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Biomass: bioethanol transformation and production process

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ABSTRACT

The economic development of a country depends on the use of energy in various processes; the use of natural sources to generate energy resources has great potential. Environmental issues such as global warming have aroused interest around the world regarding bioenergy, such as biomasses that generate a low carbon impact and are susceptible to transformation, such as sugarcane and corn. The study aims to evaluate the main energy crops and their transformation processes, as well as obtain an overview of the main bioethanol-producing countries and analyze the productivity of ethanol from sugarcane and corn. Exploratory research was conducted using published databases related to the topic and classification by relevance. It was found that the leading ethanol producers in the world are the United States, using corn, and Brazil, using sugarcane and recently corn, the production of first-generation ethanol from these biomasses has different processes, where sugarcane is capable of direct fermentation, whereas corn fermentation is indirect. The ethanol production from corn has increased in recent years in Brazil and has generated high industrial and economic development. This concludes the importance of using biomass as a precursor of energy in the development of a country.

Keywords: Energy resources, Sugarcane and corn, Biofuels, Bioenergy.

Biomassa: Processos de transformação e produção de bioetanol

RESUMO

O desenvolvimento econômico de um país depende da utilização de energia em diversos processos e a utilização das fontes naturais para a geração de recursos energéticos apresentam um grande potencial. As questões ambientais como aquecimento global tem despertado interesse por todo o mundo a respeito de bioenergia, tais como biomassas que geram um baixo impacto de carbono e são passiveis de transformação como a cana-de-açúcar e o milho. O estudo visa avaliar as principais culturas energéticas e seus processos de transformação, bem como obter um panorama dos principais países produtores de bioetanol e analisar a produtividade de etanol a partir da cana-de-açúcar e milho. Foi realizada pesquisa exploratória, utilizando base de dados publicados relacionados ao tema e classificação por relevância. Foi possível observar que os principais produtores de etanol no mundo são os Estados Unidos, utilizando milho, e o Brasil, utilizando a cana e recentemente o milho. A produção do etanol de primeira geração a partir dessas biomassas possui processos diferentes, onde a cana é passível de fermentação direta, já a fermentação do milho é indireta. A produção de etanol de milho tem aumentado nos últimos anos no Brasil e tem gerado um grande desenvolvimento industrial e econômico. Desta forma conclui-se a importância da utilização da biomassa como precursora de energia no desenvolvimento de um país.

Palavras-chave: Recursos energéticos, Cana e milho, Biocombustíveis, Bioenergia.

1. Introduction

Energy resources are fundamental for developing the economy of a country, as the production processes of goods and services depend on the availability of energy to consolidate. The growing dependence on energy has driven research in search of new energy sources that meet this world demand, with a view to economic development and the preservation of natural resources for future generations (Khan et al., 2022).

Environmental issues mainly related to global warming have directed the attention of nations to the search for new energy sources that are ecologically correct and environmentally viable; a good example is biomasses (Martinho, 2018) which are already part of the energy matrix of several countries and has the advantage of a low carbon impact (Reid et al.,2020). The production of clean energy from biomass can bring several benefits, as these are renewable resources that can be exploited without the depletion of natural sources, thus promoting sustainable development and a continuous and secure energy supply (Abdul Malek et al., 2020).

The exploration and use of biomass as a raw material for biotechnological processes is in line with the Sustainable Development Goals of the UN 2030 Agenda (SDG), especially concerning SDG 7, which has in Target 7.2 (UN) - "By 2030, substantially increase the share of renewable energies in the global energy matrix" according to Morais (2019). This goal includes biofuels, forms of renewable energy, which are obtained from biomass, which bring as a relevant factor the reduction of pollutant gas emissions in the environment, such as sugarcane ethanol, which has an efficient balance of carbon, having the gas emissions compensated in the plant photosynthesis process (Borowski, 2022).

