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Statistical evaluation of quality parameters of olive stone to predict its heating value

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HIGHLIGHTS

- Olive stone energetic properties and variability of these parameters.
- Climate and geographical variability.
- Variations between olive stone quality parameters supplied by both olive-oil mills and distribution companies.
- A correlation between the ultimate analysis and higher heating values of olive stone.

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ABSTRACT

In Andalusia, residual biomass produced in the olive sector results from the large amount of olive groves and olive oil manufacturers that generate byproducts with a potentially high energy content, suitable for thermal and electrical energy production. The main residue, olive stone, is an important solid biofuel and is widely generated and consumed. Consequently, olive stone quality parameters must be studied in order to achieve an optimum energetic efficiency. Therefore, the main objective of this study is to describe olive stone energetic properties and to evaluate variability of these parameters before consumption. For this purpose, mean values, normal distributions, intervals and deviations of these parameters have been obtained and studied. Concerning to statistical results, climate and geographical variability of quality parameters has been described. Furthermore, variations between olive stone physicochemical parameters supplied by both olive oil factories and distribution companies have been calculated. Finally, a correlation between the ultimate analysis and higher heating values (HHV) of olive stone has been determined. Results obtained show that olive stone pretreatments developed by distribution companies have a significant effect on quality parameters such as moisture content and low heating value. Moreover, olive stone properties dependence on factors such as rainfall or soil type has not been confirmed. Lastly, the calculated correlation based on ultimate analysis (i.e. $HHV(MJ/kg) = 0.401C - 0.164H + 0.493N + 2.381S + 0.791$) has been developed and validated with olive stone samples with HHV range from 20 to 21 MJ/kg (dry weight). Correlation has a mean absolute error (MAE) of 0.43% and a mean bias error (MBE) of −0.12% which indicate that it can be successfully used as a more economical and faster tool to accurately estimate olive stone HHV. The HHV prediction accuracies of 14 other correlations introduced by other researchers are also compared in this study.

1. Introduction

In the European Union, amongst renewable energy sources, the largest contribution (63%) comes from biomass. Nowadays, energy from biomass already provides approximately 4% of the total EU energy supply [1]. Energy policy established by the European Union, and its adaptation in Spain and Andalusia (Southern Spanish region) aimed at promoting renewable energy use and production. Biomass must be turned into solid biofuels to be used for bioenergy production. Solid biofuels represent about 50% of the total use of renewable energies in Spain [2] becoming a real option for thermal and electrical generation as alternative to traditional generation by fossil fuels [3]. Due to its vast forest areas and mainly agricultural use of land, the potential for biomass generation in Andalusia is high as is shown in Table 1. Within this context,

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olive industry presents a high potential for solid biofuel production because of the residues generated from olive groves and those by olive oil industries. Olive groves represent over 1,400,000 hectares of Andalusian cultivated land [4] and olive oil production is over 800,000 tons/year. Moreover, olive stone is one of the most important residues generated in this sector, being produced in Andalusia over 450,000 tons/year [5]. Olive table industry generates around 30,000 tons/year of olive stone and the rest of the total amount is generated in olive oil and olive pomace oil extractor industries when the olive stone is separated from the olive pulp to obtain olive oil or olive pomace oil. 99% of olive stone produced is used as solid biofuel to thermal power generation due to its high heating value, low moisture, uniform size and high density [6].

Olive stone residues aim at being consolidated in biofuels market and being commercialized through storage and distribution companies thus guaranteeing biomass characteristics and quality parameters [7].

Biofuel characterization constitutes a substantial improvement in the valuation of these resources, allowing a rational and controlled use of their energy potential. Based on their quality parameters, solid biofuels could be managed to obtain the most efficient energetic processes [8].

Focusing on biomass thermal process sector current situation, specifically domestic heating field, most of biomass heating appliances used in Andalusia are devised on the basis of Central Europe countries knowledge. As a result, design, construction and operation of these devices are based on combustion of European biomass (mainly pine wood pellet), whose properties are different from Mediterranean solid biofuels, for instance olive stone, leading to lower energy efficiency in heating appliances working. Olive stone properties must therefore be studied in order to achieve an optimum efficiency in the combustion within different heating appliances.

The main objective of this study is to determine olive stone energetic properties and to evaluate variability of quality parameters before consumption with the aim of describing suitability of this biomass as solid biofuel for domestic heating uses. For this purpose, mean values, normal distributions, intervals and deviations of these parameters have been obtained and studied to ensure repeatability and reproducibility of quality parameter results.

Concerning to statistical results, climate and geographical variability of quality parameters has been studied. In addition, variations between olive stone physicochemical parameters collected from both olive oil factories and distribution companies have been calculated and justified. Finally, a model for estimating higher heating values (HHV) of olive stone has been determined and compared with other HHV predictions introduced by other researchers.

Table 1
Biomass potential in Andalusia in 2007 [3,21].

	ktoe/year
Total biomass potential in Andalusia	3327
Agricultural residues	1434
Olive grove	803
Fruit trees	86
Corn	72
Sunflowers	186
Greenhouse residues	100
Rice	43
Cotton	143
Industrial residues	589
Olive oil industry	455
Bark	35
Rice husk	19
Cotton	15
Nuts	17
Wood	41
Olive stone	2
Sugar refinery	4
Cork	1
Forestry residues	136
Quercus	59
Eucalyptus	53
Pine	18
Poplar	7
Energy crops	559
Cynara	559
Biodegradable	609

2. Materials and methods

2.1. Raw material

A sampling plan was designed to collect olive stone residues from different Andalusian industries, including olive stone supplied by olive oil factories and distribution companies. This research has collected and analyzed (after a grinding-up to 0.25 mm) a total of 147 olive stone samples from 69 different places. Samples have been collected from Andalusian provinces such as Seville, Malaga and Granada and, especially, from Jaén and Córdoba where most of Andalusian olive stone production is generated [9]. Sampling plan was performed in order to obtain the widest geographical diversity and the highest quality parameters variability and it includes 85 samples collected from olive oil factories and 62 samples collected from distribution companies.

Respect to the geographical study, samples have been divided into three groups to study the climate variability inside Jaén region and the influence in olive stone properties. Three groups have been chosen according to the greater differences in annual rainfall factor observed in origin places where samples were collected [10].

To carry out the geographical variability study, samples have been divided in three groups according to different types of soils. First group include samples collected from soils rich in calcium, second group include samples collected from soils rich in chromium, and third group include samples collected from soils rich in chromium and calcium [10]. Calcium and chromium are important elements in soil quality, which have been chosen for this research because of being present in all soils studied. Calcium is present in several primary and secondary minerals in soils and it is essential for plants growing. Chromium content in soils is very variable and it is necessary in small concentrations for groves but it is a contaminant in high concentrations.

2.2. Determination of quality parameters and equipment

Quality parameters have been determined by official methods established by the European Standard Technology Committee [11]. In Spain, the adaptation of this methodology was established by the Spanish Association for Standardization and Certification (AENOR). Standards and used measurement equipment are shown in Table 2.

Samples have been characterized by content in dry weight. The content of oxygen has been calculated as the difference between 100 and the sum of carbon, hydrogen, nitrogen, sulfur, chlorine and ash content [12]. Low heating value (LHV) has been calculated based on ultimate analysis and HHV experimental values [13].

2.3. Statistical methodology

Statistical treatment of data has been performed from descriptive statistical and chemometric techniques. Kolmogorov–Smirnov test was used to contrast the normality of the distributions (confidence level 95%). With p-value higher than 0.05, the assumption of