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Fuel characterization and biomass combustion properties of selected native woody shrub species from central Portugal and NW Spain

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HIGHLIGHTS

- ▶ Selected shrub native species from Spain and Portugal were characterized.
- ▶ Ashes of 1–2%, N > 0.6%, S < 0.1% and HHV of 21–24 MJ kg^{-1}were found.
- ▶ Alkali metal 20–30% denote potential ash bed sintering/agglomeration and fouling risk.
- ▶ ash trace elements were below most of European limits.

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ABSTRACT

Selected native shrub species from central Portugal and NW Spain, *Cytisus multiflorus* (broom), *Erica arborea* (heath), *Pterospartum tridentatum* (carqueisa) and *Ulex europaeus* (gorse) were characterized for physical, thermal and chemical properties for combustion. The studied shrub species showed ash contents in the range 1–2%, nitrogen contents above 0.6%, and sulfur contents below 0.1% at both areas of study. A significant effect of species on Higher Heating Value (HHV) was observed, with no significant effect of the location of study, central Portugal or NW Spain. The higher HHV (24.4 MJ kg^{-1}) was recorded for heath, this species also shows the higher average carbon and lower nitrogen content values of the studied species. Analysis of the chemical composition of the ashes revealed alkali metals contents of 24–30%, representing a potential sintering, fouling and bed agglomeration risk in the combustion of the studied species. Ash As, Cd, Pb, Co, Cu, Mn, Ni, Cr, and Zn content was below national and most of European legislation maximum levels for these elements for ash application as fertilizer, with the exception of some of the more conservative limits for Cd, Cu, Cr, and Zn from Northern and central European countries legislation.

1. Introduction

The interest in the utilization of forest biomass for bioenergy has increased exponentially in the last decades in European countries, as an integrated strategy for climate change mitigation, increasing renewable energy security and preventing forest fires. Consequently, Portuguese [1] and Spanish [2] National strategies, have established ambitious goals for energy production in dedicated biomass plants for CHP, resulting in a large potential biomass demand in both countries. Given the limited availability of residual forest biomass in Portugal [3] and Spain [4], joined with a growing pellet production in these two countries, potentially utilizing forest residual biomass sources [5], there is an increased interest on the consideration of alternative feedstocks for biomass combustion, such as native woody shrub species.

Shrubland areas currently occupy close to 1 million hectares in the region of Galicia, NW Spain [6] and a total of 1.9 million hectares in Portuguese territory [7]. Furthermore, abandoned shrubland areas constitute a main fuel for the frequent wildfires in these two countries: approximately half of the 1.5 and 0.2 million hectares burned by wildfires in Portugal and in the region of Galicia, NW Spain, in the period 2001–2010, were shrubland areas [8]. The regular harvesting of shrubland areas, might therefore additionally be valuable for diminishing the large greenhouse gas emissions associated to these frequent wildfires [9], through the reduction of forest fires occurrence.

In order to evaluate their potential as a biomass feedstock for combustion, there is a need for an integrated biomass and ash

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characterization for the main native species in the shrubland areas of these two countries. Available information on biomass characterization and specific combustion properties of native woody shrub species in this area, however, is relatively scarce, namely the studies by Núñez-Regueira et al. [10] and Elvira and Hernando [11] in NW and central Spain, and the studies from Fernandes and Pereira [12] and from Fernandes and Rego [13] in Portugal, among others.

Fuel calorific properties are known to be influenced by biomass composition (e.g. [14–16]), this species-specific composition being potentially influenced by growing conditions such as sunlight, geographic location, climate, soil types, available water, soil pH and nutrients [16]. Therefore, it would be of interest to study whether the different local soil and climate conditions from NW Spain and central Portugal have an effect on the calorific properties of the existing native shrub species.

Moreover, available shrub characterization studies for these native species have only focused on selected biomass physical and chemical properties such as basic density (e.g. [13]), calorific value (e.g. [11]), and/or fuel proximate and ultimate analysis (e.g. [10]). However, proximate and ultimate analysis brings relatively limited information when the chemical composition of the combusted biomass is not also considered [16], particularly given the potential ash slagging and fouling risk in biomass fuels with high mobile nutrients contents, specially alkali metals, in their ashes, which can limit boiler efficiency, even lead to bed defluidization through deposit formation and boiler corrosion (e.g. [17–19]). In spite of its relevance on combustion efficiency, slagging and fouling risk, information on the ash composition of these native shrub species is scarce, together with a scarcity of information on the ash composition for shrub species in general: for instance, neither any of the main recent reviews in fuel and ash composition (e.g. [16,19,20]), nor any of the main ash composition databases (e.g. [21–26]), include any information on shrub ashes composition and/or the associated ash slagging and fouling risk. Additionally, an integrated evaluation of the potential of shrub ashes should consider the monitoring of relevant minor and trace elements contents in the ashes, which are of particular relevance for the environmental impact of the potential ashes reutilization as fertilizer (e.g. [27–29]).

