Review of literature on methods and processes to produce bioethanol from banana peels for disinfection and sanitation of the environment in communities, central region of Mozambique

Revisão da literatura sobre métodos e processos de produção de bioetanol a partir de cascas de banana para desinfeção e saneamento do ambiente nas comunidades, região central de Moçambique

Revisión de la literatura sobre métodos y procesos para la producción de bioetanol a partir de cáscaras de banano para la desinfección y saneamiento del medio ambiente en comunidades del centro de Mozambique

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Abstract
The demand for alcohol for human health and as an energy resource has attracted the attention of many researchers who have identified accessible and sustainable raw materials for bioethanol production at low cost and with reduced environmental impact. Among the variety of raw material for bioethanol, most come from agricultural and livestock products, in this case banana peel. The feedstock should not disequilibria food safety and should be sourced with adequate efficiency without involving too many complex procedures. Thus, the present research, through a literature review, seeks to discuss efficient methods and procedures to produce bioethanol from banana peels as agricultural waste, for application as a disinfectant of products, in human health and as energy source for households, in the context of rural areas. Many studies point to banana peels as an alternative feedstock for bioethanol production, however communities in Mozambique despite having this resource in abundance, still do not explore systematically in maximum efficiency due to the culture issues and anthropogenic knowledge. The results to maximize the efficiency are among control of production parameters, alkaline pretreatment with Sodium Hydroxide (NaOH), saccharification in a plastic reservoir with less than 10% of Sulfuric Acid (H_2SO_4) for hydrolysis, enzymatic fermentation using Saccharomyces cerevisiae, distillation at controlled temperatures from 80 up to 120 ^{0}C.
Keywords: Bioethanol; Disinfectant; Banana peels; Circular economy; Hydrolysis.

Resumo
A demanda por álcool para a saúde humana e como recurso energético tem atraído a atenção de muitos pesquisadores que identificaram matérias-primas acessíveis e sustentáveis para a produção de bioetanol, a baixo custo e com reduzido impacto ambiental. Entre a variedade de matéria-prima para o bioetanol, a maioria vem de produtos agrícolas e pecuários, no caso a casca de banana. A matéria-prima não deve desequilibrar a segurança alimentar e deve ser obtida com eficiência adequada, sem envolver muitos procedimentos complexos. Assim, a presente pesquisa, por meio de uma revisão de literatura, busca discutir métodos e procedimentos eficientes para a produção de bioetanol a partir de cascas de banana como resíduo agrícola, para aplicação como desinfetante de produtos, na saúde humana e como fonte de energia para residências, no contexto de áreas rurais. Muitos estudos apontam a casca de banana como uma matéria-prima alternativa para a produção de bioetanol, porém as comunidades moçambicanas apesar de possuírem este recurso em abundância, ainda não exploram sistematicamente e com a máxima eficiência devido às questões culturais e de conhecimento androgénico. Os resultados para maximizar a eficiência estão entre o controle dos parâmetros de produção, pré-tratamento alcalino com Hidróxido de Sódio (NaOH), sacarificação em reservatório plástico com menos

de 10% de Ácido Sulfúrico (H_2SO_4) para hidrólise, fermentação enzimática utilizando *Saccharomyces Cerevisiae*, destilação em temperaturas controladas de 80 até 120 ^{0}C.
Palavras-chave: Bioetanol; Desinfetante; Cascas de banana; Economia circular; Hidrólise.

Resumen
La demanda de alcohol para la salud humana y como recurso energético ha atraído la atención de muchos investigadores que han identificado materias primas accesibles y sostenibles para la producción de bioetanol, a bajo costo y con un impacto ambiental reducido. Entre la variedad de materia prima para el bioetanol, la mayoría proviene de productos agrícolas y ganaderos, en este caso cáscaras de plátano. La materia prima no debe desequilibrar la seguridad alimentaria y debe obtenerse con la eficiencia adecuada sin implicar demasiados procedimientos complejos. Así, la presente investigación, a través de una revisión bibliográfica, busca discutir métodos y procedimientos eficientes para la producción de bioetanol a partir de cáscaras de banano como residuo agrícola, para su aplicación como desinfectante de productos, en salud humana y como fuente de energía para los hogares, en el contexto de zonas rurales. Muchos estudios apuntan a la cáscara de plátano como materia prima alternativa para la producción de bioetanol, pero las comunidades mozambiqueñas, a pesar de tener este recurso en abundancia, aún no lo explotan de manera sistemática y con la máxima eficiencia debido a cuestiones culturales y conocimientos androgénicos. Los resultados para maximizar la eficiencia se encuentran entre el control de los parámetros de producción, el pretratamiento alcalino con Hidróxido de Sodio (NaOH), la sacarificación en un depósito plástico con menos del 10% de Ácido Sulfúrico (H_2SO_4) para hidrólisis, la fermentación enzimática con *Saccharomyces Cerevisiae*, la destilación a temperaturas controladas de 80 a 120 ^{0}C
Palabras clave: Bioetanol; Desinfectante; Cáscaras de plátano; Economía circular; Hidrólisis.

1. Introduction

Bioethanol has a millennial history; it started been distilled for more than 2000 years BC by the people of Babylonians in Mesopotamia for liquors (Levey, 1956). In addition, the bioethanol is widely indicated in many studies as alternative renewable energy source to fossil fuels for combustion engines as substitute of gasoline or mixed. In recently, the bioethanol power plants have grown almost all over the world, some researchers point to this growth because of the awareness of nations of the world in reducing the effects of climate change through compliance with the measures of the Kyoto Protocol. And others analyze it as a solution to the reduction of foreign exchange and economic dependence on fuels.

