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# *Assessment Of The Bioethanol Potential Of Cactus ("Opuntia Ficus Indica") From Madagascar*

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***Abstract* -- The cactus (*Opuntia ficus indica*) is an invasive plant in arid areas. The realization of several researches on the physico-chemical properties of its cladodes and fruits encourages their valuation in a new source of energy. In addition, the *Opuntia ficus indica* is a medicinal plant but also could be a source of a new material such as plastic, leather, etc. In our study, we aim to assess the bioethanol potential of different parts of the *Opuntia ficus indica* from Madagascar. For this production, we used several processes such as reducing raw materials, grinding, gelling, fermentation and distillation. The results of this study bring us to say that we can obtain bioethanol from the *Opuntia ficus indica*: a 16° bioethanol from its cladodes and a 49° bioethanol from its fruits. Nevertheless, in order to be able to commercialize this product, improvements such as rectification are needed.**

***Keywords:* Cladodes, Prickly pear, Distillation, Sugars rate, Alcohol**

## INTRODUCTION

Madagascar is not spared from the international issues linked to the World energy production: incessant rise of the barrel cost, exhaustion of World oil reserve, etc. In front of this situation, it is imperative to find out new sources of alternative renewable energies such as biomass [1]. The *Opuntia ficus indica* called "Raketa" is a widely-known crop in the Southern part of Madagascar. The average yield is 15 to 20 tons of fruits per hectare [2].Cactus is a crassulacean acid metabolism species that serves as a food, feed, and bioenergy crop. *Opuntia ficus indica* is an attractive alternative biofuel feedstock due to its low water demand and high biomass productivity [3]. The objective of our study is to prove that bioethanol could be produced from the different parts of the cactus: cladodes and fruits.

# I MATERIALS & METHODS

## I.1 Studied parts of the plant

The parts of the plant taken into account for our experiments were cladodes (or rackets) and fruits (*cf.* Fig. 1)

### I.1.1 Cladodes

Young cladodes are easier to handle but the more mature they are, the higher is their sugar contents. Nevertheless, their qualities depend on their origins and their natures [4].

### I.1.2 Fruits

The fruits of the *Opuntia ficus indica* might have different color (green, yellow, red, purple ...), shape (ovoid, round, elliptical, elongated). They are also composed of bark, pulpy juices and seeds. Their sugar contents depend on their origins as well as their maturity [5].

## I.2 . Laboratory materials used

In order to lead our experimentation, the following laboratory materials are needed:

- a bowl and a knife: to cut and wash the raw materials
- an electronic balance: for weighing
- a graduated container: to measure the volumes of liquid materials
- an electronic mixer or a centrifuge or mortar: for the grinding
- a refractometer: to measure the rate of fermentable sugar in the raw materials
- a pot: for the gelation
- a can: whose plug is provided with a flexible pipe to release the gases during fermentation
- a thermocouple or thermometer: to control the temperature
- a distiller: for the distillation
- a hermetically sealed container: to secure volatile products (alcohol)
- a container of 250 ml capacity: to retrieve distillates
- an alcoholmeter: to measure the rate of distillate alcohol

## I.3 Bioethanol obtention

The bioethanol manufacturing process corresponds to that of a distillery, however having incredible proportions. If the raw materials are not yet liquid and sweet, they have to (1) be reduced and (2) fluidified. The raw material is molded. The carbohydrates present in this mixture must first be transformed into sugar by enzymes. Yeasts then transform the sugar present in the must in alcohol, the must starts to ferment. Once the fermentation is complete, the alcohol is separated from the must during distillation. To summarize, the process of obtaining bioethanol from the cladodes and fruits is shown respectively in Fig. 2 and Fig.3.

### I.3.1 Pretreatments

#### *I.3.1.1 Reducing raw materials*

The reduction of raw materials is a step that consists of choosing the good quality of the latter. Their nature, maturity, origin and like their sugar rate were compared.

#### *I.3.1.2 Grinding*

This step consists of crushing the raw materials using a mixer or mortar, but also by an electric centrifuge. This will facilitate fermentation [6]

#### *I.3.1.3 Gelation*

The gelation (*cf.* Fig. 4) is as its name suggests the step that consists in gelling the raw material by warming it up to 80 ° C whose purpose is to improve the next reactions.