The production of biofuels is an important strategy for maintaining a strong and sustainable economy. Within this perspective, the sustainability of bioethanol and bioenergy has taken Brazil to the forefront of sustainable economic development based on raw materials with high sugar contents, such as sugarcane, corn, cassava, and sweet potato, among others, which they are susceptible to transformation (Soleymani Angili et al., 2021). Sugarcane is the most planted biomass in the world, around 1.5 billion tons and its main products are sugar and ethanol (Bordonal et al., 2018; Sydney et al., 2021).

In ethanol production, transformation processes are essential and have different stages for each raw material, mainly for obtaining fermentable sugars. Thus, depending on the biomass, it is necessary to carry out a preparation step that precedes the fermentation. According to Santos et al. (2018), saccharine substrates have high levels of fermentable sugars, which are susceptible to direct fermentation. In starchy substrates, the hydrolysis process is fundamental, as it breaks the starch into glucose by the action of enzymes so that in the presence of selected yeast strains, fermentation and ethanol production can occur (Manochio et al., 2017).

The search for clean and sustainable energy sources is due to the need to minimize environmental impacts and avoid the scarcity of natural resources. The improvement of technologies related to the production of biofuels has the objective of valuing the biomass used in this process, together with a better knowledge of the characteristics of energy crops used in the production of ethanol and bioenergy. Energy crops are plants with low harvest and maintenance costs in their cultivation, having the quality and quantity of raw materials required for the bioprocesses of obtaining renewable energy (Clauser et al., 2021). Thus, the study aims to evaluate the main energy crops and their transformation processes, as well as obtain an overview of the main bioethanol-producing countries and analyze the productivity of ethanol from sugarcane and corn.

2. Material and Methods

The study was developed at the Laboratory of Biotechnology, Biochemistry, and Biotransformation of the Center for the Study of Natural Resources – CERNA of the State University of Mato Grosso do Sul, Dourados/MS. This study conducted exploratory research about cultures and their transformation processes from the main species with processing potential for ethanol production. A bibliographic survey was carried out on the scientific production of sugarcane and corn crops and the production of ethanol. The following methods were used in the search: descriptive research - represents pre-determined particularities of the population or phenomenon, or the creation of relationships between variables, using standardized techniques for data collection (Snyder, 2019); quantitative research - is essential for enumerating and quantifying data. Such an approach suggests what can be quantified in numerical value. The search was carried out through data collection related to scientific publications in a given area or topic (Araújo and Alvarenga, 2011; Pereira et al., 2018).

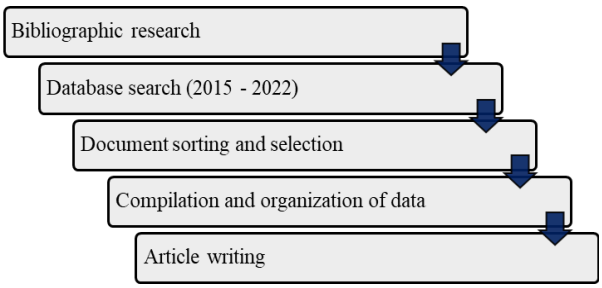

Figure 1. Flowchart of the study development stages

Data collection was carried out in an online database, free access articles, informational websites of companies, and government websites, the years from 2015 to 2022 were considered, related to the evaluated topic (Figure 1). The material obtained was analyzed and selected by the relevance of the data, and the analysis and processing were performed using Excel 2019 software.

3. Results and Discussion

The growing dependence on energy in the world has put biofuels in highlight, and bioethanol in Brazil has been considered one of the main biofuels that can meet this demand according to the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis - ANP, 2019). In Brazil, this biofuel is obtained from raw materials with high levels of sucrose or starch, such as sugarcane and corn, respectively (Sameeroddin et al., 2021; Srivastava et al., 2021). However, it can be obtained from other energy crops such as cassava, beet, and sorghum (Intaramas et al., 2019; De Laporte and Ripplinger, 2018, Santos et al., 2022).

