliveira de Azeméis (North Portugal). It is important to note that the distance between the point where the biomass was collected and the industrial unit where it was analyzed and processed is approximately 290 km. This distance is only acceptable because it is a test, since in a normal situation, similar to what happens with other forms of residual biomass, such as forest residues resulting from sanitary thinning operations in maritime pine forests, or the selection of poles in eucalyptus plantations, this biomass must be consumed locally. The issues related to biomass logistics are decisive for the viability of waste recovery projects, since the usual disadvantages such as the low density of materials, the low calorific value, and the high moisture content, make transport responsible for a significant part of the costs associated with the process [34]. Upon arrival at the industrial unit, the batches were inspected and weighed, and then unloaded at the raw material storage facility, where samples were randomly collected from all trucks transporting the biomass to the industrial unit. Ten trucks were used to transport a total of 140 tons.



**Figure 1.** The material was cut and baled in order to facilitate transport, but also to ensure that all the material collected on the ground was transported to the company for weighing, processing, and analysis.

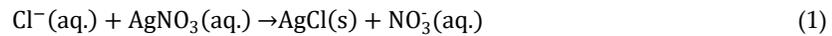
The weight of the samples that were collected in the industrial unit storage park was approximately 5 kg per truck. These samples were later crushed and mixed to homogenize the sample. Then, the materials were characterized in the laboratory and later pelletized on a laboratory scale, before moving on to the industrial scale production test. In this sampling process, all the constituent parts of the plant were collected, namely trunks with bark, branches, and leaves, since, given the young age of the plants to be cut, the separation of the different constituent parts would be impossible.

## 2.2. Laboratory Analysis

### 2.2.1. Chlorine Content

Chlorine is usually present in biomass in low concentrations; however, during combustion, chlorine acid is formed, which can lead to corrosion in the furnace. Therefore, it is crucial to determine the torrefaction temperature that eliminates this component. Chloride titration was the method chosen to determine the chlorine content, and the equipment used was a Titrator 7000 from SI Analytics. The sample preparation involved the digestion of the sample, performed in a MDS-6G microwave from Sineo, as the titration requires a liquid sample.

This method consists of measuring the potential difference, while the titrant, in this case,  $\text{AgNO}_3$ , is added. Equation (1) presents the redox reaction that occurs. Following titration, the software creates a spreadsheet with the potential difference and titrant volume variation over time. The first derivative can then be calculated through Equation (2), and consequently, the equivalence point can be determined as the volume corresponding to the maximum of the first derivative.



$$f'(x) = \frac{\Delta U}{\Delta V} = \frac{U_i - U_{i-1}}{V_i - V_{i-1}} \quad (2)$$

where  $\Delta U$  is the potential difference variation in mV, and  $\Delta V$  is the volume variation in mL. The chlorine content on a dry basis is then determined by Equation (3), in compliance with the standard EN15289.

$$W_{\text{Cl, db}}(\%) = \frac{(C - C_0) \times V}{m} \times 100 \times \frac{100}{100 - M_{\text{ad}}} \quad (3)$$

where  $C$  is the concentration of the chloride in the solution in mg/L,  $C_0$  is the concentration of chloride in the blank solution in mg/L,  $V$  is the volume of the solution in L,  $m$  is the mass of the test portion used in the digestion in mg, and  $M_{\text{ad}}$  is the moisture content in the analysis test sample in %.

### 2.2.2. Major and Minor Elements

Inductively coupled plasma optical emission spectrometry (ICP-OES) is an analytical technique, that produces excited atoms and ions that emit electromagnetic radiation at different wavelengths for the determination of trace elements. The main advantages are its multielement capability, broad dynamic range, and effective background correction. For the preparation of the samples, microwave digestion was necessary to ensure that the capillaries did not become obstructed.