Consequently, the present work aimed to study the fuel and ash characteristics and combustion properties of the selected native shrubs *Cytisus multiflorus* (L'Hér.) Sweet (broom), *Erica australis* (L.) (heath), *Ulex europaeus* (L.) (gorse) and *Pterospartum tridentatum* (L.) Willk (carqueisa), these species being representative of the main genus present in the Mediterranean native shrubland areas of NW Spain and North-Central Portugal. The analysis of physical and thermochemical properties of the shrub biomass including: (1) basic density (Db); (2) proximate analysis, namely moisture content (w%), fixed carbon (FC%), volatile matter (VM%) and ash yield (A%); (3) ultimate analysis (C, O, H, S, N); (4) calorific value (Higher and Lower Heating Value) and (5) energy density calculation, was conducted for the four species at both areas of study. Additionally, (6) ash chemical composition, including relevant minor and trace elements contents, was analysed.

2. Material and methods

2.1. Shrub biomass measurement and sampling for fuel and ash analysis

2.1.1. Shrub biomass measurement

The areas of study were Centre – North Portugal (Area 1), extending from 39°11′53″N, 06°14′17′W to 42°50′50″N, 08°19′02″W and NW Spain (Area 2), extending from 42°56′26.06″N, 7°26′25.89W to 42°31′28.05″N, 7°31′10.41W. From June to August 2007, 22 and 32 sites were sampled in Area 1 and Area 2, respectively, for aboveground biomass determination. Within each site, occupying homogeneously at least one hectare, a sampling plot with an area of 10 m^2 was established and the aboveground biomass within that plot was clipped, placed into hermetically closed containers to prevent moisture loss and transported to the laboratory, where it was divided by species, oven dried and weighted to determine the dry aboveground biomass per hectare (t ha^{-1}).

2.1.2. Sampling for biomass and ash analysis

The selected species for study of biomass and ash characterization were: *Cytisus multiflorus* (L'Hér.) Sweet (Spanish or Portuguese white broom), *Erica australis* (L.) (Spanish or Portuguese heath), *Ulex europaeus* (L.) (common gorse or furze) and *Pterospartum tridentatum* (L.) Willk (carqueisa).

For each subject woody shrub species, 7–9 biomass samples, representative of all the sampled aboveground biomass fractions, were randomly selected from the harvested biomass for fuel and ash laboratory analyses (Section 2.2). Aboveground biomass samples included leaves and all woody fractions from aboveground biomass. In addition, in Area 1 of study, belowground root biomass samples were taken for proximate and ultimate analyses, by cutting representative small fractions of the exposed root system. Soil particles were carefully removed with high pressure water application.

All samples were prepared according to the technical specifications CEN/TS 14780:2005 [30] for sample preparation for the physical, thermal and chemical characterization of biomass.

2.2. Analytical measurements

2.2.1. Proximate analysis and basic density

Moisture content (wet basis) was determined following the European Standard CEN EN 14774-1:2009 [31]. The determination of ash content (dry basis) was carried out at 550 °C ± 10 °C according to CEN EN 14775:2009 [32] The volatile matter content (dry basis) was determined at 900 °C ± 10 °C according to CEN EN 15148:2009 [33]. Fixed carbon content (%) is the difference between the sum of volatile matter and ash contents from 100. Shrub basic density (Db) was calculated by water displacement technique and expressed as dry weight per unit volume [34].

2.2.2. Ultimate analysis

Elemental composition of shrub biomass was measured following CEN/TS 15104:2005 [35] European Standard for determining Carbon (C), Hydrogen (H) and Nitrogen (N) and CEN/TS 15289:2006 [36] for Sulfur (S) content in solid biofuels. The simultaneous determination of CHN was carried out in a Leco TruSpec Elemental Determinator. Sulfur content determination was done in a Leco SC-144DR using direct combustion and infrared detection. The oxygen content was obtained by subtracting from 100% the sum of (C, H, N, S and ash) contents in percentage.

2.2.3. Higher and lower heating values

The higher heating value (HHV), also called gross calorific value (GCV), of biomass at constant volume in dry basis was determined following the CEN EN 14918:2009 [37] The HHV in dry basis was calculated by the Eq. (1) [37]:

$$q_{v,gr,d} = q_{v,gr} \frac{100}{(100 - M_{ad})} \tag{1}$$

where $q_{v,gr,d}$ is the higher heating value at constant volume of the dry (moisture-free) fuel, in joules per gram. M_{ad} is the moisture in the analysis sample, in percentage by mass. $q_{v,gr}$ is the higher