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Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production

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ABSTRACT

In this paper the fuel ethanol production from empty fruit bunches was experimentally evaluated using alkaline pretreatment and enzymatic hydrolysis for sugars release. Fermentation was accomplished using a native *Saccharomyces cerevisiae* strain. Ethanol concentration was carried on using a glass bench-scale distillation column. Experimental results were used for planning and designing the process scheme using Aspen Plus. Process simulation allowed calculating the mass and energy balances. It was found that coupling alkaline pretreatment with a later autoclaving improved the sugars yield in enzymatic hydrolysis. However, the use of the remaining soaking solution from pretreatment as hydrolysis medium had negative effects on sugars yield suggesting that there exist inhibit substance for the enzyme. Better results for enzymatic hydrolysis were obtained when sodium acetate buffer was used. Ethanol yield obtained from both experiments and simulation were very similar (66.50 and 65.84 dm^3 of ethanol per each t of empty fruit bunches, respectively). These low ethanol yields were obtained because the native *S. cerevisiae* does not assimilate all reducing sugars, suggesting that those sugars were pentoses. Simulated alkaline and autoclaving pretreatment contributed only with 2% of the total energy consumption (198.4 GJ m^{-3} ethanol) while product recovery represented 57% of the total energy.

1. Introduction

Processing of palm for oil extraction leads to the formation of several by-products and residues that have an economical potential. These products, by-products and residues have well described in Ref. [1] along with their current and potential applications. The empty fruit bunches (EFB) are the solid residue that is produced in the highest amount from the fresh fruit bunches (FFB) of oil palm. EFB composition is shown in Table 1 according to the data of Refs. [2–4]. Due to its high moisture content, this material is not appropriate as a fuel and it is mostly used as manure [5]. The use of EFB as a substrate for cultivation of mushrooms by solid-state fermentation has been proposed. In this case, previous treatment of this material is not required [6,7]. In addition, the remaining material after mushroom harvest presents better fertilizing properties. On the other hand, the fiber resulting from separation of press cake (palm press fiber, PPF) has an important content of the lignocellulosic complex and a lower moisture content. The oil retained in the fiber makes this material to be a good solid fuel. When palm processing facilities produce both process steam and electricity, the total amount of PPF undergoes combustion. However, if only steam is to be produced, 70% of PPF is not used and becomes a waste [7]. The

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Abbreviations: FFB, fresh fruit bunches; EFB, empty fruit bunches; PPF, palm press fiber; RSC, reducing sugars concentration.

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Table 1 – Average composition of empty fruit bunches and palm press fiber.

	Content (wt.%)		
	EFB		PPF
References	[2][a]	[3]	[4]
Component			
Cellulose	46.77	15.47	24.00
Hemicellulose	17.92	11.73	14.40
Lignin	4.15	7.14	12.60
Ash	–	0.67	3.00
Oil	–	–	3.48
Moisture	–	65.00	40.00
Others	–	–	2.52

a Dry basis.

lignocellulosic biomass contained in both EFB and PPF can be used for ethanol production as was described in Ref. [1]. In the case of ethanol from EFB, the lignocellulosic content must be previously in form of fibers to be used.

Fuel ethanol is the most employed liquid biofuel worldwide. A broad variety of plant materials containing the sugars required for fermentation process can be utilized for fuel ethanol production like sugarcane juice and cane or beet molasses. Starchy materials are also used for these purposes. The United States has become the first world producer of ethanol [8], which is produced from corn. Ethanol can be produced from lignocellulosic biomass as well. It is considered that lignocellulosic biomass is the most promising feedstock at mid term for ethanol production due to its availability and low cost.

Many countries have implemented or are implementing programs for addition of ethanol to gasoline [8] or biodiesel to diesel. For instance, European Union has issued different directives about the addition of renewable oxygenates to fuels. The oxygenation target of fuels considered the addition of 2 wt.% by 2005 and 5.75 wt.% by 2010. However, the implementation of these directives varies too much among the different countries. Spain and France are leading the production of bioethanol in Europe. In contrast, Germany has developed the production of biodiesel from rapeseed. In this country, it is considered that the production of fuel ethanol is not economically feasible in comparison to gasoline due to the high costs of feedstocks (grains, sugar beet) [9,10].

Colombian government has encouraged the utilization of renewable biofuels for national transport sector in order to achieve several goals: diminish the volume of polluting emissions improving the air quality in Colombian cities, reduce the dependence on fossil fuels through the decrease of diesel and gasoline imports, and boost the development of Colombian rural sector through the consolidation of agro-industrial chains for biofuels production. Colombian Congress issued the Act 693 of 2001, which made mandatory the utilization of fuel ethanol as a gasoline oxygenate [11]. In a similar way, the Act 939 of 2004 [12] offers tax exemptions for both biodiesel production and oilseed cropping intended to the production of this biofuel.

Typically the empty fruit bunch (EFB) on a dry basis is 120–260 kg t^{-1} fresh fruit bunch (EFB) on an as received basis [13]. Given the current yield of FFB and the area of harvested production, Colombia produces 1 Mt of EFB, at a rate of 438 t km^{-2} [14]. Fedepalma [14] estimates that this quantity could increase three times in 2020. Considering the above-mentioned, Colombia has the material basis for high-scale production of both bioethanol and biodiesel. At present, ethanol is obtained from sugarcane in Colombia. On the other hand, the extraction of palm oil generates significant amounts of lignocellulosic residues, which may be employed as feedstock for ethanol production. The aims of this work were determining the feasibility of using EFB in ethanol production and evaluate the pretreatment technology influence on sugars yield before enzymatic hydrolysis.

2. Materials and methods

2.1. *Materials*

2.1.1. *Raw material and reagents*

The EFB were obtained from a palm oil extraction plant (Palmar Santa Elena) located at Tumaco town (1° 48′ 24″ N, 78° 45′ 53″ W), in the southwest cost of Colombia, which altitude is 2 m above sea level. The temperature in Tumaco ranges from an average high of 33 °C to an average low of 18 °C. Rainfall is constant throughout the year (annual mean 250 cm). The humidity is relatively high, with measures that lie between 80 and 88%, reaching 100% at night. EFB obtained after fruit extraction were immediately sent to the laboratory without drying and/or milling.

The chemical reagents used for the compositional study were analytical grade without further purification. Sodium hydroxide was purchased from Merck; acetic acid, sodium and potassium tartrate, sulfuric acid, and anhydrous ethanol were purchased from Carlo Erba. Calcium hydroxide and anhydrous glucose were purchased from J.T. Baker.

2.1.2. *Microorganism and enzyme*

Cellulase cocktail (Celulasa CE 2) from *Trichoderma reesei* was purchased from Proenzimas (Cali-Colombia). *Saccahromyces cerevisiae* strain (commercial bakery yeast grown in sugarcane molasses) was purchased from Levapan S.A. (Palmira-Colombia).

2.2. *Methods*

2.2.1. *Raw material characterization*

All determinations were carried out on duplicate samples. Moisture contents were measured at 105 °C using a moisture analyzer LP 11 (METTLER).

2.2.1.1. *Total lignin content*. The total lignin content was determined as the added quantities of Klason lignin and acid-soluble lignin contents, according to Technical Association of Pulp and Paper Industry (TAPPI) T-222 om-83 and TAPPI 250UM-85 standards, respectively [15].

2.2.1.2. *Holocellulose content*. Holocellulose was determined with the chlorination method described by the ASTM Standard D1104 [15].