Renewable Energy 93 (2016) 691–699

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Characterization and productivity of cassava waste and its use as an energy source

João Paulo Soto Veiga [a, 1], Teresa Losada Valle [b], José Carlos Feltran [b], Waldir Antonio Bizzo [a, *]

[a] Faculty of Mechanical Engineering, University of Campinas – UNICAMP, 13083-970 Campinas, SP, Brazil
[b] Agronomic Institute of Campinas – IAC, 13012-970 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form
25 February 2016
Accepted 27 February 2016
Available online 19 March 2016

Keywords:
Cassava
Agricultural waste
Energy
Biomass
Biofuels

ABSTRACT

This study sought to quantify and characterize cassava waste as fuel. The wastes from three cultivars were collected to study and were divided into three distinct parts of the cassava plant: seed stem, thick stalks, and thin stalks. Physical and chemical analyzes were carried out to determine the elemental composition of the waste: volatile matter; fixed carbon; ash; moisture; lignin; cellulose; hemicellulose; ash composition and higher heating value were determined. We conducted a thermogravimetric analysis in oxidizing and inert atmospheres to study the behavior of the waste as fuel. The root productivity obtained ranged from 7.7 to 13.0 t ha^{-1} yr^{-1} on a dry basis (db), and the ratio between waste and roots varied from 0.36 to 0.91. The physical and chemical properties of cassava waste are analogous to those of woody biomass regarding the elemental composition, the higher heating value, and thermogravimetric analysis. Ash content varied from 2.5% to 3.5%, reaching around 6.0% in samples unwashed. Approximately 60% of the ashes are alkali oxides, especially P_2O_5, K_2O, and CaO, which have low melting points. The alkali index calculated suggests that there is a strong tendency that the combustion process leads to ash fouling and the formation of ash deposits.

1. Introduction

The world economy is characterized by a growing demand for energy, which usually comes from non-renewable energy sources (e.g., fossil fuels such as oil and coal), accounting for 81.1% of the world's primary energy [28]. The use of such sources is assigned as responsible for the increasing of CO_2 concentration in the atmosphere and the consequent negative impacts caused by climate changes and global warming [29]. With the growth in research into alternative energy sources, the use of biomass is an attractive option and has attracted considerable interest since the '90s as a way of mitigating global climate change [11].

To avoid a conflict of land use interests, agricultural wastes of food crops has been the subject of research in order to determine their potential for biomass to energy production, on a local scale [20] and its characteristics as fuel for thermal processes [41,48]. These characteristics include the elemental composition and heating value of the biomass and its behavior when subjected to thermal treatment [13].

Several studies have determined the productivity and physical-chemical characteristics of crop residues as corn stover and corn cobs [25], cotton stalks [2,24] and wheat straw [17]. Literature data on traditional residues is vast [16,32], but there is a lack of detailed information about cassava (*Manihot esculenta* Crantz) waste.

Cassava is cultivated in the tropics to produce roots, used primarily for human consumption but also for animal feed and the extraction of starch. Cassava plants have a high biomass yield under good environmental conditions and a great ability to adapt to environments with biotic and abiotic stresses, such as poor-fertility or water-stressed soils where other cultures are not feasible. The aerial part of the plant consists of thick and thin stalks, petioles and leaves, and the underground part consists of roots and the seed stem.

Seed stems are cassava stalks that were cut into approximately 200 mm-long sections and planted to reproduce the plant asexually, and after it grows it looks like woody biomass. The structure of

* Corresponding author.
E-mail addresses: jpsveiga@usp.br (J.P.S. Veiga), teresalv@iac.sp.gov.br (T.L. Valle), feltran@iac.sp.gov.br (J.C. Feltran), bizzo@fem.unicamp.br (W.A. Bizzo).
[1] Current address: Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, SP, Brazil.

http://dx.doi.org/10.1016/j.renene.2016.02.078

the plant is shown in Fig. 1. Harvesting usually involves cutting the stalks, uprooting the plant from the soil and removing the roots. While the first two operations can be done by mechanical equipment, the seed stem and roots are separated manually as there is no mechanical equipment available to carry out this operation.

After all the process of harvest, about half of the biomass produced is abandoned in the fields.

Worldwide, production of cassava in 2010 was approximately 230 million tons, with an average productivity of 12.4 t ha^{-1} on a wet basis (wb), making it the ninth largest agricultural commodity by weight produced. The world's largest producers are Nigeria (54 million tons per annum), Indonesia (24 million tons), Brazil (23.5 million tons) and Thailand (22.5 million tons) [19]. Cassava is usually grown in tropical regions by low-income populations, to meet their food needs, and any surplus is traded with small local or regional businesses. Only a small percentage of world production is traded internationally, and this trade is largely accounted by Thailand, which serves the European and Asian markets.

Cassava, therefore, represents a major opportunity for increasing productivity through technological innovation. Brazil has a low average productivity of 13.8 t ha^{-1} [19], slightly higher than the world's average (12.4 t ha^{-1}).