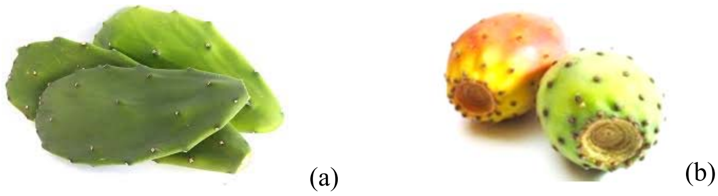


Fig. 1 : Different parts of Opuntia ficus indica: cladodes (a) and fruits (b)

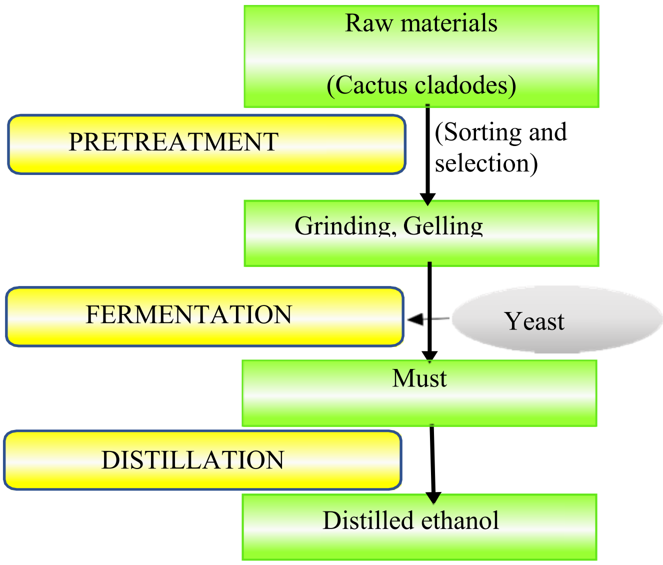


Fig. 2 : Ethanol production from cladodes

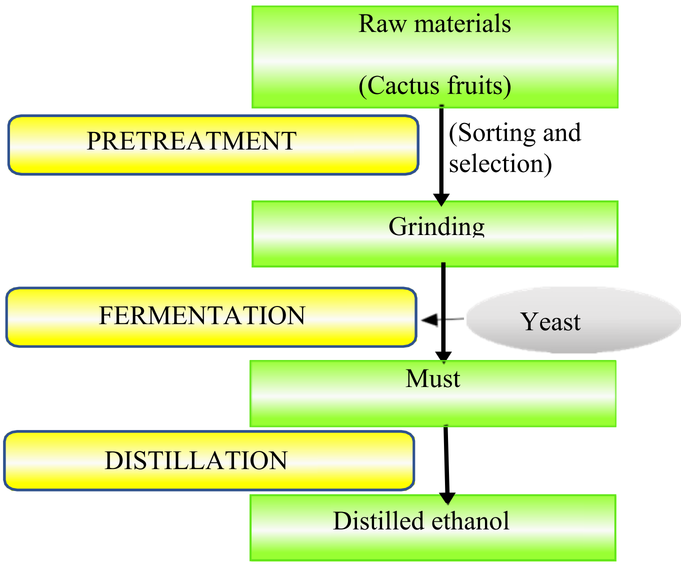


Fig. 3 : Ethanol production from fruits

Fig. 4 : Gelation of crushed cactus cladodes

### I.3.2 Fermentation

The fermentation is the phase in which the organic compounds, such as the sugars, decompose into alcohols such as bioethanol [7]. The simple commercially available baker yeast can be used for the fermentation process. Once the cladodes or fruits are crushed, the bakery yeast is added to the mixture. After incorporating the mixture, it is poured into a closed tank with a pipe plunged into water. The limits of the fermentation take root in the fact that the bacteria strains used to ferment pentoses are not as efficient as the yeast *Saccharomyces cerevisiae* commonly used to ferment glucose whose equation is as follows:

Sugars + yeasts → Ethanol + CO2 + Energy (1)

C6H12O6 (glucose) → 2 C2H5OH (ethanol) + 2 $CO_2$ (2)