Lately, alcohol is useful in health as an antiseptic and disinfectant, in the recent past, the searches in bioethanol production were busted with the emergence of the COVID-19 pandemic, recommended by the World Health Organization (WHO) for disinfection of the SARS-CoV-2 virus.

The demand for alcohol for human health and as energy resource has attracted the attention of many researchers who as identified accessible and sustainable raw materials for producing bioethanol at low cost with no environmental impact, thus reducing dependence on alcohol and fuel imports. Among the variety of feedstock for bioethanol most are from agricultural and livestock products: fruits, rice, sugarcane, corn, cassava, animal manure and the agriculture waste.

The challenge remains to optimizing the methods and process of production. New emerging methods are being tested and discussed to maximize bioethanol production. The bioethanol production methods starting from the first generation up to the fourth generation are still being tested. These methods consider the local needs and the accessibility of raw material used, this makes the field of production very varied with very particular procedures and technologies from one region to another.

Mozambique is richly endowed with renewable and non-renewable energy resources (Cristóvão et al. 2021) and is a country based in agriculture, it has about 36 million hectares available for agriculture in which only 15% are in use (Ministry of Agriculture and Rural Development, 2016). The existing product in the agriculture farms, about 30% of post-harvest products (fruits and vegetables) are lost by weak conservation infrastructures in rural areas, (FAO, 2012/2015 and FEWS NET, 2020/2023).

In the short term, agrarian development will grow, and it will imply more land occupation and more production of waste post-harvest products. The actual models of agricultural development practiced in the country are scoped with increasing production and productivity, using agrarian mechanization. But it doesn't care about the environmental impacts of the agriculture wastes generated. The policy of rural development should start to consider the circular economy in agriculture. The concept is to reduce environmental impacts, value aggregate to agricultural losses and waste generated (Velasco-Muñoz et al. 2021)

With the lack of conditions for conservation, processing, and transportation of post-harvest products in rural areas, its forecast a generation of enormous agricultural losses, setting back investment and development of communities. Among several post-harvest losses, fruits and vegetables are the ones that have deserved a lot of attention due to the short maturation cycle (Thakur & Kumar 2017).

In the specific case of the city of Chimoio, Manica Province, many banana producers have complained a lot about post-harvest banana losses. Bananas are the most commercialized and consumed fruits in Manica, they are part of the main human diet. The fruit is rich in potassium, vitamins and fiber and energy. According to Ministry of Industry and Trading (2018), banana production in Manica was 303,442.53 tons, tending to grow every year and it is highly perishable fruit, 30% of this amount is assumed to be post-harvest (Ahmed et al. 2020). Considering the application of circular economy concepts useful in agriculture, many researchers showed positive results reusing banana peels for bioethanol productions. This approach can be applied to different sector of agriculture production to maximize the income for rural communities.

Published results appoint different methodologies for bioethanol production. However, it is not enough to produce alcohol, it must be obtained from local raw materials that are easily accessible and available in communities, it's specifications must attend to its purpose, and not create food scarcity, also must be obtained with adequate efficiency without involving many complex procedures.

Thus, the present research, through a critic review, seeks to discuss efficient methods and procedures to produce bioethanol from banana peels for application as products disinfectant, in human health and energy source for households, in the context of the Mozambican rural environment. The measure seeks to value health and aggregate value in post-harvest losses reducing environmental impacts derived from deforestation in the search for woody biomass for food supply and thermal comfort in homes.

2. Methodology

This article is an integral part of the project "Solar Dryer Integrated with Natural Rocks as Storage for Drying Fruits and Vegetable in Mozambique" - *SoDiRo,* implemented at Zambezi University and its partners. This study is the primary step for conception of the equipment to produce bioethanol from banana peels. In that context, the research is conducted with a systematic review and exploratory research to greater familiarity to face weak capacity in bioethanol production, case of central region of Mozambique (Kauark, et al., 2010). According to Ferrari (2015), the systematic review method allows synthesizing the published literature about the researched (bioethanol production with banana peels) and its state of the art. In addition, Snyder (2019) support that reviews can be the basis for development knowledge and create the guidelines for new policies and practices in researched field.

The basic source of literature reviews for the study was Google Academic, ResearchGate and other repositories. The procedures were analyzed with a focusing the accessibility conditions of the energy and local agrarian infrastructures in the Mozambican rural environment. The approach in this work is simple, it focuses on strategies to overcome the challenges in the bioethanol production with the necessary quality, based on the experiences of other researchers. It is hoped that the results of this research will serve as a starting point for local communities interested in reusing post-harvest banana losses for alcohol production.

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2.1 Location of implementation

The Figure 1 illustrate the local where the project is taking place and some the main local features.

Figure 1 - Map of Manica Province, Mozambique.

Total Area: 62,272 km2 (24,043 sq mi); **Highest elevation** 2,436 m (7,992 ft);

Total Population (2017 census) - 1,945,994 habitants; Divided into 12 districts.

Human Development Index: 0.480 in 3rd position in the country -year 2021

Principal agriculture practicing: Subsistence agriculture.

Climate: Favored by the high rainfall and mild climate.

Main agriculture products: maize, cassava, and goat meat.

