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Characterization of *Cytisus striatus* (Hill) Rothm.: Waste Biomass Energy Recovery as a Measure to Reduce the Risk of Rural Fires

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Abstract: Shrub species play a critical ecological role in ecosystems, covering significant areas. However, with the current development of vegetation cover, conditioned by climate change, certain species have acquired a dominant role, which suffocates the other ecosystem species in a natural monoculture model. Thus, some species, such as *Cytisus striatus* (Hill) Rothm., have acquired preponderance, mainly due to the dense forests they establish. This situation has contributed to the increased risk of rural fires, forcing permanent actions to control the settlements. These actions entail costs that make the continuity and permanence of control unsustainable. The energetic valorization of residual biomass resulting from operations to reduce fuel load is an option that seems viable, mainly if used in the production of biomass pellets in a mixture with other biomasses, such as *Pinus pinaster* or *Eucalyptus globulus*. The laboratory characterization tests demonstrated that the residual biomass of *C. striatus* presents parameters that fall within limits defined by the standard ENPlus®. The processing of this residual biomass on an industrial scale line is also feasible. However, given the configuration of the material to be processed, production lines may be necessary, especially concerning the detachment of the material. The logistical issue may also impose restrictions since the material has a low density, even when baled.

Keywords: biomass waste; rural fires; energy recovery; forest management

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1. Introduction

Shrub species are important biological assets, constituting the largest fraction in many ecosystems like in prairies and mountainous systems, but also as transition species, forming part of the progressive sequence of grassland areas, usually where herbaceous species dominate, for understory located on the edges of forests, usually dominated by tree species [1–3]. There are many species that can fit within this group, adapted to all types of ecosystems, climates and environments [4–6]. In Portugal, there is a species that stands out for its dispersion and abundance, which in recent times assumed prominence due to the exuberant growth it presents and the way it covered extensive areas, mainly in mountainous regions, as is the case of Serra da Estrela [7–9].

Cytisus striatus (Hill) Rotham. presents extensive settlements that slowly occupied the landscape [10,11]. This species creates dense stands with the accumulation of large amounts of biomass, increasing the risk of the occurrence of rural fires during the summer, which is normally hot and dry [12,13]. In fact, *C. striatus* can create extremely dense stands with an intertwined structure carrying additional risks for the occurrence of rural fires, associated with the amount of biomass that is capable to produce in each area [10,14]. This species, despite its shrubby character, usually presents a main woody trunk, which can reach average basal diameters of 8 to 10 cm in older specimens, and are documented stands in which the plants reach heights close to 4 m [15].

In Portugal, the most extensive stands that are registered can be found in the districts of Viseu, Guarda and Castelo Branco. From those, the Serra da Estrela occurrences stand out where, for example, dense stands of *C. striatus* are visible throughout the road that connects Lagoa Comprida to Seia (EN309) with the plants forming extensive mantles, forcing permanent control actions to avoid the accumulation of fuel load. However, there are many examples of similar situations in different parts in Viseu, Guarda and Castelo Branco where the proliferation of *C. striatus* acquires greater importance. In the rest of the national territory, *C. striatus*, although abundant, does not normally appear with such intensity, except perhaps in the mountainous areas of the north of the country, such as the mountains of Gerês or Marão; but there they are slowly replaced by invasive species such as *Acacia dealbata* Link., which is also increasingly densely populated, and therefore also contributes to the increased risk of rural fires [16].

The need to control the dense stands of *C. striatus* to avoid the accumulation of fuel and thus to reduce the risk of rural fires requires that the cleaning operations be carried out with some regularity [15,17]. However, these cleaning operations lead to a set of difficulties, among which the orography of the terrain, often very hilly, makes it impossible to mechanize the operations, and the need to periodically repeat the procedures can be highlighted, given the regeneration capacity of *C. striatus* [18,19]. However, perhaps the main difficulty are the financial costs associated with the cleaning operations, which, due to these high costs, are not carried out with the required regularity to minimize the risk of rural fires [20–22].

For this reason, the creation of value chains that can add some value to the residual materials resulting from the cleaning operations of the *C. striatus* stands presents itself as a possibility that could contribute for the reduction of costs associated with the control operations [23–25]—for example, by incorporating these waste materials as raw materials in the production of biomass pellets or in the production of torrefied biomass [26–28]. These possibilities, in addition to the introduction of a circular economy component to the rural fire prevention process, would counterbalance the fact that currently these targets are no longer used for traditional practices, such as accommodation of livestock or in the production of rudimentary brooms, or even used as firewood [29–31]. In addition, the elimination of these materials would be avoided using the traditional burning of leftovers, which normally occur in the place where cleaning operations were carried out and are identified as the main cause instigating rural fires in Portugal [32–35].