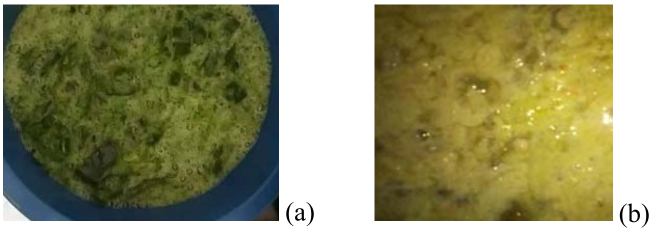


Fig. 5: Cladodes before (a) and after 3 days of fermentation (b)

### I.3.3 Distillation

Distillation is the procedure for obtaining alcohol. The mixture is heated until boiling. The vaporization then the condensation of the volatile substances forms the distillate. These volatile substances vaporize and cross the pipe, then condense in the coil refrigerant. In the refrigerant, the cold water gets inside from the bottom and leaves up. To do this, the material used is the distiller.


Fig. 6 : Distiller

## I.4 Experiments

### I.4.1 Experiments on the cladodes

The experiment was made with fresh cladodes that were collected from Vontovorona site. To make the preparation, 2000g of fresh cladodes have been weighed with an electric balance. The fresh cladodes are cut into cube from about 2 cm aside. After that, they are crushed into a mixer by adding 2000 ml of water to get after a viscous and fluid mixture. Once crushed, the mixture is put in water bath to a temperature of 80 ° C and then they are mixed with *Saccharomyces cerevisiae* or yeast baker that weighs 5% of the weight of the total mixture was 200 g. The mixture is poured into the fermentation tank.

### I.4.2 Experiments on the fruits

For this experiment, flesh and skin of cacti are used together. 1 kg of fruit gives separately 550g of skin whose sugar's rate is 5°Bx; and 450g of flesh whose sugar level is 11°Bx. When mixed, the fermentable sugar level is 9°Bx. After crushing it, 1 L of water and 100 g of *Saccharomyces cerevisiae* are added to the mixture. Once the mixture is prepared, it is poured into a can with a plug pipe. To clear the $CO_2$ inside during fermentation; whose other end is plunged into a bottle filled with water. Just a few minutes later, bubbles bubbling are observed.

# II RESULTS

## II.1 Results from the cladodes

The sugar level of the cladodes before fermentation is 5° Bx and has attenuated at 2°Bx after. The distillation begins after the mixture was fermented for four days in the tank. The first drop of bioethanol appears after 25 minutes. After a test with an alcoholmeter, the first distillate was an alcohol of 16 ° (*cf.* TABLE 1).

TABLE 1: RESULTS OF THE EXPERIMENT WITH FRESH CLADODES BY APPLYING GELATION

| **Duration (mn)** | 0 | 25 | 40 | 55 | 70 | 85 | 100 | 115 | 130 |
|---|---|---|---|---|---|---|---|---|---|
| **Temperature** | 25°C | 52°C | 78°C | 78°C | 80°C | 80°C | 80°C | 80°C | 80°C |
| **Alcoholic degree** | - | - | 16° | 10° | 9° | 7° | 5° | 4° | 3° |
| **Quantity** | - | 1st drop | 50 ml | 70 ml | 50 ml | 50 ml | 50 ml | 50 ml | 50 ml |

Fig. 7 : The results of the experiment with fresh cladodes by applying gelation

## II.2 Results from the fruits

The preparation of the fruit must is the same as the preparation of the cladodes must. The fruits do not need any gelation step. The grinded fruits are immediately mixed with 5% proportion of bakery yeast. After 4 days of fermentation, attenuation is 5°Bx if the sugar level was 11°Bx before. As for bioethanol produces, it has an alcoholic degree of 49 ° to the first drop (*cf.* TABLE 2).

TABLE 2: RESULTS OF THE EXPERIMENT ON THE FRUIT OF THE WHOLE PRICKLY PEAR

| **Duration (mn)** | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
|---|---|---|---|---|---|---|---|
| **Temperature** | 28°C | 50°C | 72°C | 72°C | 72°C | 72°C | 72°C |
| **Alcoholic degree** | - | - | 49° | 35° | 23° | 10° | 5° |
| **Quantity** | - | 1st drop | 40 ml | 40 ml | 40 ml | 40 ml | 40 ml |

Fig. 8 : The results of the experiment on the fruit of the whole prickly pear

### II.3 Comparison between the 2 experiments

TABLE 3 compares the results obtained from the different experiments : bioethanol from the cladodes and bioethanol from the fruits.