Source: Wikipedia; Retrieved 2024-04-01

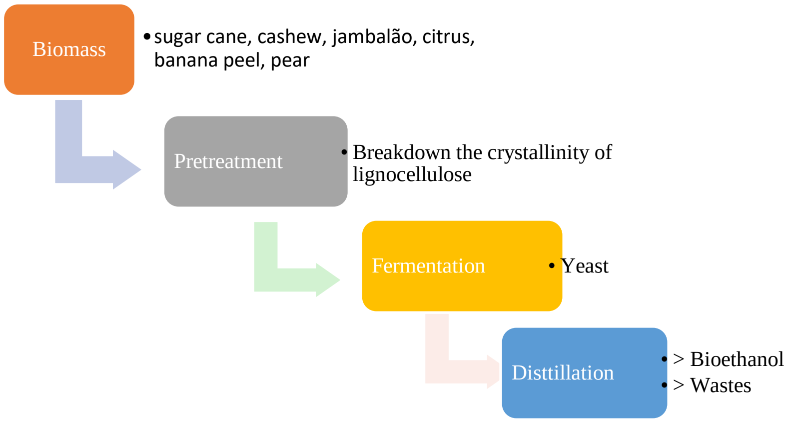
The figure above illustrates the central of Mozambique where the studies take place. It's notable from this point, once the project succeeds, the technology can easily transfer to all the country.

In terms of the review of bioethanol production methods and procedures, bioethanol is a fuel substance; it can be produced by naturally or synthetic methods through yeasts from plant matter. The feedstocks of this fuel and the combustion products make it renewable and environmentally more attractive compared to fossil fuels. However, as the raw material is mostly fruits and vegetables, it competes in a certain way, with the production of food, especially in arable land and in post-harvest products, that situation is more serious in developing countries which are fighting to ensure the food security (Oyegoke et al. 2022a). To handle with competition of food and fuel and environmental sustainability, according to the feedstocks, three generations classes of bioethanol productions methods are now available. The first generation is known and consolidated, the second is being implemented in large scale in bio refineries industries, and the third is till developed.

First-generation Bioethanol (EG1): The Bioethanol of the first generation is obtained by the oldest known production method. It consists basically in fermentation of the edible crops. In this class, two principal categories of feedstock are considered: sugar or starch in which, the sugarcane and maize are the principal crops. Other crops are watermelon juice, sweet sorghum; for s sugar; for starch are cassava, maize, sorghum, and others.

For Senna (2016), the bioethanol obtained by this method consists of the conversion of sucrose, it is glycose-type sugar from plants during the photosynthesis process, its formed by a glucose molecule and a fructose molecule. Sucrose is abundant in fruits, beets, banana peels, sugar cane. The feedstock for this class fit for human consumption, this is the reasons the EG1 method compete with food security. The advantage of EG1 lies in the opportunity to produce bioethanol in areas without electrification. Technology doesn't demand very elaborate processes. The process is presented in Figure 2 below.

Figure 2 - Simplified bioethanol production Process.



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Source: Authors.

The production process in the diagram in Figure 2 above despite as simplified, it's useful because it illustrates the principal steps of the production input/output of resource in each process.

However, bioethanol production dependent on the category of raw material, many crops to sucrose produce are seasonal. The process requires much water, and labor intensive for industry scale and there is a need for repeated distillations to produce anhydrous alcohol.