Thus, the objective of this study is to proceed with the characterization of the *C. striatus* biomass to know its properties and to evaluate the potential of its use in the production of biomass pellets, but also the characterization of the pellets produced with these materials, so that they can be compared with the quality criteria presented in the ENPlus® standard.

2. Materials and Methods

The samples of *C. striatus* were collected in the municipality of Sabugal (Guarda, Portugal), having been cut with the use of motorized machinery, being subsequently loaded into a moving floor truck and transported to an industrial unit to produce biomass pellets, where laboratory characterization and pelletization tests were carried out. Figure 1 shows the preparation sequence of the material, namely through its shredding using mobile equipment brand MUS-MAX (Groß St. Florian, Austria).

Figure 1. Moments of unloading the biomass bales of *C. striatus* in the park of the industrial pellet production unit. (**a**) Truck unloading the biomass bales; (**b**) preparation of the bales for the shredding; (**c**) shredding process.

The shredding equipment uses a blade technology that is not the most suitable for destroying shrub and fibrous materials, especially when packed in light and loose bales [36,37]. However, as the amount of material was significant, at approximately 5.66 tons it was possible to maintain a constant supply to the shredder, causing the load to be high. This procedure, associated with the high speed and power of the shredder, allowed the *C. striatus* chip to have an appropriate dimension of approximately 30 mm × 10 mm × 5 mm, as maximum dimensions for the produced woodchips. This maximum value was analyzed and verified because it is the maximum dimension that the industrial equipment of the production unit could accept, in case it is intended to use biomass through the industrial process. However, this option was only adopted after the conclusion of the laboratory tests and as a way to eliminate all the surplus material, incorporating it in the biomass pellet production process.

It was also found that the chip produced had a low density when compared to the woodchips of *Pinus pinaster* or *Eucalyptus globulus*, which is usually around 450 kg m^{-3}, while that of *C. striatus* presented an average value of 190 kg m^{-3} [38,39]. It was proven that the material, which is made up of a high quantity of fines originated by the destruction of smaller woody parts, such as green leaves and stems, tended to aggregate in the presence of water, forming a paste. It was necessary to carry out the entire operation under a roof to avoid material loss during the pre-treatment operations.

Then, samples were collected at different points of the pile produced with the *C. striatus* chippings, ensuring that the collection ensured enough material for all laboratory characterization tests and allowed the production of *C. striatus* biomass pellets in the quantity that would allow their characterization. For the laboratory characterization, the standards indicated in the ENPlus® were used for further analysis, namely for calorimetry, elemental analysis, thermogravimetry and ash fusibility.

After the laboratory characterization of the chip, the material was pelletized. It was necessary to dry the material, placed on trays inside a laboratory greenhouse, at a temperature of 105 °C for 12 h, thus guaranteeing the maximum possible drying. After drying, the material was ground using a laboratory mill so that the particles had a granulometric curve as close as possible to the ideal d_{50}, i.e., d_{50} = 3.14 mm. Subsequently, the material was homogenized, and the humidity corrected so that it remained as close as possible to 12%. Figure 2 shows the sequence of operations for the pelletizing process.

Figure 2. Different stages of the pelletization process of *C. striatus* biomass. (**a**) Homogenization and correction of humidity; (**b**) pellet production; (**c**) final product.

3. Results and Discussion

The results obtained in the laboratory characterization tests for the *C. striatus* woodchips and pellets are shown in Table 1.

As can be seen, the results obtained for the thermogravimetric analysis and the elementary analysis are pretty similar to each other. In the case of ash content, there is an increase of 0.60% in the pellets of *C. striatus* concerning the woodchips, related to the fact that in the pellets, all parts of the plant were used, namely the bark and the foliage, which certainly has a greater propensity for ash formation, in line with what also occurs with other species. It is very likely that in the collection of samples of woodchips for laboratory characterization, there was a preferential selection of larger particles, of woody type, to the detriment of smaller ones, produced from the bark and foliage. The fixed carbon content presents a slight difference of 2.10%, justified by the fact that the proportion of woody material is dominant. It was found that many specimens have woody stems with large diameters, as can be seen in Figure 3 where there are examples of stems cut close to the base, in specimens of different ages, respectively, from right to left, six years, four years and three years.

