PRODUCTION OF ETHANOL FROM BANANA FRUIT WASTE. CASE OF THE MURISSERIES WHOLESALERS OF THE CITY OF ANTANANARIVO, MADAGASCAR

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ABSTRACT

As a tropical country, Madagascar has a great potential in different varieties of fruits such as: lychee, corossol, pineapple, guava and banana. The latter is the object of this research work because it is a fruit that exists all year round and all regions of the island have the same amount of it. The city of Antananarivo alone consumes an average of 24,000 t to 30,000 t of bananas every year for a minimum of 80 to 100 murisseries in the capital, i.e. an annual production of 300 t per murisseries. The banana fruit waste recorded at each stakeholder level is not the same. They vary from 5 to 20% depending on each player.
For the city of Antananarivo, the banana fruit has its own commercial circuit, which has enabled this research work to have access to databases relating to the waste potential at the level of the different actors in this sector such as collectors-transporters, wholesale transporters and wholesalers of the murisseries.
This research work made it possible to highlight the various stages to be followed for the production of ethanol from raw banana fruit waste through fermentation, distillation and rectification. Several factors are involved in the production of ethanol, but of prime importance is that the fruit on board has a significant sugar content.
A technical-economic pre-feasibility study was carried out within the framework of this research work, which led to the conclusion that the recovery of banana fruit waste into ethanol is financially profitable, as profitability indicators confirm it with an IRR rate of 28.46%, an investment will be recovered after 2 years 1 month 12 days and a profitability indicator of 1.3, i.e. invest 1 MGA and obtain 0.3 MGA of profit.

Keyword: *waste, banana, ethanol, biomass, fermentation, distillation.*

1. INTRODUCTION

The protection of the environment is a concern of the utmost importance, all over the world. Madagascar is not to be outdone and the Malagasy State is committed to it. For our country, one of the most violent causes of environmental deterioration is due to the combined harmful effects of the practice of slash-and-burn agriculture and the excessive use of wood energy. Energy plays an important role in the economic development of a developing country like

Madagascar. Currently, our country is facing serious energy problems, particularly in the area of electric power and especially in rural areas.
One of the solutions is to make use of the renewable energy potential that our country has in considerable quantity. Promoting the use of renewable energies could generate interesting prospects in rural areas, since it promotes local development through the use of endogenous resources.
This calls for research into technologies aimed at using agricultural by-products and waste as a source of energy, such as innovative technologies for manufacturing ethanol from fruit waste and the roots and tubers of certain plants.
Taking into account these stakes and noting that the banana culture, almost everywhere in Madagascar, generates a significant quantity of waste, from its exploitation circuit to its consumption, we initiated this project of : "Production of ethanol from banana fruit waste".

2. METHODOLOGIES

2.1. Study area: urban commune of Antananarivo, Madagascar

2.1.1. Geographical location

The urban commune of Antananarivo is located in the centre of the Antananarivo region and covers an area of 78 Km2. It contains an important agglomeration area and is limited by the districts namely :
- Antananarivo Avaradrano to the North and East
- Antananarivo Atsimondrano to the south and west
- Ambohidratrimo in the North and West

Being the capital of Madagascar, it is the point of convergence of the main national roads such as RN1, RN 2, RN 4 and RN 7 connecting the city with the other regions.