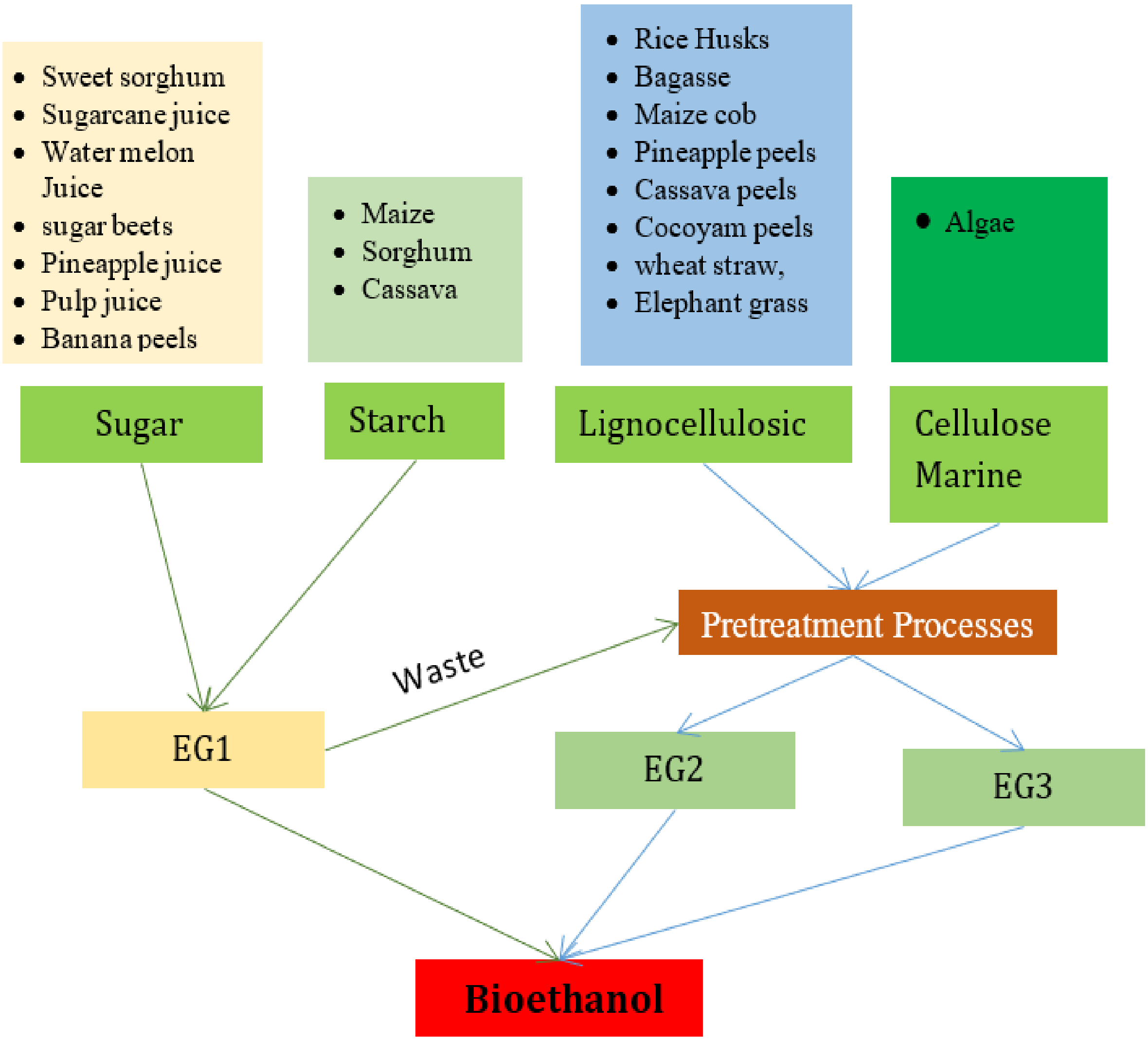
Second-generation Bioethanol (EG2): The method of obtaining bioethanol, named second generation was developed to resolve the drawbacks of the EG1, this new generation represents a more promising alternative for renewable energy. Lignocellulosic material is the raw material for EG2, which is the material discarded in ago-industry practices. For example, the sugarcane substrate, which is waste in EG1 production, this is the main raw material to produce EG2 (Senna, 2016). The other feedstock for EG2 include rice husks, maize cob, beyond energy crops and other waste.

The advantages of EG2 production are beyond the environmental preserve, they include the low costs of production. For example, the total costs of feedstocks in EG1 are around 40-70% while for EG2 are only about 30% in total production (Oyegoke et al. 2022b). However, there are barrier in developing EG2 in domestic scale, the tailbacks in this class are related to energy demand, skill labor and suitable infrastructure for pre-treatment of feedstocks, which are lignocellulosic material resulting from EG1 or, from other agriculture processes. The feedstocks are for examples sugarcane bagasse, elephant grass, cellulosic algae, wheat straws, rice husk and other biomass. It must be pretreated using complex conversion before submission to fermentation process.

The saccharification of the biomass to bioethanol is a challenging process in EG2 because of the highly recalcitrant nature of lignin of the feedstocks, to this end, it requires enzymatic hydrolyses or acid procedures. Thus, it requires qualified labor skills, knowledge in selecting appropriate enzymes to specific substrate or feedstock. Furthermore, this process demands high and controlled temperatures (Oyegoke et al., 2022b). However, the researchers are quite optimist in this class of bioethanol. Milaneza, et al., (2015) and Ansanelli et al., (2016) foreseeing the prospect of increasing of EG2 production in long term period, reaching 350 million liters of EG2 per year, and the reduction costs to around 60%. Seeking in environmental sustainability and food security new bioethanol production using feedstock available are still being researching.

Third-generation Bioethanol (EG3): Belong to this generation, the bioethanol primary produced from alga biomass. Among several algae species, there are fast-growing species: *Chlamydomonas Reinhardtian* and *Dunaliella salina*. They were identified as potential biomass raw material for EG3. The various chlorella species were also successful examined (Medeiros, et, al.,2015). Hence, the EG3 as also as EG2, has the advantages to do not compete with food, in addition, the feedstocks have a fast growth rate, and can be increased in wastewater and land unsuitable for agriculture (Oyegoke et al. 2022b). The resume of the three bioethanol generations processes productions can be illustrated in Figure 3 below.

Figure 3 - Feedstock and schematic processes to obtain bioethanol.



Source: Authors

In Figure 3 it is notable the EG1 wastes can be feedstock for EG2, and EG3 the unique known raw material are marine algae. The EG2 and EG3 are both methods which require specific pretreatment according to the raw material used.

3. Results and Discussion

Bioethanol is generally confounded with ethanol, although they have the same chemical formula C_2H_5OH, they differ in produces sources, while ethanol is product from petroleum the another is from biomass. The physical aspect is a colorless, flammable, low toxicity, volatile liquid, the molecular formula is given by C_2H_5OH, the molecular weight per mole is 46.07, the

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volumetric density is 0.789 g/cm3, it boils at 78ºC, and the melting point is -114ºC, it has a calorific value of 5.2kW/liter conferring high potential energy (Santiago et al. 2022). The alcohol concentration per production can vary according to technology used, procedures and the quality of feedstock. For an antiseptic, it's recommended that the alcohol has at least 70% of concentrated volume. The efficiency of the bioethanol from banana peel obtained in laboratory experiments ranges from 1.5 up to 3 g/L per hour (Souza et al. 2012).