The model used for the sample analysis was the iCAP 6000 series from Thermo Scientific. A peristaltic bomb delivers the digested samples to an analytical nebulizer, which is then introduced into the plasma flame. The sample is broken down into charged ions and eventually gives off radiation at the characteristic wavelengths of the elements involved. In the end, the software of the device generates a spreadsheet with all the results. Equations (4) and (5) were used to calculate the content of each element in the sample on a dry basis to guarantee compliance with the standards EN15289, EN15290, and EN15297.

$$w_{i, \text{db}}(\text{mg/kg}) = \frac{(C_i - C_{i,0}) \times V}{m} \times \frac{100}{100 - M_{\text{ad}}} \quad (4)$$

$$w_{\text{S, db}}(\%) = \frac{(C - C_0) \times V}{m} \times 0.3338 \times 100 \times \frac{100}{100 - M_{\text{ad}}} \quad (5)$$

where, for Equation (4),  $C_i$  is the concentration of the element in the diluted sample digest in mg/L,  $C_{i,0}$  is the concentration of the element in the solution of the blank experiment in mg/L,  $V$  is the volume of the diluted sample digest solution in mL,  $m$  is the mass of the test portion used in g, and  $M_{\text{ad}}$  is the moisture content in the analysis test sample in %; and where, for Equation (5),  $C_i$  is the concentration of the sulphate in the solution in mg/L,  $C_{i,0}$  is the concentration of the sulphate in the solution of the

blank experiment in mg/L,  $V$  is the volume of the diluted sample digest solution in mL,  $m$  is the mass of the test portion used in g, 0.3338 is the stoichiometric ratio of the relative molar masses of sulfur and sulphate, and  $M_{ad}$  is the moisture content in the analysis test sample in %.

### 2.2.3. Elemental Analysis

The elemental analysis was performed in a Leco CHN628 Carbon/Hydrogen/Nitrogen analyzer. The operation principle consists of weighing a sample into a tin foil that is later placed in the autoloader. The sample is then introduced to the primary furnace containing pure oxygen, which results in fast and complete combustion.

The carbon, hydrogen, and nitrogen present in the sample are oxidized to carbon dioxide ( $\text{CO}_2$ ), water ( $\text{H}_2\text{O}$ ), and  $\text{NO}_x$ , respectively, and are swept by the oxygen carrier gas through into a secondary furnace for further oxidation and particulate removal. The detection of  $\text{H}_2\text{O}$  and  $\text{CO}_2$  occurs through separate optimized non-dispersive infrared cells, while the  $\text{NO}_x$  gases are reduced to N. Lastly,  $\text{N}_2$  is detected when the gas passes through a thermal conductivity cell. After the analysis is complete, the moisture content obtained through the thermogravimetric analysis is introduced into the software, and the carbon, hydrogen, and nitrogen contents are automatically calculated. Following that, it is possible to estimate the oxygen content on a dry basis ( $w_{\text{O,db}}$ ) from Equation (6).

$$w_{\text{O,db}}(\%) = 100 - w_{\text{C,db}} - w_{\text{H,db}} - w_{\text{N,db}} - w_{\text{S,db}} - w_{\text{Cl,db}} \quad (6)$$

where  $w_{\text{C,db}}$  is the carbon content on a dry basis in %,  $w_{\text{H,db}}$  is the hydrogen content on a dry basis in %,  $w_{\text{N,db}}$  is the nitrogen content on a dry basis in %,  $w_{\text{S,db}}$  is the sulfur content on a dry basis in %, and  $w_{\text{Cl,db}}$  is the chlorine content on a dry basis in %. This procedure is in compliance with the standard EN 15104.

### 2.2.4. Proximate Analysis

Proximate analysis by thermogravimetry enables the study of the mass loss of the sample, in a controlled environment, as a function of the temperature. The thermogravimetric analyzer used during this project was the Eltra Thermostep model. One gram of each sample is introduced into crucibles and placed inside the oven, along with an empty reference crucible. As the temperature rises, the crucibles are weighed on a precision scale. Moisture, volatiles, and fixed carbon content are determined in this order throughout the heating process. Lastly, the final residue represents the ash content.

### 2.2.5. Heating Value

The heating value, also known as the calorific value, defines the energy content of biomass fuel. This parameter can be described in two ways: The higher heating value (HHV), or gross calorific value, refers to the heat released from the fuel combustion along with the vaporization energy from the water; and the lower heating value (LHV), or net calorific value, is based on steam as the product, which means its vaporization energy is not considered as heat. The heating value of biomass, both higher and lower, can be determined experimentally by employing an adiabatic bomb calorimeter. The model used in this project was the 6400 Automatic Calorimeter from Parr Instrument.

