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Production of bioethanol from a mixture of agricultural feedstocks: Biofuels characterization

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HIGHLIGHTS

- Bioethanol production from a mixture of agricultural feedstock.
- The mixture of Mech Degla dates and grapes juices has the higher bioethanol concentration.
- The addition of 5% of ethanol, to lead-free gasoline raises the RON to around 96.4.

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ABSTRACT

Bioethanol production from a mixture of agricultural feedstock was carried out in a batch fermenter. To study the effect of optimal mixture ratio of fruit juices (100% dates; 70% dates + 30% grapes, 50% dates + 50% grapes, 30% dates + 70% grapes, 100% grapes) on ethanol yield (g ethanol/g sugar), different parameters have been monitored such as ethanol yield, total sugar, ammoniacal nitrogen, pH. It was found that the mixture of Mech Degla dates and grapes juices has the higher bioethanol concentration than that obtained from a single juice from one kind of fruit. Higher bioethanol production 155.5 g/L at 72 h was obtained when 30% dates juice was blended with 70% grapes juice. In such case, the higher initial sugar concentration is close to 228.34 g/L, and the pH droped from 4.5 to 3.87. The Luedeking-Piret model was used to describe the bioethanol production. A good agreement was found between simulated and experimental data. The influence of some physical properties on the addition of ethanol to lead-free gasoline has been studied. It was found that the addition of 5% of ethanol, to lead-free gasoline raises the RON to around 96.4, that can improve its octane number by 2 points.

1. Introduction

Fossil fuels represent >80% of the total energy supplies in the world. The continued burning of fossil fuels generates a significant greenhouse gas emission in the atmosphere. In the last years, the level of greenhouse gasses in the earth's atmosphere has drastically increased [1]; causing global warming. Annual global oil production will begin to decline within the near future [2]. The current trend is towards the development of new techniques using renewable energy sources such as wind, solar, biomass, geothermal. The future energy supply must be met with a simultaneous substantial reduction of greenhouse gas emissions [3] and avoid the risk of an energy shortage across the world. This contributes to the achievement of sustainable development goals.

Agricultural organic wastes are currently one of the major problems of agriculture from an environmental point of view, so that the use of this biomass for generating energy is vitally important [4]. To provide clean, affordable and sustainable energy, bioethanol from agricultural wastes might be able to partly replace fossil fuels and preserve fossil energy storage.

The United States is the world's largest producer of ethanol, accounting for nearly 58% of global output in 2014. Brazil has been considered as the second producer with a world production of 6.2 billion gallons, accounting for nearly 25%. While the European Union followed with 6%. The remaining 11% is produced by the rest of world [5]. It has been expected that the production of bioethanol will keep on increasing in the next 10 years [6].

There are two main techniques often used to produce bioethanol: separate hydrolysis and fermentation and simultaneous saccharification and fermentation processes. They take into account the advantages and the disadvantages of either technique in

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semi-simultaneous saccharification and fermentation processes, which consists of pre-hydrolysis prior to fermentation and uses the substrate obtained after hydrolysis without separation from hydrolizate [7].

To enhance ethanol fermentation process, combined aerobic and anaerobic fed-batch operation can be used. This could improve the growth of microbes because of the well use the characteristics of both of the microbial metabolism [8]. The development of efficient process requires the selection of suitable microorganisms, in the case of ethanolic fermentation; these include yeasts, *Saccharomyces cerevisiae*, *Schizosaccharomyces pombe*, bacteria *Zymomonas mobilis*, fungus *Fusariumoxys porum* and thermophilic bacteria [9]. *S. cerevisiae* and *S. pombe* remains the most commonly used yeasts due to their ability to ferment different range of sugars.

Ethanol has certain environmental advantages over gasoline, because it can be produced from a variety of renewable energy sources, it is biodegradable and less toxic than fossil fuels.

Ethanol can be used as an industrial feedstock or solvent. It is the most widely used liquid biofuel for motor vehicles [10]. It can be used directly or as additive with gasoline in an amount not exceeding 10% [11]. It has a higher octane number (108), broader flammability limits, higher flame speed and higher heat of vaporization. These properties provide higher compression ratio with shorter burning time, leading to a better theoretical efficiency over gasoline in an integrated circuit engine [12]. In the USA, bioethanol has been blended with gasoline to form an E10 blend (10% bioethanol and 90% gasoline) [13]. Besides, it can be used in higher concentrations such as E85, in such case, engine modification is required [14].