Despite as Mozambique is an agriculture country and generate enormous of postharvest agriculture wastes, there is no evidence or effective plan of agriculture circular economy implementation. At the outbreak of covid 19, were verified a demand for alcohol and some institutions began to produce and selling it, but after that, facing many challenges due to poverty and some Cyclones which devasted the communities around (Meque et al., 2023), many abandoned the production of bioethanol for hand disinfection, standing out for liquors only.

According to Graziano et al., (2013) the alcohol 70% can disinfect various objects, hair and nail clippers, medicine bottles and equipment, furniture, water, and vegetables, among others. In rural areas without alcohol, the population is vulnerable to diseases transmitted by microorganisms. The deficient health system, the distance that must be traveled, financial incapacity and cultural issues are some of barriers that cause deaths due to lack of health care and reduction of life expectancy in communities, in the local market the alcohol is around 200MZN up to 500MZN per 100ml. With the technology to produce the disinfectant locally and promotion of the health prevention education in the communities, it can greatly improve the health and income in the communities.

Conferring to the literature review, for the feedstock available in Manica, it is wise to produce first-generation bioethanol at this early stage, because commercial and post-harvest banana waste is huge and destined for landfills, although it has the energy value associated with, an educational campaign for alcohol production in communities, associated with demonstrative practices, it is probable to add value to this waste in favor of environmental sustainability and the development of the family economy. The challenge now lies in the techniques and procedures of alcohol production to obtain the desired concentration for application as a disinfectant, because, as previously mentioned, the population already produces alcohol for consumption as an alcoholic beverage naturally, without the appropriate concentration and quality for this purpose.

According to academics' documents published the simple procedures for obtaining bioethanol from banana peel are illustrated in Figure 2 above, with the description:

Banana peel is abundant in Manica's market. can be jointly and clean. The cleaning allows the removal of unwanted particles (preferably with distilled water), drying allows the elimination part of water in the material (drying temperature can vary from 50ºC to 60ºC for 24h), and the solar dryer presented by (Chichango et al. 2023) in the project is ideal for this propose.

The material is crushed (for dimensions of 3cm to 5cm) to increase the surface area for the hydrolysis process, since in the structure of the banana peel the crystalline cellulose is interconnected by a hemicellulose structure covered by lignin. This preparation is called Mechanical processes in this, the material does not change the proprieties as illustrated in Figure 4 bellow.

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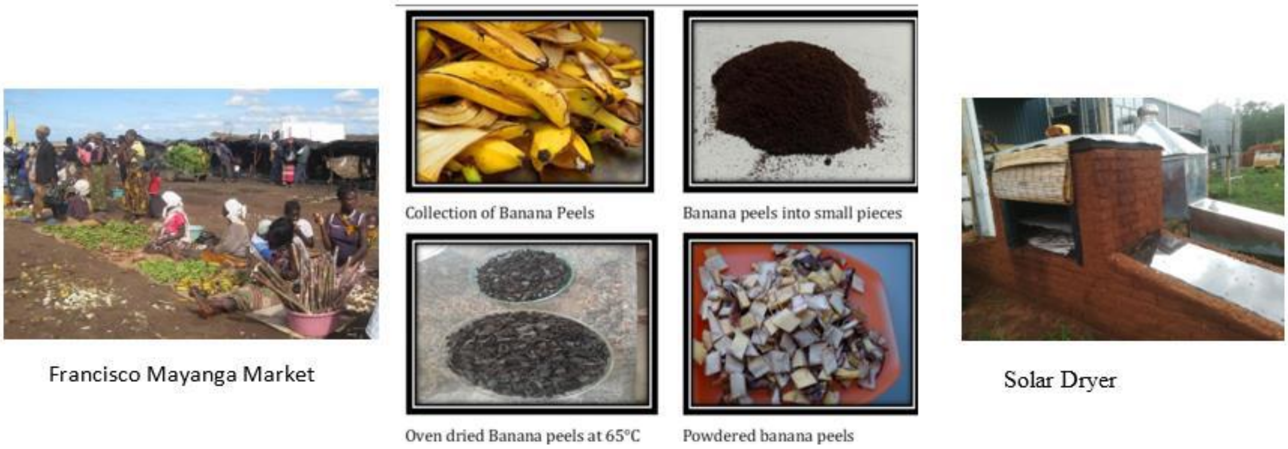
Figure 4 - Pretreatment of Banana Peels.