These biomasses are used for the production of first-generation ethanol (E1G); meanwhile, cellulosic biomasses such as sugarcane bagasse, rice, and wheat straw, which are also subject of transformation for ethanol production (Ramsurrun and Surroop, 2019), are used in the second-generation ethanol (E2G) production process, according to (Damay et al., 2018). It can be observed that energy crops, sugarcane, sorghum, and beetroot have sucrose as the main fermentable sugar, which is susceptible to direct fermentation; in the case of indirect fermentation, which have starch as their main sugar, they need to undergo a pre-treatment process known as hydrolysis, this occurs by adding enzymes to release glucose, a molecule capable of being fermented (Table 1).

The energy crops that stand out in terms of yield, ethanol per hectare, are sugarcane and corn due to significant contributions from plant breeding and efficient management, as well as wide territorial coverage, fertile lands, and specific microclimates that favor the good development of these species in different times. Brazilian ethanol, produced from sugarcane, is considered the most competitive, having advantages over the others, as it has a high raw material yield with lower production costs, a good energy balance with possibilities of reducing environmental impacts (Pereira et al., 2019). In Brazil, 1.1% of agricultural lands are destined for sugarcane production, with around 600 million tons per year. In comparison, corn occupies 1.9% of the area and produces less than 100 million tons per year. The sugarcane yield, per hectare, is 15 times higher than corn, according to the Brazilian Institute of Geography and Statistics - Instituto Brasileiro de Geografia e Estatística - (IBGE, 2020); however, they present advantageous agronomic and economic characteristics for the production of ethanol. In Brazil, there are currently 356 mills (UDOP, 2022), concentrated mainly in the Center-South The state of Mato Grosso do Sul has 17 sugarcane mills and one corn mill, and the Grande Dourados region has become a significant sugar-energy hub.

The sugarcane ethanol production contributes to 2.0 million liters sold in the country, making up 83% hydrous ethanol and 17% anhydrous ethanol in the 2020/2021 harvest, according to the Association of Bioenergy Producers of Mato Grosso do Sul - Associação dos Produtores de Bioenergia de Mato Grosso do Sul – (BIOSUL, 2021). In the last decade, Brazil has been presenting super crops of corn. This grain has leveraged Brazilian exports, being, in this sense, an important export commodity. Its production has been increasing in the last harvests, mainly in the Midwest region (Lopes et al., 2022). This increase was due to the expansion of the planted area. The climate and soil conditions make it possible to carry out two or more harvests (Goulart et al., 2021).

The main biofuel-producing countries use renewable raw materials with high agricultural potential and sugar contents to be used in the production process. The United States is the largest producer of global ethanol, representing 55% of total production, while Brazil, with 27%, is the second largest producer of this biofuel, followed by the European Union with 5%, and China and India with 3% (Figure 2). Global warming and environmental issues have been widely discussed worldwide, and biofuels from renewable sources are an important ally in environmental issues since there is a retention of CO_2 during the photosynthesis process carried out by the biomasses (Perišić et al., 2022; Vedanarayanan et al., 2022).

The production chain of this biofuel contributes significantly to minimizing environmental impacts, especially concerning global warming. Brazilian ethanol is a good example, as it is mainly produced from sugarcane, a grass with a high capacity to sequester carbon dioxide - CO_2 dispersed in the atmosphere during its development (Moitinho et al., 2021). The main ethanol producers in the world are the United States and Brazil; together, they produce about 82%, using corn as the main source in the US, sugarcane in Brazil, and more recently, corn (Silva and Castañeda-Ayarza, 2021). In the world scenario, due to high energy demand, energy crops are promising sources to meet this need because they can produce energy and biofuels through processing.