After each procedure, the equipment provides the corrected temperature rise which is later used for the determination of the heating value. As a result of the nitrogen and oxygen rich atmosphere inside the calorimeter, nitric and sulfuric acid are formed, respectively, and the heat from the formation of both acids must be disregarded. For the  $\text{HNO}_3$ , the wash water for the pump was titrated with NaOH 0.1 M, and Equation (7) was applied; while for the  $\text{H}_2\text{SO}_4$ , the knowledge of the sulfur content is enough to utilize Equation (8).

$$Q_{\text{N,S}} = 1.43 \times V_{\text{NaOH}} \quad (7)$$

where  $Q_{\text{N,S}}$  is the heat contribution relative to nitric acid formation in calories, and  $V_{\text{NaOH}}$  is the volume of NaOH spent in the titration of the wash water of the pump in mL.

$$Q_{S,add} = 13.61 \times w_{S,db} \quad (8)$$

where  $Q_{S,add}$  is the additional contribution relative to sulfur dioxide formation in calories, and  $w_{S,db}$  is the sulfur content on a dry basis in %. Following this, Equation (9) can be applied to obtain the gross calorific value at constant volume ( $q_{V,gr}$ ) in J/g.

$$q_{V,gr} = \left( \frac{\varepsilon \times \theta - Q_{thread} - Q_{N,S}}{m} - Q_{S,add} \right) \times 4.1868 \quad (9)$$

where  $\varepsilon$  is the calorific capacity of the calorimeter (previously determined) in cal/°C,  $\theta$  is the corrected temperature rise in °C,  $Q_{thread}$  is the heat contribution relative to the thread combustion in calories,  $Q_{N,S}$  is the heat contribution relative to nitric acid formation in calories,  $Q_{S,add}$  is the additional contribution relative to sulfur dioxide formation in cal, and  $m$  is the mass of the sample in g. Equation (10) is used to calculate the gross calorific value at constant volume on a dry basis ( $q_{V,gr,db}$ ) in J/g.

$$q_{V,gr,db} = q_{V,gr} \times \frac{100}{100 - M_{ad}} \quad (10)$$

where  $q_{V,gr,db}$  is the gross calorific value at a constant volume in J/g, and  $M_{ad}$  is the moisture content in the analysis test sample in %. Net calorific value at constant pressure on a dry basis ( $q_{p,net,db}$ ) in J/g can be calculated through Equation (11).

$$q_{p,net,db} = q_{V,gr,db} - 212.2 \times w_{H,db} - 0.8 \times (w_{O,db} + w_{N,db}) \quad (11)$$

where  $q_{V,gr,db}$  is the gross calorific value at a constant volume on a dry basis in J/g,  $w_{H,db}$  is the hydrogen content on a dry basis in %,  $w_{O,db}$  is the oxygen content on a dry basis in %, and  $w_{N,db}$  is the nitrogen content on a dry basis in %. It should be noted that the oxygen content used in Equation (11) is not the same as the one calculated in Equation (6). According to EN14918,  $(w_{O,db} + w_{N,db})$  is obtained from Equation (12).

$$(w_{O,db} + w_{N,db}) = 100 - w_{A,db} - w_{C,db} - w_{H,db} - w_{S,db}, \quad (12)$$

where  $w_{A,db}$  is the ash content on a dry basis in %,  $w_{C,db}$  is the carbon content on a dry basis in %,  $w_{H,db}$  is the hydrogen content on a dry basis in %, and  $w_{S,db}$  is the sulfur content on a dry basis in %.

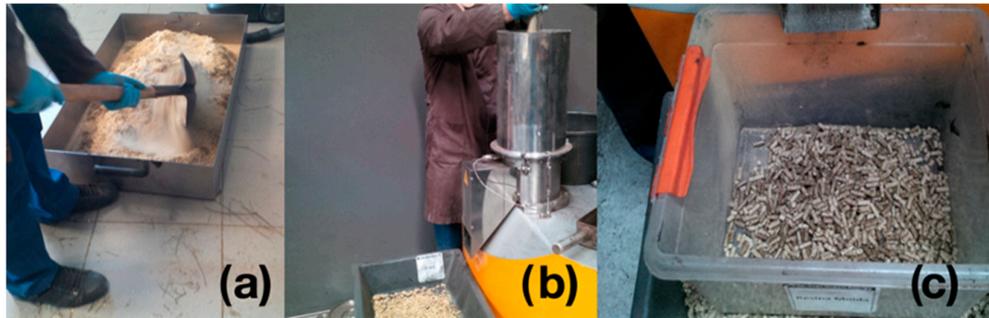
### 2.2.6. Ash Fusibility Test

Ash samples were prepared by igniting biomass samples in a muffle furnace at 550 °C (BS EN 14775). The digestion of the ashes was performed in a microwave oven with H<sub>2</sub>O<sub>2</sub>, HNO<sub>3</sub> and HF in a heating ramp. Subsequently, acids were neutralized with H<sub>3</sub>BO<sub>3</sub> and heated again. After the ash digestion procedure, the determination of the major elements was achieved with an ICP-OES instrument (iCAP 6000 Series—Thermo Scientific, Waltham, MA, USA).