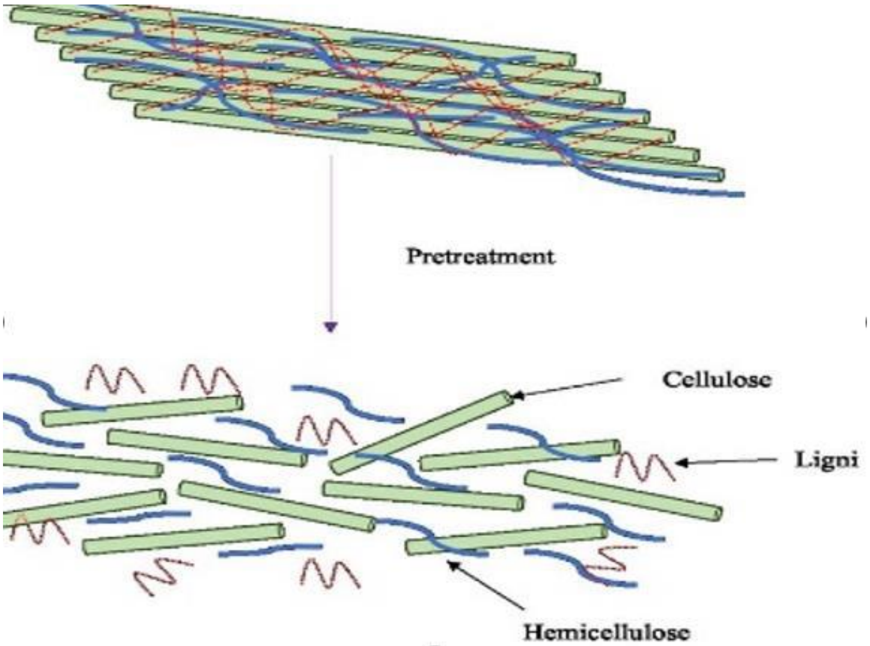


Source: Adapted in Santosh, et al., (2023) and Chichango et al. (2023).

In the figure above is notable the concerning by the banana peel which is thrown out without any treatment. Collecting and pretreating banana peels can be a wise option for reducing environmental impacts. Solar dryer showed in the picture is a wise option for reducing energy in pretreatment process.

Pretreatment is the phase that precedes the hydrolysis and fermentation, according to Agrawal et al. (2021); the main objective pretreatment is breaking down the crystallinity of cellulosic and interrupting the recalcitrant structures of the cellulosic biomass and, facilitate the accessibility to cellulose by the enzymes to convert carbohydrate polymers into fermentable sugars. One of the agents that can be used in pretreatment to aid bonds in the biomass cell wall is Ammonia. The illustration of pretreatment is shown in Figure 5.

Figure 5 - Breaking down the lignocellulose into Hemicellulose, Lignin, and cellulose.



Source: Latif et al., (2018).

In the Figure 5 above, the complex structure separated into simple structures creating conditions for microorganisms to access the sugar in the biomass, increasing thus the condition for high efficiency in fermentation for ethanol production (Xu and Huang (2014) and Latif et al. (2018)).

There are three main pretreatment methods that are most widely known, some are still under research, to increase the productivity of the bioethanol production process, they are: physicochemical, chemical, and biological. Each method has its advantages and disadvantages that may be related to side effects on equipment and users, energy requirement, operating cost, and performance, etc., the Table 1 presents the briefing of pretreatment methods.

Table 1 - Lignocellulose Pretreatment Methods and proprieties.

Pretreatment Method	Process	Aim/ action	Observation
Physic - chemical	Mechanical: Cutting, crushing, milling, and grinding	enhance the contact surface	Do not change the chemical properties of the materials.
	Thermophysical: milling, steam exploding, high-pressure steaming, etc.	improve the contact surface, decrease the polymerization degree of cellulose, decrease the crystallinity of cellulose, and somewhat crack the lignin cross-linking.	woody materials/ High cost/ energy required
	Ionic liquid or melting organic salts	green solvent	Hardwoods/ high cost
Chemical	Aqueous acidic: H2SO4 and HCl	Solvent	Softwoods and grasses/ Corrosion/feasible/toxic/ furfural formation
	Alkaline solutions: NaOH; Ca (OH)2	Solvent	Softwoods and grasses/ Feasible/efficient/
Biological	Fungus agents: Pleurotus, Pycnoporus, Echinoderm, Phlebia, etc.	Metabolism of the microorganism to destruct the crystallinity of cellulose and remove lignin	Low cost/ limited research results

Source: Adapted from (Dong et al. 2011).

According to what is shown in Table 1, considering the conditions of the communities in the region in question (lack of energy and low financial capacity, etc.) pre-treatment using the chemical method is ideal. But comparing the application of acid and alkaline solution, last one is more recommended, according to (Umagiliyage et al., (2015), Kim et al. (2016), Chang and Holtzapple (2000), the alkaline solution minimizes the losses of carbohydrates in hydrolysis by removing acetyl groups, to later facilitate hydrolysis, in addition this chemical inhibits formation of furfural.

After the pretreatment process follows the hydrolysis phase, the process goal is to further degrade the polysaccharides present in lignocellulosic in banana peel into, monosaccharide subunits to enhance the fermentation process. The hydrolysis usually occurs in two phases, liquefaction and saccharification. The main difference between liquefaction and saccharification is the conversion of starch into its soluble form (liquefaction), while in saccharification starch is converted to soluble glucose.

Liquefaction is the process to break down of the starch with alpha-amylase (α-amylase). Alpha-amylase is an enzyme that breaks down starch and converts it into liquid sugar, initiating the breakdown of starch molecules in starch hydrolysis. Almost all living organisms widely produce this enzyme. According to Raveendran et al. (2018) these enzymes have applications in various food industries, with sugar liquefaction being the main applications at the end, by saccharification, the soluble starch is converted into even-sized chains, resulting in maltose, dextrin, malt-pentose, and malt-triose. In this, several parameters, process duration, temperature, pH, enzyme, acid, and substrate concentration, may affect the alteration of starch into simple sugars structures and efficiency, so they must be carefully controlled to achieve the best results (Meegoda et al. 2018).