Table 1- Main energy crops with potential for ethanol production and are susceptible to transformation

Biomass subject to transformation	Substrate Type	Fermentation process
Sugar cane (*Saccharum officinarum*)	Saccharine	Direct
Sorghum (*Sorghum bicolor*)	Saccharine	Direct
Beet (*Beta vulgaris*)	Saccharine	Direct
Corn (*Zea mays*)	Starchy	Indirect
Sweet potato (*Ipomoea batatas*)	Starchy	Indirect

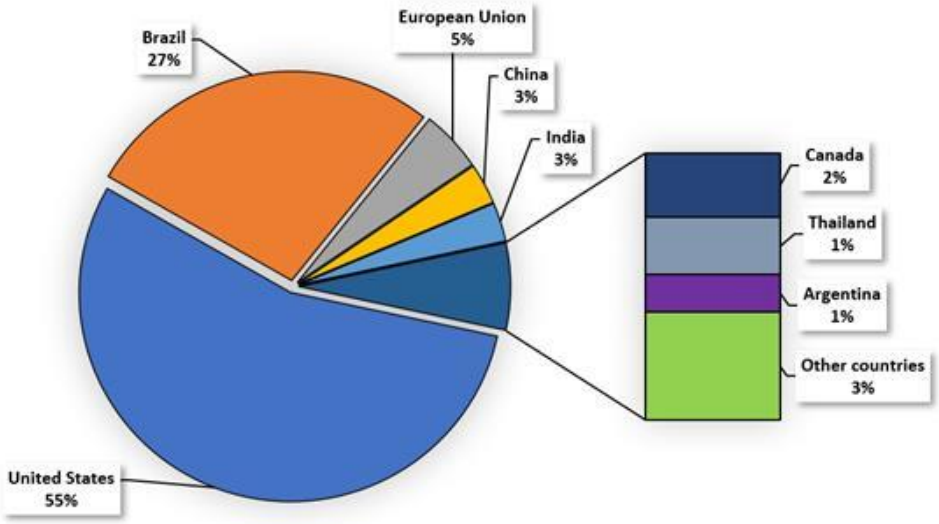

Figure 2. Main ethanol-producing countries in the world, from renewable biomass.

The production of first-generation ethanol (E1G) from sugarcane and corn has different characteristics in the initial stages. In the sugarcane production process, the steps of grinding and extracting the juice and a pre-treatment that precedes fermentation occur. The average conversion productivity of sugarcane ethanol is 80 L t^{-1} and corn 370 L t^{-1}; however, each raw material has advantages in terms of productivity (Nakamya, 2022). The production cost for sugarcane ethanol is R$1.16 and corn ethanol R$1.86, respectively, highlighting environmental issues concerning fossil fuels (Dall Agnol, 2019).

The industrial units that produce the mix, sugar, and ethanol, mix the cane juice with the residue from sugar production, molasses. This broth then goes to the vats, where the main fermentation occurs with the addition of yeasts. After fermentation, the broth goes to the centrifuges where the yeasts are separated; at this moment, the unleavened broth goes to the distillation towers, and the yeasts return to the process, and the cycle begins again (Marsit and Dequin, 2015). For corn, one more step is necessary, and initially, the corn is crushed, and water and amylase enzymes are added to break the starch into sugars. The broth is then heated, temperature control is necessary, and another enzyme is added to glucoamylase so that the starch saccharification is carried out efficiently (Eckert et al., 2018), as shown in the bioethanol production scheme (Figure 3).

In this segment of agribusiness, the sugar-energy sector is concerned with the raw material, driving the development of crops that are more responsive to environmental conditions, such as water availability, resistance to pests, and a higher percentage of sugars, and there is also an eminent search for selected microorganisms with high fermentative capacity (Carmo Junior et al., 2021). This process is recognized as a successful example, and a large part of the residue generated during the ethanol production process is reused in the maintenance of the production chain (Sydney et al., 2021). For ethanol produced from corn, important technological advances are also observed, such as obtaining a variety of corn with higher starch content and high grain yield (Yu and Moon, 2021).