Table 1. Laboratory characterization of woodchips and pellets of *C. striatus*.

Parameters	Woodchips	Pellets
Volatiles (%)	82.00	79.30
Ashes (%)	0.90	1.50
Fixed carbon (%)	17.10	19.20
C (%)	46.30	45.70
H (%)	5.02	5.23
N (%)	1.00	0.79
O (%)	47.68	48.28
LHV (MJ kg^{-1})	10.07	18.82

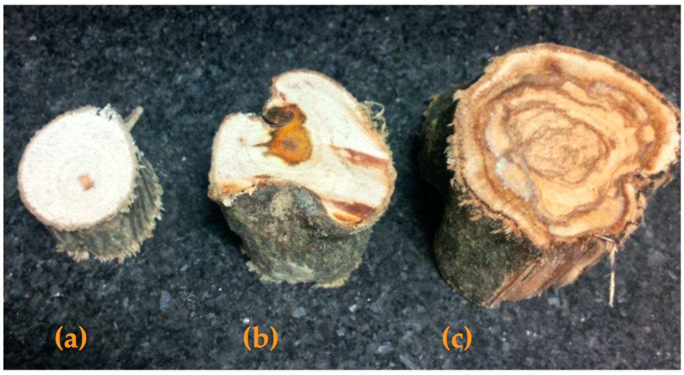

Figure 3. Specimens of *C. striatus* aged: (**a**) 3 years; (**b**) 4 years; and (**c**) 6 years.

The values obtained in the elementary analysis show values very close to each other, namely for the carbon content, which presents a slight difference of 0.6%, and in the case of the hydrogen content, which presents a difference of 0.21%. These reduced differences are more important when related to these two elements since these are the ones that most contribute to the calorific value. The nitrogen content observed, between 0.79% and 1.00%, respectively, for pellets and chippings, is relatively high, above the value admitted by the standard ENPlus®, which is $\leq$0.30%. This high value is due to *C. striatus* being a leguminous species, therefore having the ability to fix nitrogen, thus justifying the high content. The calorific value has very different values since it is a characteristic that is also related to the moisture content of the samples. In this case, the materials analyzed before pelletizing showed an average value of 52.11%, while the pellets of *C. striatus* showed a value of 8.23% moisture. Thus, the difference between the two types of material, with 10.07 MJ kg^{-1} for woodchips, and 18.82 MJ kg^{-1} for pellets, is in line with other biomasses.

The physical characterization tests performed on the pellets led to the results shown in Table 2.

Table 2. Physical properties of *C. striatus* pellets.

Parameters	Units	*C. striatus* Pellets
Diameter	(mm)	7
Density	(kg m^{-3})	594
Moisture	(%)	8.23
Mechanical durability	(%)	96.20
Fines content	(%)	3.80
Average length	(mm)	2.70

The pellets produced in the laboratory showed results slightly below what would be expected, as those presented in the ENPlus® standard [32]. In fact, in this pellet production test, a flat die pelletizing equipment was used, with 7 mm diameter holes and a 30 mm matrix thickness, while in the industrial process, matrices with 6 mm diameter holes and thicknesses of at least 45 mm are used. Figure 4 shows a diagram of the pellet mill die holes and the relationship between the elements.

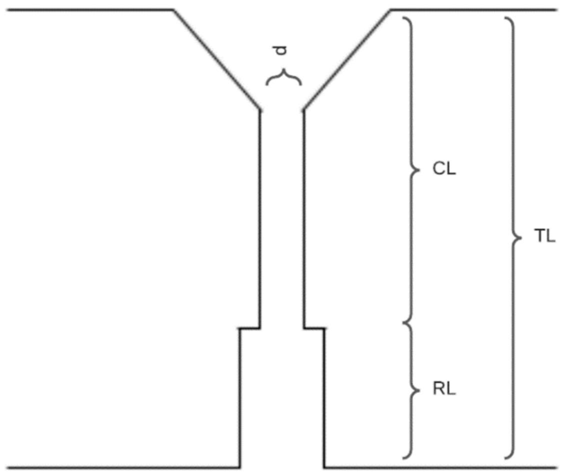

Figure 4. Diagram of the die hole and the relationship between the elements for calculating the Compression Rate (CR), where d is the diameter, CL is the compression length, RL is the relief length and TL is the total length. following relations between the elements presented in the scheme: CR = CL + RL and CR = CL/d [40].