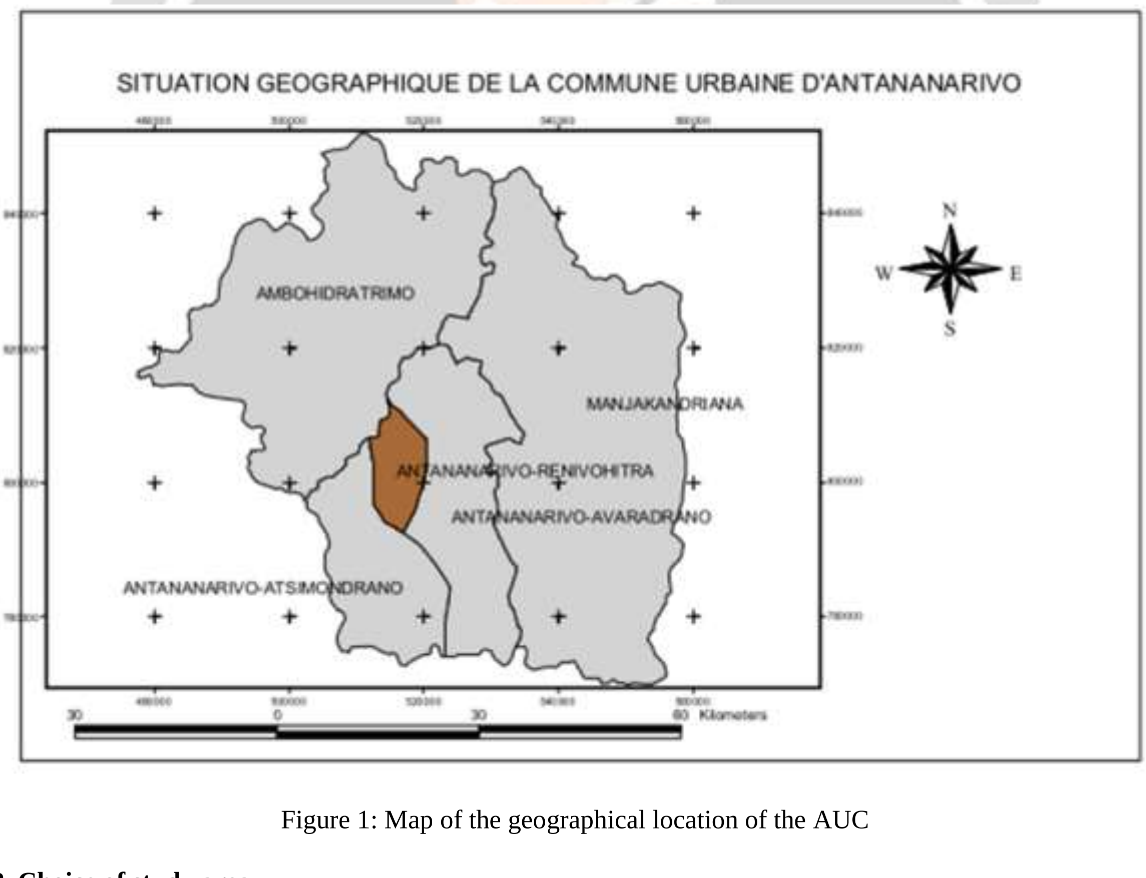

Figure 1: Map of the geographical location of the AUC

2.1.2. Choice of study area

The study sites were selected in the neighborhoods of Antananarivo and, in particular, the main banana landing sites and murisserie wholesalers.

This choice is due to the fact that the capital of Madagascar is the most populated of all the provinces. It is, therefore, the city most polluted by waste. The identification of these sites makes it possible to know the flow of banana that feeds the city and to determine the importance of the quantity of waste generated. The actors of the banana sector targeted for the surveys on the quantity of bananas and waste are the transport wholesalers, the wholesalers of the murisseries, the retailers and the customers.

2.1.3. Approach adopted for the determination of banana fruit waste in Antananarivo

a) Survey methodology

Surveys were carried out to collect general information on banana marketing in Antananarivo. The interview method adopted is to discuss with stakeholders involved in the banana trade. Discussions and interviews were conducted with transport wholesalers to find out the quantity of bananas entering the city and with murisserie wholesalers in the different districts of the city to assess the volume of waste generated.

b) Data analysis

Bibliographical research, field visits and data collected from banana industry stakeholders enabled us to understand the banana marketing circuit and to estimate the corresponding quantity of waste.

The physical post-harvest losses are linked to the length of storage in the truck. These losses are mainly caused by the evapotranspiration of the bunches and their crushing in the trucks (sometimes heterogeneity of cutting stages).

For a 12-ton truck, between loading and unloading (2 to 3 days), 700 kilos of fruit can be lost (about 6%), but beyond 3 days, losses amount to 1 to 2 tons (about 16%).