Brazil has seventeen corn power plants, ten of which are located in the State of Mato Grosso, one in São Paulo and Paraná, and five in Goiás; there is a great expectation that the production of this biofuel will grow even more, it appears that fifteen projects for new power plants are under construction and licensing process, most of them located in the Midwest region according to the National Bioenergy Union - União Nacional da Bioenergia - (UDOP, 2022). A growth forecast for ethanol demand in Brazil could be 50 billion liters in 2030, accounting for 87.5% of consumption (EPE, 2017).

In the state of Mato Grosso, ethanol production occurs through a flex distillery/factory, with sugarcane and corn being used alternately. In the sugarcane off-season, corn is used, which can transform 400 t day^{-1}, converting about 150.00 liters of ethanol (Lopes et al., 2016). The production process can generate co-products, such as proteins, minerals, fats, and fibers, which are essential products in the human consumption chain. However, if the mill is dry, it obtains the Distiller's wet grain (DWG) or Distiller's Dried Grains with Soluble (DDGS); such products have high added value (Fardisi et al., 2019).

The consumption of biofuels from renewable sources has been growing both in Brazil and the world. This has contributed to the expressive numbers of ethanol production in the last harvests, mainly in the consolidating production using sugarcane. However, Brazil started to produce ethanol from corn, and this process has been mainly in the Midwest region. In 2019, the highest production peak occurred at approximately 35 million liters of sugarcane ethanol, and the same behavior was observed for corn ethanol since, in 2020, the production was just over 2 million liters (Figure 4). Due to the high productivity and technological quality of the corn crop in Brazil, mainly in the state of Mato Grosso, the first state in terms of corn production, due to the logistics for exporting the grain, this may prove to be an important strategic moment to increase bioenergy productivity in the country.

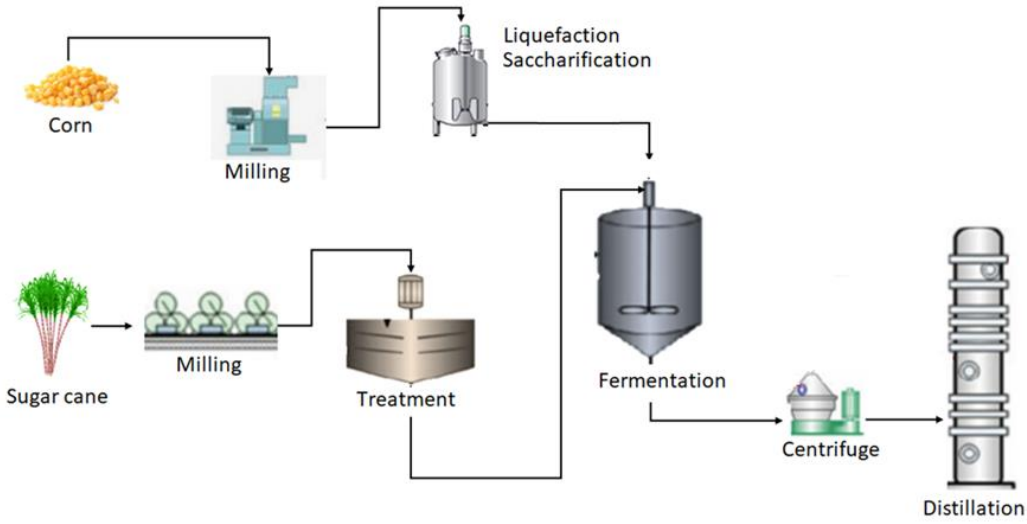

Figure 3. Scheme of the fermentation process for producing first-generation ethanol (E1G) from sugarcane and corn.

