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Research paper

Production and quality analysis of pellets manufactured from five potential energy crops in the Northern Region of Costa Rica

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ABSTRACT

Modifications to a pellet manufacturing process must be made based on the characteristics of raw material used. The purpose of this work was to determine the alternations required to a wood pellet manufacturing process and the quality of the pellets produced using this process from five energy crops. Quality measurements include: the caloric value, the loss of moisture content in each production stage, the efficiency index of particle-pellet, ash content and quality as defined using the quantity of cracks and the transversal density and longitudinal density determined using X-ray radiography. The crops analyzed were rhizomatous plants, with caloric values ranging between 17.1 and 20.3 MJ kg^{-1}. This work determined that it was possible to produce pellets with *Gynerium sagittatum* and *Phyllostachys aurea* using the same production process for wood; however, *Arundo donax* and *Pennisetum purpureum* needed pre-air-drying and the *Sorghum bicolor* required mechanical dewatering before drying. *A. donax*, *P. purpureum* and *G. sagittatum* provided the highest efficiency index. When evaluating the pellet quality *P. aurea* and *G. sagittatum* hard a large quantity of cracks, unlike *A. donax*, *P. purpureum* and *S. bicolor*. The transversal and longitudinal pellet density varied from 1129 to 1294 kg m^{-3}. The highest values of bulk density were obtained in *A. donax* and *P. purpureum*, followed by *G. sagittatum* and *P. aurea*, and the lowest bulk density was obtained in *S. bicolor*. Althogh out, some species produced cracks and high ash content, this work demonstrated that it is possible to produce pellets with moderate quality.

1. Introduction

Tropical conditions in Costa Rica allow the development of many agricultural and forestry crops, which generate a large amount of lignocellulosic waste [1]. For example, the agricultural sector produces approximately 1.5 million Mg of residues per year [2] the forest industry generates about 500,000 Mg of residues [3] and this estimate does not consider the 43% of tree volume that remains in the field as residue [4]. The forest industry has been concerned with finding solutions to the residue problem and one possible solution is to generate heat by direct combustion of the raw residue [5]. Manufacturing residues into pellets is of interest to these industries since the pellets would allow for better utilization of the material. Pellets could provide the heat for other processes, such as drying of fruits and vegetables, cooking or cleaning products [2].

Wood pellets are manufactured by a mechanical process, where pressure is applied to crush the cell structure and increase its density [6]. The normal process of producing wood pellets consists of: (i) using grinders and mills (discs, rollers, balls, blades or hammers) to reduce the size of the material, (ii) drying the biomass with rotary drum or pneumatic type driers to a 10% moisture content and (iii) compressing the material using rotary rollers, which pushes the particles from the inside of a ring or die (cylindrical or annular type or flat matrix) outwardly through a series of holes [7,8], a technology commonly used to produce animal feed. While pellets can be made from wood, the high demand for wood residues in fiberboard and particleboard production represents direct competition for pellet industries in Costa Rica [5]. There are

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two important aspects regarding the use of wood residues in Costa Rica: (i) a tendency to reduce wood consumption in industry [9] and (ii) the residues produced are in high demand to keep chicken, horse and cattle breeding sites clean [5]. Pellet industries are therefore seeking an alternative raw material with high lignocellulosic content, such as agro-residues, or the cultivation of energy crops that can be densified [8]. Agricultural residues are currently in high demand as a supplement for animal feed concentrate [10,11] or to produce organic compost products [12].

The use of agricultural or sawmill residues for pellet production is highly developed in many countries [7]. Pellets are as efficient as other fuels in boilers [13]. For pellet production to be economically viable, the raw material is processed with moisture content less than 55% [14]. One limiting factor to using energy crops for pellet manufacturing is that many have initial moisture contents above 50%, have lower hardness values, and smaller sizes than wood residue [15]. For the industry to be profitable manufacturing pellets from different types of biomass, such as the energy crops, with different morphology and moisture content, the process needs modification [1]. For example, air-drying the raw material in areas with appropriate environmental conditions [16] would result in more cost-effective production [17].

With knowledge of these constraints, the objective of the present work is to define the alterations in a wood pellet production process that would allow the use of five potential energy crops (*Arundo donax*, *Gynerium sagittatum*, *Pennisetum purpureum*, *Phyllostachys aurea*, and *Sorghum bicolor*) in Costa Rica. Specifically, the authors investigated the caloric value, the particle size prior to pelletizing, process efficiency, moisture content in each stage of the pellet production and quality (ash content, transversal density and longitudinal density) of the pellets by X-ray spectrometry. Quality measurements include: the caloric value, the loss of moisture content in each production stage and the efficiency index of particle-pellet, quality, transversal density and longitudinal density of the pellets through X-ray radiography.

2. Materials and methods

2.1. Selected crops

Five energy crops were selected for use in Costa Rica (Fig. 1 and Table 1) based on the following constraints: adaptation to climatic and edaphic conditions of this country, dry biomass production above 20 Mg ha^{-1} and availability throughout the year. The five selected crops are perennial, with straight stems ranging from 2 to 6 m high and diameters from 1 to 5 cm (Fig. 1). *G. sagittatum*, *P. aurea*, and *S. bicolor* samples were harvested and transported to the plant located in San Carlos in one day and the pellets were prepared the next morning. For *A. donax* and *P. purpureum* material was left in the field where it was cut, and allowed to dry to decrease moisture content for three day (see 2.3.1).

2.2. Crop characterization

The characterization of each crop was based on the evaluation of the caloric value in the wet condition (after harvest, named Gross Caloric Value), the dry condition (0% moisture content, Net Caloric Value) and the ash content of the pellet produced. For these analyses, 3 stalks were randomly selected, cut and then milled to less than 2 mm and then sieved with #60 and #40 meshes (0.25 mm and 0.42 mm respectively). The material between #60 and #40, mesh was selected and 3, approximately 1 g, samples were extracted. This material was then divided in two parts of 0.5 g each. A sample with the moisture content at the time of harvesting was used to determine the Gross Caloric Value (GCV); the second sample was kiln-dried at 103 °C for 24 h, and then the net caloric value (NCV) was determined using ASTM D-5865 [18]. Net and gross caloric values were determined using Parr calorimetric test. Carbon fraction (C), Nitrogen content (N) and the C/N relationship were determined from milled dust using Elementar Analysensysteme, Vario Macro Cube model. The material was sieved through 0.25 mm and 0.42 mm meshes (40–60 meshes respectively), until approximately 8 g per test were obtained.

2.3. Crop evaluation in the production process

Six aspects were considered in the evaluation of potential energy crops in Costa Rica: (i) adaptation of the crop to a wood pellet production process; (ii) net caloric values, (iii) loss of moisture content during the pellet production; (iv) characteristics of the produced particles; (v) efficiency in the process and (vi) pellet quality.

Fig. 1. Agricultural crops with energetic potential in Costa Rica. a) *Arundo donax* b) *Gynerium sagittatum* c) *Pennisetum purpureum* d) *Phyllostachys aurea* e) *Sorghum bicolor*.