Ash fusibility was examined with imaging sintering point-testing equipment (Sylab-IF2000-G) and the measurements were carried out following ISO 540 and ASTM D1857. Ash samples for the fusibility test were obtained by igniting the biomass in a muffle furnace at 550 °C, then shaping it into cylinders. Ash fusion temperature measurements were performed with a maximum temperature of 1500 °C, in the presence of an oxidizing atmosphere. Throughout the testing process, the different phases of the ash fusibility (initial deformation temperature—IDT; softening temperature—ST; hemisphere temperature—HT; and fluid temperature—FT) were recorded according to the shapes of the ash.

### 2.3. Laboratorial Scale Pellet Production

In the second stage, pellets were produced using laboratory scale equipment, and the density, humidity, lower heating value (LHV), and ash content were characterized. Figure 2 shows the sequence of the biomass preparation tasks, with the homogenization phase of the previously ground material, which later went on to the pelletization phase. In this process, as previously mentioned, all parts of the plant were used, namely, bark, branches, and leaves.



**Figure 2.** Pellet production process using a KAHL laboratory scale pelletizing machine with a production capacity of 25 kg/h. (a) The mixing process for homogenizing the product to be pelletized, mainly to ensure that the humidity is uniform; (b) the equipment used to produce the pellets; (c) the final result. The pellets were produced exclusively with *Acacia dealbata* biomass.

#### 2.4. Industrial Scale Pellet Production

In the production test of biomass pellets on an industrial scale, a line with a production capacity of 1200 kg/h was used. It is a conventional line, with two stages of fine grinding, being a wet grinding and a dry grinding, that is, before and after drying the material, with the objective of fixing the maximum particle size  $< 6$  mm, with the  $d_{50}$  being 3.15 mm. The material was dried to reach a moisture content of approximately 10–12%. The pelletizer used in the test was a LaMeccanica machine, with a horizontal axis ring die, with two rollers. Subsequently, the produced pellets were cooled using a water-cooled double-walled screw conveyor and bagged. Figure 3 shows the equipment used in pelletizing and the product already bagged.



**Figure 3.** The production of pellets in industrial scale test. (a) The equipment used in the test: a LaMeccanica pelletizer with a production of 1200 kg/h; and (b) the produced pellets bagged and ready to be consumed in domestic equipment.

#### 2.5. Combustion Test

In the fourth stage, about 50 tons of these pellets were consumed in a biomass industrial boiler to assess the fuel efficiency, while the remainder were bagged in 15 kg packages, as previously presented in Figure 3b, and used in household equipment to verify its quality as a fuel. This verification of the quality of the pellets was, in this work, made through the comparison with the consumption that the users had of conventional biomass pellets, bought in the market as being produced only with *Pinus pinaster* wood (maritime pine). In this comparative study, the collaboration of an industrial pine resin processing unit was requested in order to obtain data on high-performance equipment.

The collaboration of 20 domestic users was also requested, who used the *A. dealbata* pellets in domestic boilers and stoves. In all situations, the users indicated similarity in the consumptions obtained with the pellets of *A. dealbata*, in comparison with the consumptions that were verified with the previously used pellets, of maritime pine wood.

### 3. Results

#### 3.1. Laboratory Analysis

The results obtained in the laboratory analysis of the biomass samples of *A. dealbata* are shown in Table 1.