Difference between Hydrolase acid and enzymatic: Acid hydrolysis uses strong acids (hydrochloric acid) but is a simple and inexpensive method to hydrolyze a wide variety of compounds like hardwood, it can be performed under mild conditions. However, it can cause corrosion of the equipment and formation of unwanted by-products and may require more cautious with

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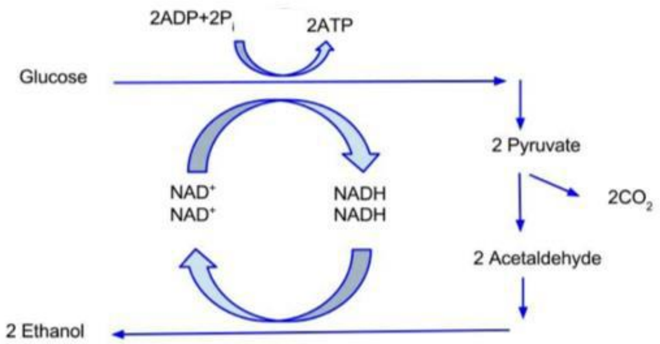
the acid used. In other hand, enzymatic hydrolysis, uses naturally occurring enzymes and is more specific and targeted than acid hydrolysis. It's performed under mild conditions and is suitable for a wide range of compounds, despite as taking more time than another. However, its expensive, may require careful handling enzyme used, and may not be suitable for all types of compounds (Azmi et al., 2017).

Fermentation process: After hydrolysis, the subsequent step is fermentation process. Two types of fermenting biomass compounds: anaerobic fermentation and aerobic fermentation. According to Zenikov 2016) aerobic fermentation takes place within livestock organisms (plants and animals) in the mitochondria and cytoplasm, in this, glucose is completely broken down into carbon dioxide and oxygen. While anaerobic fermentation occurs in parasites, bacteria, and yeasts in abscess of oxygen, in this, incomplete glucose is partially oxidized to ethanol and lactic acid, (Huang & Tang 2006; Murphy 2011).

According to BD Editors (2019); bioethanol fermentation occurs in two steps: First, pyruvate releases CO2 and forms acetaldehyde to form coenzyme Nicotinamide Adenine Dinucleotide (NAD). Acetaldehyde is then reduced by NADH (from NAD reduction) to bioethanol, regenerating NDA for use in glucose, where each glucose molecule is converted into two molecules of carbon dioxide and two molecules of ethanol as shown in figure 6. In this procedure, yeast Saccharomyces cerevisiae and the bacterium Symmons mobilis are the most used. Saccharomyces cerevisiae is the yeast that has been most prominent in this process and recent developments have been improving the fermentation of pentoses (Vieira 2009). According to Usman at Usman et al. 2016 in (Usman et al. 2016) It can produce bioethanol in a great quantity and has resisting many inhibitors such as formation of furfurans, phenolic compounds, and organic acids.

Figure 6 - Bioethanol fermentation Process from glucose and molecular formula.



Molecular Formula

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Glycose (s) Bioethanol (l) Carbon Dioxide (g)

Source: Biology Dictionary (2017).

The Figure 6 above, shows that fermentation of glucose only yields a net of 2 adenosine triphosphate (ATP) per glucose molecule (through glycolysis), the coenzyme nicotinamide adenine dinucleotide (NAD+), convert NADH back into the coenzyme NAD+, and it is used again for glycolysis. During this process pyruvate or acetaldehyde reacts with NADH to form NAD+, generating bioethanol fermentation. The fermentation process is one of the principal processes of bioethanol production (after pretreatment), it can be affected by some factores that need to be controlled, such as the presence of oxygen, the temperature and pH of the medium, the molecular formula shows that bioethanol as the principal product output.

Distillation is the last process in the production of bioethanol; The main purpose of distillation is to purify the bioethanol from the other fermentation products. According to published studies, this process demands more energy than others, and this contribute negatively to energy balance in bioethanol production, (Tgarguifa et al. 2017) did a critical review of distillation methods such as azeotropic distillation, vacuum distillation, extractive distillation, molecular sieve adsorption, pervaporation, and hybrid process.

The results have shown the hybrid pervaporation-distillation process was more economical, saving about 30% to 40%

compared to the conventional methods with easy maintenance. According to concept of Solar thermal mentioned by Chichango and Cristóvão (2021), saving energy in this process should be more effective. Furthermore, Acharya and Shukla (2023), presented a review paper on Hybrid Distillation Pervaporation, where concluded as well, that limitations of the distillation and pervaporation process can be eliminated by hybrid process (Acharya and Shukla 2023). In addition, developing green distillation techniques, are teste and are showing energy - saving promising to be alternatives (Gavahian et al. 2019).

Considering approach of the bioethanol production process presented above, it is evident that each process requires effective control to result in quality product desired, in this case 70% of concentrated alcohol. This is the bottleneck for the communities, as effective and efficient production methods require certain knowledge about the processes since the raw material (biomass) types, pre-processing, choosing of the type of fermentation and the distillation process, etc. The figure 6 below, presents the typical first-generation bioethanol production in the rural communities. The feedstock varies, it depends on the season, but frequently, the communities use, sugar cane, cashew, jambalão (Syzygium cumini), citrus (orange, tangerine, lemon, grapefruit, banana, and banana peel) and to a lesser extent is also used mango and some wild fruits such as pear, masala, among others. The production is in small scale, the concentration of the alcohol usually can reach 50% depending on the feedstock. As mentioned before, the production is for liquor.