This low yield is the result of a wide variety of production systems, from subsistence crops in highly stressful environments with low productivity to technically highly advanced crops in favorable environments with high productivities. Table 1 shows typical productivity values in four regions of São Paulo and other four regions in Brazil, the largest cassava-producing region in São Paulo has a yield average twice higher than the national average. Improving yield, biomass productivity can increase threefold among producers.

In Brazil, the main use for the cassava root is for human consumption. A negligible portion of the production of cassava is used for ethanol production; however, we did not find data available on the amount of ethanol produced from cassava root in Brazil.

Authors that have studied cassava in the field [39,42,50,57] tested a range of production conditions including different varieties, types of soil preparation, irrigation methods and resistance to plant diseases. They carried out these works as a way to improve

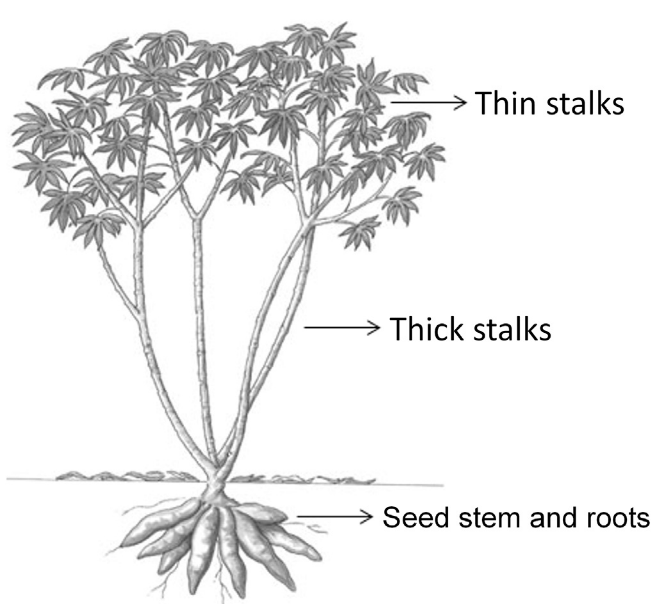

Fig. 1. Cassava plant.

root yield, but little importance has been given to the productivity of cassava crop residues.

To harness energy from agricultural waste, local and regional parameters such as productivity and volume of waste produced must be taken into consideration, especially in large countries and environmentally diverse as Brazil. These factors are important when planning and implementing projects like the Brazilian and the United States projects of ethanol [23], the WBP/SIGAME utilizing forest biomass [14], the UK government's target to generate 10% of the national electricity from renewable sources, being a significant part from biomass [37] and the EU Renewable Energy Directive 2009/28 (RED) [55].

Since energy-production projects involve large amounts of investments, a project using cassava wastes, or any other biomass, as an energy source, it cannot be justified by applying national productivity because subsistence productions will always have an economically prohibitive yield. Besides, to correctly assessing productivity in the field, the essential characteristics of cassava waste as a feedstock for energy production must be determined in each case.

Although it is not the main subject of this work, it is important to point out that the root of the cassava has a high potential for ethanol production, and can be used exclusively for fuel purposes, and also there is the possibility to use the residues from cassava starch and flour industries. The production of ethanol from starch involves cooking, liquefaction, saccharification, and then, the same route as ethanol from saccharose: fermentation, and distillation [9].

Adelekan [1] recommends the production of ethanol from cassava among the technologies to solve energy and environmental problems in tropical regions of the world. In plantations with high yield, 30 t ha^{-1} for example, it can be retrieved 6.2 m^3 ha^{-1}, this value is comparable to the typical productivity of ethanol from sugarcane, which is 7.0 m^3 ha^{-1} [10].

The residues of the cassava industry can also be used to produce bio-oils after pyrolysis or be treated before saccharification, optimizing the process [59,60].

Few works in the literature discuss the use of cassava waste as a source of energy. Antonio-Cisneros and Elizalde-González [3] separated rind, vascular system and pith from residues of cassava stems and characterized it for activated carbon preparation. Pattiya [45] characterized cassava waste to provide information to support its use as fuel in Thailand, the author classified the stalks and seed stem (called rhizome by Pattiya) as waste and characterized them physically and chemically. Wei et al. [61] discuss the possibility to extract starch from the branches to produce ethanol, evaluating aspects as the region of production, varieties and time of harvest to find the better results.

Regions where there are large areas of cassava fields, its waste can be used as a source of energy by root-processing mills, and, if the investment is economically viable, a surplus of energy can be sold, improving the profits. As the production around the world increased 30% in the last decade [18], the potential to produce energy with cassava wastes is also increasing.

The utilization of cassava wastes can also combine food and fuel production, as described by Zhu et al. [63], reducing the competition between the land use for this two important issues in the growing population of the world.

As cassava waste has the potential to make a significant contribution to Brazilian energy production because it is a widespread crop in this country, the objective of the present work is to characterize this type of waste as raw material for energy production. Stalk and seed stem yields were assessed experimentally, and both parts of the plant were characterized as raw material for biofuel production.