The aim of this study is to investigate the agricultural feedstocks such as dates and grapes wastes, to produce the bioethanol by yeast *Saccharomyces cerevisiae*. The effect of optimal mixture ratio of fruits on ethanol yield (g ethanol/g sugar) was investigated. Different parameters were monitored such as ethanol yield, yeast viability, total sugar, ammoniacal nitrogen, pH. Furthermore, the Luedeking-Piret model was used to adequately describe the bioethanol formation. Characterization of bioethanol and its blend with lead-free gasoline and additive-free gasoline was performed, including distillation curve, Reid vapor pressure (RVP), sulfur content and octane number.

2. Materials and methods

2.1. Raw materials

The raw materials used in this study are shown in Photo 1. They consist of a dried variety of Mech Deglet dates from the south region of Algeria, which has a low market value, and raw residual carignan grapes obtained from local market at 15.75 Brix. Selection was based on the damaged varieties that can neither be used to human feed nor to animal feed.

Photo 1. Mech Deglet variety and carignan grape.

2.2. Pretreatment of raw materials

Pretreatment is essential to improve both biomass fractionation and fast conversion into ethanol and carbon dioxide. In this study, dates juice was extracted as stated by [15]. One kilogram of dates wastes was immersed in 3 L of hot water for 45 min at a constant temperature of 83 °C and stirrer speed of 300 rpm. In the case of grape juice, 5 kg of grape berries was removed from each bunch and seeds and crushed using a blender, once the dates and grape juices had been extracted; they were stored at 4 °C until use in the experiments. The composition of the substrates regarding total sugars, protein, lipids, is given in Table 1.

2.3. Yeast strain

Strain of VdH2 of *Saccharomyces cerevisiae* was used for bioethanol fermentation; it's a Baker's yeast with good ability to assimilate glucose.

2.4. Inoculum preparation

The yeast has been activated before bioethanol fermentation. For such case, the fermentation medium contains 10 g of dry yeast in 300 mL. This inoculum was added also to 2700 ml of fermentation medium in order to obtain 10% (v/v) inoculum size as outlined by [16,17]. The medium was mixed for 45 min at 30 °C and has been enriched by adding nutriments: 6 g/L yeast extract, 5 g/L KH2PO4, 1 g/L MgSO4.7H2O; 2 g/L $(NH_4)_2SO_4$.

2.5. Experimental set-up

The Fed-batch fermentations were conducted in a cylindrical stainless steel fermenter of 0.45 m height and 0.168 m in diameter. The base of the reactor is conical with a height of about 0.230 m, a diameter of 0.168 m for the upper base and 0.08 m for the lower one. In order to keep a constant temperature during the fermentation process, the bioreactor is equipped with integrated heating element. The fermenter consists of a 3 L active volume; it was filled up with dates juice or grapes juice or with blending of both juices. The nutritional value of dates is due to their high proportion of natural sugar and many vitamins [18–20]. The alcoholic fermentation was conducted by using an active dry yeast culture rehydrated in juice, 10% (v/v) [16,17]. Geometrical details of experimental setup have been given in Table 2. The reactor cover was provided with several pipes in order to monitor different parameters such as ethanol yield, yeast growth, pH value, temperature and so one. The bleed valve is located at the bottom of the bioreactor. Also, it includes a stainless steel flange to prevent gas leakage.

For low-to-medium-viscosity liquids, often the flat-blade turbines are recommended. The most frequently-used impeller in the fermentation is the six-flat-blade disc-mounted turbine shown in Fig. 1, this impeller is also known as the *Rushton turbine* of 0.056 m diameter, the latter induced a radial flow inside the fermenter. The ratio of bioreactor diameter to impeller diameter is about 1.43. The bottom impeller is located at a distance about

Table 1
Composition of the raw materials.

Raw materials	Mech Degla juice	Grape juice
pH	5.08 ± 0.02	3.28 ± 0.02
Total soluble solids (°Brix)	10.50 ± 0.2	15.75 ± 0.2
Total sugars (g/kg dry matter)	800.07 ± 0.01	170 ± 0.01
Protein (g/kg dry matter)	24.6 ± 0.29	6 ± 0.4
Lipids((g/kg dry matter))	2.7 ± 0.08	1 ± 0.08