Thus, for the pellets produced, a compression ratio of 4.29 is obtained, while for a 45 mm thick die, with holes of 6 mm in diameter, the compression ratio is 7.5. This difference justifies that the values obtained for the density of 594 kg m^{-3} are inferior to the one required by the ENPlus® standard, ≥600 kg m^{-3}. However, the value is close enough to that required by the standard to be able to be corrected by changing the matrix, so it is expected that the material has a good capacity for densification. The material density is also a determinant for durability, which the ENPlus® standard presents as a reference value, ≥97.5%. As can be seen, the value of 96.2% also seems correctable if the compression ratio of the matrix used is changed, and the same is true of the fines content, which is directly related to the durability of the pellets produced [41–45].

Concerning the ash melting temperatures, the results obtained are those shown in Table 3.

Table 3. *C. striatus* ash fusibility temperatures.

	Temperatures (°C)
Initial deformation temperature (IDT)	1163
Softening temperature (ST)	1255
Hemispherical temperature (HT)	1275
Flow temperature (FT)	1283

As shown in the temperatures obtained, namely for the softening temperature with a value of 1255 °C, these are high and fall within the admissible values by the ENPlus® standard, which is ≥1200 °C. This temperature may indicate that *C. striatus* has low Ca content, which works as a fluidizer, and indeed its combustion will present a low risk of ash sintering inside the energy recovery equipment [46–48].

After the characterization of the materials received and the production of pellets in the laboratory, all the woodchips produced, about 5.66 tons, was included in the production process of the industrial unit that collaborated in this test to analyze the behavior of the materials in an industrial line, as these presented some characteristics that differ from those of the materials that are usually used as raw materials to produce pellets in the industrial unit in question [37]. The differences verified both in the density and in the shape of the chip indicated the possibility that difficulties in handling the materials may occur [49]. Thus, the transformation of the material proceeded.

Throughout the process, there were some situations related to the fact that the material is less dense than that usually used, with an average density of 450 kg m^{-3}, causing interlocks, as presented in Figure 5a. Even after the second grinding, with the material already dry, it was found that the shape coefficient maintains an elongated structure, causing other constraints to occur mainly in areas where it is possible the accumulation of material, as is the case of the example shown in Figure 5b.

Figure 5. (**a**) Clogging caused by low density and shape coefficient occurred in the transition between the self-feeder (system feed point) and the first hammer mill; (**b**) the accumulation of material inside the auger caused the propeller to warp, forcing it to stop for repairing.

All these constraints in industrial line production, associated with the problems observed in the physical-chemical characterization of *C. striatus* biomass, point out that it is not biomass that can be energetically valued. However, despite these constraints, the indicators analyzed in the industrial process, namely the fact that it is an accessible material to pelletize, may indicate that it can be added to other materials in mixtures, allowing the dilution of less positive characteristics, such as the nitrogen content, for example, or even the ash content, in order to allow its incorporation in biomass pellets with ENPlus® certificate [50].

This possibility of incorporating residual biomass, such as *C. striatus* resulting from cleaning operations to reduce the risk of rural fires allows creating a value chain [16]. The creation of a value chain for waste materials has contributed to the costs associated with the control and cleaning of species that produce large fuel loads, such as *C. striatus*, but also others such as *Acacia dealbata* or *Hakea sericea*, being reduced [15]. In this way, with the revenues from the commercialization of the residual biomass, the control and cleaning operations can become more sustainable and regular, fulfilling its purpose, which is to mitigate the risk of the occurrence of rural fires [51–54].

4. Conclusions

Shrub species are an integral part of ecosystems and make up a significant part of the landscape. These species are also a significant part of the available fuel load and contribute to the increased risk of rural fires. This proliferation capacity requires permanent control operations as a way of reducing the risk of rural fires. However, these operations entail costs, making it impossible for the operations to be carried out as often as necessary to control the growth of these species—the creation of value chains that can minimize costs and thus guarantee the sustainability of the processes is required. The valorization of biomass of species such as *C. striatus* may be a possibility, namely through its inclusion in the production of biomass pellets, mainly if used in the production of pellets that are not intended for certification through the ENPlus® standard, since that some of the physical and chemical properties of *C. striatus* do not fall within limits imposed by the standard.

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