The loss of tonnage suffered by the wholesaler of the ripeners on the quantity purchased can reach up to 20% (one purchased ton generates 200 kilos of waste).

For resellers and customers, for a "*garaba*" of 20 kilos, there is a loss of around 1 kilo or 5%.

c) Marketing chain and potential of banana waste.

- **Actors**

Collectors/transporters are the most dynamic elements of the sector in that they criss-cross all the producing regions to supply farmers with basic necessities and various materials and travel up to the Highlands with banana loads.

There are several main operators: transport wholesalers, wholesalers of banana ripeners, retailers and customers.

- **Wholesale transporters**

They have their own truck and obtain their supplies mainly from the collecting wholesalers at the raft unloading sites. Wholesale transporters do not have storage facilities in town. The bananas are sold immediately upon arrival to the buyers. A load of 12 tonnes will be sold to an average of 10 to 12 customers (wholesale ripeners), i.e. an average of around one tonne per customer. The transport wholesalers set the purchase price of the banana from the ripening wholesalers.

- **Wholesalers of ripeners or "customers" are the following**

Wholesalers of wall murals are in permanent contact with the transporters of a given geographical area. They manage their supply according to the quantity of green bananas they can store in their warehouse.

Almost all the production consumed in Antananarivo, i.e. about 25,000 tonnes, passes through these ripening plants. With an average annual capacity of approximately 300 tons per ripening plant, the number of ripening plants can be estimated at between 80 and 100.

Green bananas can be kept for 15 to 30 days, but once ripe, they can be kept for only 2 to 3 days. Ripening plants must therefore regulate the supply of ripe bananas to retail markets according to their green stock.

The wholesalers of the ripening plants then sell their ripe bananas to retailers. The wholesaler packs his banana in "*garaba*" (baskets with an average capacity of 20 kg). One ton of blackberries can supply five to six retailers located in different markets in the city.

2.2. Laboratory work

Laboratory work has been carried out within CNRIT, more specifically concerning the manufacture of ethanol from banana waste. The process consists of the following three main steps:

- Fermentation
- Distillation
- Rectification

Thus various experimental works relating to these stages have been successively elaborated with :

- banana pulp
- the banana peel
- the mixture of pulp and skin

2.2.1. Fermentation

- **Fermentation procedure**

- Weighing waste

- Cutting waste into small pieces
- Mixing the pieces with a food processor to maximize extraction efficiency
- Add distilled water and "Saccharomyces cerevisiae" yeast.
- Brix degree measurement of the mixture

- **Course of the experience**

The waste is first weighed and then crushed to facilitate the fermentation process. Before measuring the brix degree, the product obtained will be mixed with distilled water and added with the yeast 'Saccharomyces cerevisiae'. Finally, the mixture obtained will be enclosed in an anaerobic environment in the fermentation tank.

Several tests have been carried out in the laboratory. The following tables illustrate the stages of these experiments.

Table 1: Fermentation (1,000g)

Waste	Quantity MP (g)	Yeast (g)	Volume of water (L)	Sugar content before fermentation (Brix)	Sugar level after fermentation (Brix)	time of the 1st drop (min)
Peau	1 000	22	1	2,5	1	42
Pulp	1 000	22	1	4	1,5	52

Table 2: Fermentation (1500g)

Waste	Quantity MP (g)	Yeast (g)	Volume of water (L)	Sugar content before fermentation (Brix)	Sugar level after fermentation (Brix)	time of the 1st drop (min)
Peau	1 500	33	1,5	2,5	1	79
Pulp	1 500	33	1,5	4,5	1,5	155

Table 3: Fermentation (2,000g)

Waste	Quantity MP (g)	Yeast (g)	Volume of water (L)	Sugar content before fermentation (Brix)	Sugar level after fermentation (Brix)	time of the 1st drop (min)
Peau	2 000	44	2	3	1	65
Mixture	2 000	44	2	7	2	75

In the tests carried out, the percentage of yeast used is 2% of the volume of the raw material.