**Table 1.** Results obtained in the laboratory analysis.

Laboratory Analysis	Parameter	Result	
Elemental analysis CHN (% db) (EN 15104)	C	48.2	
	H	5.79	
	N	0.314	
Chlorine content (% db)	Cl	0.04	
	Al	3.44	
	Ba	0.27	
	Ca	55.6	
	Cd	0.002	
	Co	0.003	
	Cr	0.02	
	Cu	0.04	
	Fe	1.44	
	K	16.1	
	Element content (% db) (Sample digestion for ICP based on EN 15105, EN 15289, EN 15290, and EN 15297)	Mg	7.08
		Mn	0.69
		Na	3.90
		Ni	0.01
		Pb	0.03
		Zn	0.49
As *		-	
Si		10.9	
P *		-	
S *		-	
Ti *	~		
Thermogravimetric analysis (% db)	Ashes (EN 14775)	0.663	
	Volatiles (EN 15148)	79.745	
	Fixed carbon (by calculation)	19.563	
	Moisture (EN 14774-3)	0.646	
Heating value (MJ/kg db) (EN 14918)	High Heating Value (HHV)	19.297	
	Low Heating Value (LHV)	18.032	
Ash fusibility test (°C) (CEN/TS 15370-1, in reducing atmosphere)	Initial deformation temperature (IDT)	662	
	Softening temperature (ST)	1270	
	Hemisphere temperature (HT)	1292	
	Fluid temperature (FT)	1320	

\* The contents of As, P, S, and Ti presented values below the detection limit (% < 0.001).

#### 3.2. Laboratorial Scale Pellet Production

The results obtained in the laboratory analysis of *A. dealbata* biomass pellets produced using a laboratory scale equipment are shown in Table 2.

**Table 2.** Characterization of the density, moisture, lower heating value (LHV), and ashes of lab scale pellets as received.

Parameter	Result
LHV (MJ/kg, ar)	16.95
Bulk density (kg/m <sup>3</sup> , ar)	>600
Moisture (% , ar)	8–10
Ashes (% , ar)	<1

### 3.3. Industrial Scale Pellet Production

In the third stage, and after satisfactory results were obtained in the two previous phases, the 140 tons received were processed in an industrial scale test, producing 75 tons of pellets (Figure 3). This indicates a very good conversion rate as compared to the rate normally obtained from the conversion of pinewood, which is 2 tons of raw material for 1 ton of finished product; while with *A. dealbata*, the conversion rate was 1.87 tons of raw material for 1 ton of finished product. This more favorable conversion rate, which presented an average value of 1.83 tons of raw material, for 1 ton of final product, has to do with the fact that this species has a high drying rate after cutting. That is, during the time that mediates cutting, baling packaging, forming the loader and transporting it to the industrial unit to produce pellets, moisture loss can drop from the initial 50% to average values within the range 38–42%. In addition to this aspect of the productive yield, there was also a greater ease in the pelletization process, verified through the amperage reached by the densification equipment, which presented values about 15% below those verified for the pelletization of maritime pine and eucalyptus, indicating a lower energy consumption per mass unit produced. Another aspect observed during the pelletizing process was less wear on the parts where this phenomenon usually occurs, namely on the roller shells and on the pellet mill die.

### 3.4. Combustion Test

In this test, *A. dealbata* pellets were used in an industrial boiler for heating thermal oil, replacing pellets produced exclusively with maritime pine, as is presented in Figure 4. The compared parameters were the quantity of pellets consumed, the average temperature of the furnace, and the average temperature of the thermal oil during the same period of operation of the boiler. After the test it was found that the parameters referring to the average temperature of the furnace and the average temperature of the thermal oil were similar to those verified during the use of pellets produced with maritime pine, being, respectively, 568 and 195 °C. Regarding the quantities consumed, there was an increase of approximately 5% in the same period of work, which is in line with the difference in LHV between the pellets produced with *A. dealbata* and with maritime pine, as can be seen in Table 3

**Table 3.** Comparison between the properties of the *A. dealbata* biomass and the reference values presented in the ENPlus standard.

Properties	Units	Enplus-A1	<i>P. Pinaster</i>	<i>E. Globulus</i>	<i>A. Dealbata</i>
Length	mm	3.15–35	3.15–35	3.15–35	3.15–35
Diameter	mm	6–8	6–8	6–8	6
Bulk density	kg/m <sup>3</sup>	≥600	≥600	≥600	≥600
Moisture	%	≤10	≤10	≤10	8–10

Durability	%	≥97.5	≥97.5	≥97.5	≥97.5
Ash	%	<0.7	0.603	1.236	0.663
Volatile	% (db)	---	79.55	79.85	79.75
Fixed carbon	% (db)	---	19.85	17.41	19.56
Carbon	% (db)	---	56.4	52.70	48.2
Hydrogen	% (db)	---	5.85	5.82	5.79
Nitrogen	% (db)	≥0.3	0.138	0.166	0.314
Oxygen	% (db)	---	37.61	41.31	45.70
Sulphur	% (db)	≤0.03	≤0.01	≤0.01	≤0.01
Chlorine	% (db)	≤0.02	0.01	0.02	0.04
LHV	MJ/kg (db)	16.5 ≤ LHV ≤ 19	18.36	17.56	16.95