TABLE 3: FRUITS BIOETHANOL VS CLADODES BIOETHANOL

| Parameters | Fruits | Cladodes |
|---|---|---|
| Initial mass raw material (g) | 1000 | 2000 |
| Amount of water added (ml) | 1000 | 2000 |
| *Saccharomyces* quantity (g) | 100 | 200 |
| Sugar level before fermentation (°Bx) | 11 | 5 |
| Sugar level after fermentation (°Bx) | 5 | 2 |
| First drop (mn) | 15 | 25 |
| Quantity obtained (ml) | 40 | 50 |
| Alcoholic degree (°) | 49 | 16 |

## III DISCUSSION

### III.1 Bioethanol from the cladodes of *Opuntia ficus indica*

By performing the experiments on the cladodes, it is observed that the best result was on the fresh cladodes by applying the gelation that gave us an alcohol of 16 ° for the first drop. The crushed cladodes have been gelled for the fermentation to be efficient. To obtain bioethanol from the cladodes of the *Opuntia ficus indica*, gelation is the stage to be used if you want a better result. In some research, the method of which is the enzymatic fermentation, the *Opuntia ficus indica* is a good alternative for the production of a bioethanol with a low cost of production in semi-arid locations [8].

### III.2 Bioethanol from the fruits of cactus *Opuntia ficus indica*

The fruit of *Opuntia ficus indica* is a succulent fruit, so its sugar level is interesting. But since there are several types of *Opuntia ficus indica*, this sugar rate varies from 5 to 15 °Bx. In this experiment, he was 11°Bx. The best method for better performance is to use the entire fruits. Just when the preparation is in the can, bubbles are emerging from the water. This is what proves that fermentation begins well; $CO_2$ emerges, odor changes [9]. And during distillation, the first distillate obtained is an alcohol of 49 °. In some researches, they obtain bioethanol after only 16 hours; instead of using the *Saccharomyces cerevisiae*, they used the *Kluyveromyces marxianus* (YMEK23), a thermoresistant yeast strain [10]. It is therefore necessary to choose mature fruits or why not even rotten for the production of bioethanol. The yeast also holds a big role in profitability so you have to make the right choice.

### III.3 Bioethanol from fruits *vs.* bioethanol from cladodes

Several experiments of this kind have been made but the results are different from each other. This difference can be explained by the type of soil, the variations of the climatic conditions, the process followed during its preparation, and also the quality and maturity of the raw materials, not to mention the errors of manipulation [11]. Even the time to harvest them might have a considerable impact on their pH and then the bioethanol production [12].So fruits harvested with the same foot of cactus do not necessarily have the same rate of fermentable sugar. It can be noted that the cactus *Opuntia ficus indica* can produce bioethanol; whether from its cladodes or from its fruits. According to this result, it is well recognized that exploiting the fruits is profitable than the cladodes. Even by preparing them, it is found that it is much easier to manipulate the fruits than the cladodes because they are very thorny and gives off an unpleasant smell after fermentation. It is therefore possible to use the cladodes to make biogas, leather or paper with its fibers, plastic or edible gelatin because it contains a lot of gel, and other products that will soon be discovered. For now, let's keep the fruits for bioethanol production. However, a perspective of improvement is needed. The alcohol obtained here could still be redistilled in a rectifier [13]. It is an apparatus with a distillation column for more effectively separating water alcohol in order to obtain higher degree alcohol

## IV CONCLUSION

Energy is a large part of a Country's economy, so this project will contribute great importance to economic development. It could allow us to produce new products because apart from bioethanol, biogas, one can also use pear fig trees as chemical fertilizer. Of the thousands of plants that exist, cactus is the one that is hardly greedy so it is a predilection plant of arid zones. This project proved that the cactus *Opuntia ficus indica* is a used crop to produce bioethanol. The exploit would therefore be very beneficial because it also offers us a wide opportunity for the production of several new subjects that will contribute to the preservation of nature.

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