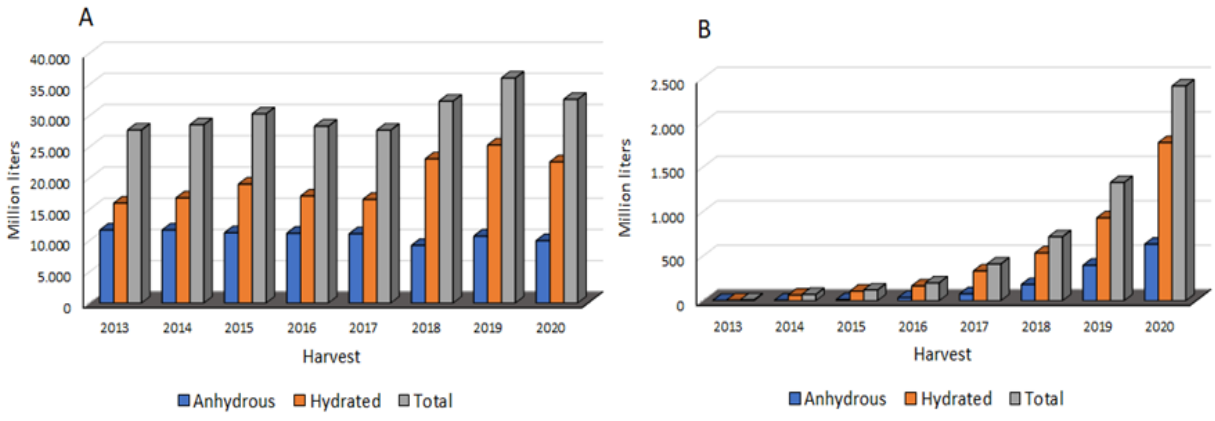

Figure 4. Evolution of anhydrous and hydrated ethanol production from sugarcane (A) and corn (B) juice in Brazil.

Ethanol fuel is part of a formidable energy matrix for Brazil due to its high sustainability and productivity and for providing socioeconomic development for different regions in which the industrial units are located. Corn and sugarcane are important energy crops in terms of productivity and profitability in ethanol conversion. These crops have high yields and have consolidated technologies from planting through harvesting and reaching industrial processing, where fermentation by selected *Saccharomyces cerevisiae strains* occurs (Jacobus et al., 2021). These microorganisms are used because they have fundamental biotechnological characteristics for the process, such as high substrate conversion, high ethanol tolerance, high viability rate, and an efficient yield in the final product (Azhar et al., 2017).

For more than 40 years, Brazil has produced ethanol from sugarcane; however, in 2018, the expansion in the quality and quantity of corn, mainly in the Midwest region, has changed this scenery, allowing competitive profits in domestic and foreign markets. The increase in biofuel productivity from corn tends to help develop and integrate new materials and studies, aiming to diversify the Brazilian bioethanol market and ensure greater productivity of this important biotechnological product.

4. Conclusions

Direct fermentation energy cultures are more advantageous from the point of view of the fermentation and economic process, but all aspects of the production chain must be taken into account, related to culture viability, productivity, cultural treatment, and product yield. The main large-scale ethanol-producing countries are the United States, using corn, and Brazil using sugarcane, and together, they supply the global demand. In these countries, energy crops have been the pillar of energy and environmental sustainability.

In the analysis of ethanol productivity from sugarcane and corn, sugarcane stands out; however, the production of corn ethanol grew exponentially between 2019 and 2020. With the crop productivity scenery and the installation of new distilleries in the Midwest region, mainly in the state of Mato Grosso, corn promises to be a strong ally in terms of competitiveness and productivity in ethanol production, in addition to producing important value-added products.

Authors' Contribution

Author Contributions Rebeca Fasioli Silva and Maria do Socorro Mascarenhas contributed to the execution of the experiment, data collection, analysis and interpretation of results, writing of the manuscript and final correction of the manuscript. Margareth Batistote contributed with analysis and interpretation of results, manuscript writing and final correction of the manuscript.

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