Figure 7 - Typical rural process for bioethanol production.

Legend:

1. Distillatory (200L drum).
2. Condenser (hollowed-out tree trunk).
3. Condensate outlet (rod or thin tube).
4. Reservoir for alcohol collection.
5. Water tank for condenser.
6. Reservoir for fermentation.

Source: https://tsevele.co.mz (2020) accessed on 10th /01/2024.

In the Figure 7, it is notable the easily process and the material involved in distillation, which may reveal that the population have some skills about the process, although with low concentrate alcohol percentage, but the emerging procedures guarantee more efficiency obtaining the bioethanol with the desired concentration. The Table 2, presents some differences of improvements made in some published works to increase the efficiency in EG1 from bananas peels.

Table 2 - Some key notes of the improvements in bioethanol productions from bananas peels.

Process and Improvement	Source			
	Usman et al. 2016a	Bhatia and Shirish Paliwal 2010	Souza et al. 2012	Bilyartinus and Siswanto 2021
Colleting type of raw material	Mixed banana peels and banana pierced	Fresh banana peels	The waste was collected from an industry in the region,	Waste banana peels were collected from local market.
Pretreatment	Alkaline pretreatment NaOH and liquor to fiber ratio of 6:1.	Cut into sizes between 4cm to 5 cm. Washed and drying operation in hot air oven for a period of 24 h at 65ºC. Grounded to powdered form.	Reduction sizes, cutting into pieces of 1-2 cm	Washing banana peels with water; Smooth the banana peel with a grinder or blender
Hydrolysis	This study used 10% sulfuric acid (H2SO4)	Acid Hydrolysis (HCl) solution heated in a water bath.	Acid hydrolysis is not recommended	Acid hydrolysis H2SO4) and Urea
Fermentation	Invertase and zymase enzymes present in Saccharomyces cerevisiae.	Employed Saccharomyces cerevisiae MTCC 178	Used Saccharomyces. Cerevisiae, and at 30 °C and pH 4.5 ± 0.1, automatically controlled by the addition of 1M KOH and 1M HCl.	uses Saccharomyces cerevisiae and Bacillus subtilis bacteria, time 6 days.
Distillation	N/A used Chromatogram, production under lab conditions.	N/A Production under lab conditions.	N/A N/A Production under lab conditions.	Distillation temperature 78ºC, time 90 min.

Source: Authors.

In addition to presented in Table 2, it's fundamental to control the variables: Hydrolysis time, concentration of acid or alkaline used for hydrolysis, Fermentation time, type of the yeast must be according to the type of wort, and the type of the fermentation, distillation time, and temperature. According to literature, enzymatic hydrolysis can be carried out simultaneously with fermentation. However, there are limitations of the temperature difference between the processes, and the quality of the reservoir used. Acid hydrolysis causes oxidation and corrosion of metals. Thus, studies recommend the separation of reservoirs for the fermentation of the wort. On the other hand, the cost of enzymes for enzymatic hydrolyses is still relatively high, but studies are underway to develop hydrolysis processes to reduce the amount of enzyme used (Gasparotto et al. 2014). Finally, a knowledge transferee should be necessary in the communities' entrepreneurs, it should do as through vocational training method which is more effective (Chichango et al., 2023).

4. Final Considerations

Mozambique has high potential to produce bioethanol for personal or environmental sanitation, as well as for the diversification of its energy matrix. This is evident because there are huge losses of organic matter in the form of agricultural and forestry residues, with the forecast of an increase in these residues with the occupation of productive areas that are still idle.

Due to the availability of residues that, if nothing is done, will negatively impact the environment, the reuse of these residues as raw material to produce bioethanol would be a smart solution, in addition to adding value to post-harvest residues, it can contribute to the family income of farmers in rural areas.

The technical capacity to produce bioethanol, not only with banana peels, but also with other residues, may require continuous training of the communities in the knowledge transfer units with equipment and instruments for controlling production parameters available.

From the review made in this study, many studies revealed high efficiency results in bioethanol production from banana peel production, but all production were in small quantities, lab scale and, it is not always faithful to extrapolate parameters to large or medium quantities, so it's highly recommended for the future researchers to step up to medium bioethanol production scale. It would be important for testing and modeling the production parameters to high bioethanol from banana peels production efficiency.

5. Conclusion

In different studies, banana peels cited and tested satisfactorily as alternative bioethanol production feedstock, however there is still no specific methods and procedures for the production of bioethanol with maximum possible efficiency, due to several associated paraments that must be controlled, however, the review of methods and processes of bioethanol production from agricultural residues with banana peel has been shown to be possible whose processes are summarized in the collection of raw material, pre-treatment, hydrolysis, fermentation and distillation. In each process, there are variables such as the number of enzymes, temperatures, and duration of the process that must be controlled to inhibit other reactions, maximize the break down complex plant material into simpler sugars that can be converted into bioethanol. Furthermore, types of pretreatments, alkaline or acid hydrolysis, enzymatic or acid fermentation must be chosen. For conditions of the Mozambique communities, in the center of country, bioethanol production from banana peels would be wisely the alkaline pretreatment with Sodium Hydroxide (NaOH), using plastic reservoir saccharification with no more than 10% of Sulfuric Acid (H_2SO_4) for hydrolysis, and enzymatic fermentation use Saccharomyces cerevisiae. The distillation should be in separated drum com temperatures controlled de 80 up to 120 ^{0}C.

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