**Figure 4.** Combustion test of the pellets in an industrial thermal oil boiler. (a) The discharge of a pellet big bag into the boiler feed system; (b) the detail of the pellet discharge; (c) the boiler where the test was conducted; (d) the detail of the “eye” of the furnace in full combustion; and (e) the boiler control unit and the operating parameters.

Combustion tests carried out by the 20 volunteers, who agreed to use the biomass pellets of *A. dealbata*, returned the information of total satisfaction with the product, without any report of problems during the use.

#### 4. Discussion

As mentioned in the introductory section, climate change has decisively affected the development of forest cover in many regions of the planet, for example, causing changes in hydrological cycles [35]. These changes in the hydrological cycle cause long periods of drought in many regions, and this lack of precipitation increases the risk of rural fires, which in turn, by destroying the forest cover composed of native species, opens the way for invasive species, many of them pyrophytes [36,37]. In addition to the issue associated with the occurrence of rural fires, there is also the possibility of the occurrence of diseases and pests, which can also contribute to the weakening and death of native species, opening spaces where invasive species can take advantage of with their heliophile character, as described in the work of Boyd et al. (2013) [38].

This capacity that these invasive species have to dominate the space very quickly, creates a greater need to find ways that allow its eradication. However, several studies, such as the presented by Baker et al. (2017) or Forsyth et al. (2018), indicate that in most cases, eradication is not possible [39,40], or else it is extremely costly, as presented in the works of Epanchin-Niell (2017), Jardine and Sanchirico (2018) or Ngorima and Shackleton (2019) [41–43]. Thus, the control of these species presents itself as an unequal struggle, where failure can only be countered by maintaining their populations at levels that do not compromise native biodiversity, knowing in advance that the costs associated with control will always be very high. For this reason, related to the financial costs associated with the control of invasive species, the possibility of valorizing the collected biomass in

some way, will allow to minimize the costs of the process, allowing its continuity and even its intensification, with the perspective of obtaining the best possible results.

It remains, however, an issue that must be raised, since the possibility of creating a value chain that justifies the collection of *A. dealbata* biomass, and that values it as a raw material for production of biomass pellets, may lead to the temptation, due to its rapid growth and potential for the supply of biomass, to be considered an energy culture and to be disseminated intentionally. In any case, in Portugal, the classification of invasive species and the ban on their dissemination has been legally prohibited since 1999, through Decree-Law No. 565/99, of 21 December, which was revised in 2019, and replaced by Decree-Law No. 92/2019, of 10 July, implementing one of the measures provided for in the National Strategy for the Conservation of Nature and Biodiversity for 2030 (ENCNB 2030), while allowing full implementation in the national legal system to the regime established by the Regulation (EU) Nr. 1143/2014, of the European Parliament and of the Council, of 22 October 2014, on the prevention and management of the introduction and spread of invasive alien species, so that the impossibility of any type of use of *A. dealbata* as a culture is guarded, which is not the result of control operations.

It is also important, when considering the possibility of creating a chain that values the biomass resulting from the collection of *A. dealbata*, that a growth model of the species is found, in order to be able to quantify the available quantities in an expeditious manner and assess the feasibility of creating the value chain. In the situation reported here, the land had been cleaned two years earlier. At the time of cutting for this test, the height of the trees, which can be measured when the bales are formed, of which an example is shown in Figure 1, is within the range of 2–6 m, while the diameters (DCH-Diameter at Chest Height) vary between 2 and 8 cm. Anyway, as mentioned, it is important to estimate the potential of a given region, in order to be able to assess the feasibility of creating a carbon neutral value chain. Tools already exist, based on satellite images or aerial and 3D data, that allow mapping the distribution of acacias that, based on data such as the size of plants and soil cover, are also able to determine the available quantities, but also, by georeferencing their location, they allow the optimization of collection routes, often reconciling with other forest products, such as maritime pine or eucalyptus. This optimization is important, since it can contribute to the reduction of logistical costs associated with the species control process. The works by Viana et al. (2010a), Martins et al. (2016), or Monteiro et al. (2017) present a set of works on discussing the potential to map acacias based on the coverage or height of plants using satellite [44–46]. The work of Große-Stoltenberg et al. (2018) presents the use of aerial and 3D data for the same purpose [47].