We used a plastic canister with a volume of 10 l as a fermentation tank. The latter is equipped with a small plastic pipe at its opening to evacuate the CO_2 generated during fermentation. The end of this pipe is immersed in a container containing water. Alcoholic fermentation begins after the addition of yeast and takes place in an anaerobic environment, away from light and at room temperature. It lasts about 6 days. The transformation of sugar into ethanol produces a release of CO_2.

Not all the sugar present in the must is fermented completely into ethanol. The yield of the fermentation can be determined by knowing the initial sugar level (before fermentation) and the sugar level remaining after fermentation.

$$Attenuation=(E-Ea)/E*100$$

With:

E: sugar level in the initial solution.

Ea: Sugar level in the final state.

Among these three experiments, the third is the best, with a yield of 66.66% and 71.42%.

2.2.2. Distillation

Distillation separates bioethanol from water thanks to its ability to evaporate at a certain temperature. The following paragraphs describe the processes adopted during distillation.

- **Procedure for distillation**

- Measuring the remaining sugar level
- Preparing the distiller
- Pour in the fermented wort
- Close the distiller tightly and plug in the socket (assembly).
- Collecting the distillate

- **Preparation for distillation**

First prepare the distiller and pour the wort into the boiler. Then check the distiller pipes for leaks and start the distillation process.

2.2.3. Rectification

- **Principle of operation**

The alcohol obtained from the first distillation will be introduced into the rectifier's boiler and heated by the electrical resistance. The vapor thus formed passes through the column lined with structured material (tray). The temperature drops as it rises in the column. The vapour consisting of the least volatile component (water) cools and condenses on the trays of the column and falls back into the boiler. The vapor rich in the most volatile component (alcohol) continues to rise in the distillation column, then passes through the piping (vapor circuit) and passes through the condenser to give distilled liquid alcohol.

- **Procedure for distillation**

- Measure the alcoholic degree and temperature of the alcohol from the first distillation.
- Prepare the alcohol then pour the quantity of alcohol to be rectified into the boiler through the loading funnel (minimum 1L, maximum 4.5L).
- After loading, open the funnel valve and when all the component in the funnel is evacuated into the boiler, close the valve a second time to avoid leakage, especially as high grade alcohol is very volatile.
-open the cooling water circuit, then check that all the taps on the appliance are hermetically sealed and connect the plug
- Gradually collect the formed distillate using a graduated container (glassware).
- At the end of the distillate, wait for the apparatus to cool down and for the residue to be cold, then open the discharge valve and collect the residue.

3. RESULTS

3.1 Result of the first distillation process

At the end of the first distillation, the alcoholic degrees of the product obtained vary between 5° and 68° for each 120 ml of distillate taken.

However, the measurement of the alcoholic degrees of the first drafts of collected distillates corresponding to each type of waste experimented gives:

- 72° for banana pulp
- 52° for bruised bananas (pulp and skin)
- 35° for banana peels

For this reason, we have opted to use only bruised banana (mixture of pulp and skin) in order to reduce the various pre-treatment tasks before distillation. The separation of the pulp and peel from the banana waste is far from being a convenient operation.

The results of the experiments are illustrated in the following tables:

Table 4: Distillation of 2,000g of raw material (3.5 liters of wort)

Headings	Banana pulp	Bruised banana	Banana peel
1st distillate stream	68°	48°	30°
2nd distillate stream	40°	34°	18°
3rd distillate stream	28°	22°	8°
4th distillate stream	15°	12°	5°
5th distillate stream	9	7°	

These five jets have the same volume when measuring the alcoholic degree, i.e. 120 milliliters each with 2,000g of raw material for each test.

3.2. Result of rectification

Before the rectification, we gathered the alcohol obtained by the first distillation in three groups of alcoholic degree: 10°, 20°, and 30°.