The quantities of biomass available in Portugal for energy have already been quantified in the work of Viana et al. (2010b). This work consisted of forest cover classification and mapping, and in the estimation of the available forest biomass and annual growth at national and regional levels, which allowed the evaluation of the geographical location of existing power plants, and the relationship between existing biomass and the power plants wood-fuel demand was examined with the application of a GIS-based analysis [48]. It is important to relate these data presented by Viana et al. (2010b) with the work of Vaz et al. (2017), since biomass is an important ecosystem service provided by the invader, since, like other species, it also contributes to carbon capture and sequestration, provides shelter for animal species, protects the soil from erosion, among others [49]. However, invasion by *A. dealbata* can also have a negative effect on the growth of populations of other species, such as the maritime pine, as described by Rascher et al. (2011), since in forest systems where water is scarcer, competition between species will favorably pend on *A. dealbata*, limiting the growth of maritime pine, reducing its productivity [50].

Regarding the creation of a chain that values the biomass of *A. dealbata*, there are several possibilities, for example, as mentioned in the example presented in the introductory section, the fact that *A. dealbata* is rich in tannins, which can be a renewable bioproduct, but which can prevent decomposition and is therefore not favorable for a scenario in which recovery is carried out using composting [51–53]. For this reason, the use of the biomass collected as raw material for the production of biomass pellets, presents itself as a promising alternative, since it can even be included

in the collection networks already implemented for other species, optimizing the logistical operations.

From the tests carried out, results were obtained that indicate the use of the biomass of *A. dealbata* for the production of pellets and its use in everything similar to what already happens with other more conventional forms of biomass, namely the maritime pine or eucalyptus. As can be seen in Table 3, where a comparison is made between the reference values of the ENPlus standard, only the value for the chlorine content is above that indicated, being about twice the reference value of the standard. In this perspective, only the maritime pine falls within the reference values, since eucalyptus also presents values above 0.02%. In other words, since it is not possible to certify pellets produced only with *A. dealbata*, it is possible to incorporate the biomass of this exotic and invasive species, together with biomass, for example, from maritime pine. This incorporation may allow the creation of a value chain that justifies the collection of this form of biomass, contributing financially to the control of the species, while creating pressure on the resource, preventing its dispersion and proliferation.

The same table also presents indicative values for the characterization of maritime pine and eucalyptus. As can be seen, the values presented by *A. dealbata* are similar to those presented by the other two species, with a difference for the chlorine content, which is higher than that presented by the maritime pine, but equivalent to that presented by eucalyptus. There is also a small difference with respect to LHV, but it falls within the values of the ENPlus standard. This small difference may indicate a slight increase in the consumption of these pellets produced with *A. dealbata*, compared to pellets produced with maritime pine and eucalyptus.

Regarding the production process, it was found that the material is much easier to pellet than the biomasses normally used in this industrial unit. This is most likely due to the fact that *A. dealbata* presents values for the lignin content slightly higher than those found for maritime pine, 34% for *A. dealbata* and approximately 25% for maritime pine, respectively [54–59].

## 5. Conclusions

It was found in this study that *A. dealbata* has a large capacity for biomass supply. This was proven by the amount obtained in the test, with the cutting of the 2 ha resulting in approximately 140 tons of material. These results indicate its potential as a valuable raw material for biomass supply.

Laboratory tests showed that both the raw material and the finished product are similar to those obtained from *P. pinaster*, another species commonly used in Portugal for pellet production; that is except for the chlorine content, which was 0.04%, whereas the content normally obtained for resinous species is less than 0.02%. Thus, it was concluded in this study that there is a high potential for this species in the production of biomass pellets for energy. However, this is a purely indicative result, since the quantity supplied to each of the participants in the test, being the domestic or the industrial end users, did not allowed a prolonged use, and the results were only the communication of satisfaction, the type of equipment used, and if the consumption was similar that previously, when wood pellets produced with other raw materials were used, namely *P. pinaster* biomass.

Despite the positive results, it cannot be forgotten that *A. dealbata* is an invasive species, and that even if a value chain is created around this source of biomass, the objective should be only to contribute to reducing the costs associated with its eradication and control.

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