First test group

The following conditions were chosen:

- Alcoholic strength 10°.
- Initial volume of alcohol 1.5L per test

- Set point temperature of the boiler controller (θb): 150°C
- Set point temperature of the head controller (θ tc) 78°C

At the end of this first test group, we obtained the following results:

Table 5: Characteristics of distillate and 10 % residue

Headings	Boiler temperature (θb = 150 °C)
Degree of alcohol (in °)	69
Volume of alcohol (in L)	0,100
Volume of residue (in L)	1,275
Degree of residue (in °)	2
Duration of distillation (in minutes)	170

Table 6: Temperature and time of appearance of the first distillate stream for 10°.

Headings	Boiler temperature (θb = 150 °C)
Temperature displayed by the boiler regulator (in °C)	131
Temperature displayed by the column head regulator (in °C)	78
Time of appearance of the first distillate jet (in mn)	138

As shown in these tables, for rectification of alcohol at 10°, the volume of alcohol distilled is minimal but the alcoholic strength is satisfactory.

Taking into account the time of appearance of the first distillate jet, when the temperature displayed by the boiler regulator and the temperature displayed by the column head regulator reaches its set point, there is the presence of the first jet. Note that if the temperature of the boiler is high the alcoholic degree decreases. Therefore, in order to have a higher degree, the temperature of the boiler must not exceed 150°C.

Second test group

The following conditions were chosen:
- Alcoholic strength 20° Initial volume of alcohol 1.5 L per test
- Setpoint temperature of the boiler controller (θb: 150°C)
- Setpoint temperature of the head controller (θ tc) 78°C

At the end of this second test group, we obtained the following results:

Table 7: Characteristics of the distillate and residue at 20°.

Headings	Boiler temperature (θb = 150 °C)
Degree of alcohol (en °)	75
Volume of alcohol (in L)	0,288
Volume of residue (in L)	1,146
Degree of residue (in °)	4
Duration of distillation (in minutes)	168

Table 8: Temperature and time of appearance of the first distillate stream for 20°.

Headings	Boiler temperature (θb = 150 °C)
Temperature displayed by the boiler regulator (in °C)	153
Temperature displayed by the column head regulator (in °C)	78
Time of appearance of the first distillate jet (in mn)	47

Third test group

The following conditions were chosen:
- Alcoholic strength 30° Initial volume of alcohol 1.5L per test
- Set point temperature of the boiler controller (θb): 150°C
- Set point temperature of the head controller (θ tc) 78°C

At the end of this third test group, we obtained the following results:

Table 9: Characteristics of the distillate and residue at 30°.

Headings	Boiler temperature (θb = 150 °C)
Degree of alcohol (in °)	79
Volume of alcohol (in L)	0,400
Volume of residue (in L)	0,948
Degree of residue (in °)	5
Duration of distillation (in minutes)	160

Table 10: Temperature and time of appearance of the first distillate stream for 30°.

Headings	Boiler temperature (θb = 150 °C)
Temperature displayed by the boiler regulator (in °C)	151
Temperature displayed by the column head regulator (in °C)	78
Time of appearance of the first distillate jet (in mn)	41

It is easy to see that the duration of the rectification of alcohol at 30° is less, the alcoholic degree and the volume obtained increase. This led us to gather the results of the first distillation in order to create a single solution of 30° alcohol content. This not only reduces the duration of the distillation process but also gives satisfactory results in terms of both the alcoholic strength and the volume of the distillate produced.
The results obtained are shown in the following tables:
Table 11: Characteristics of the distillate and residue at 30°.

Headings	1st jet	2^{nd} jet	3rd jet	4th jet	Residual
Degree (en°)	89	87	82	70	5
Volume (L)	0,096	0,104	0,160	0,106	960

Table 12: Temperature and time of appearance of the first distillate stream for 30

Headings	Boiler temperature (θb = 150 °C)
Temperature displayed by the boiler regulator (in °C)	155
Temperature displayed by the column head regulator (in °C)	78
Time of appearance of the first distillate jet (in mn)	40

The total volume of rectified alcohol obtained from 1,5 liters of alcohol at 30° is 0,466 liters.

4. DISCUSSION

For both developed and developing countries, ethanol is already being used and considered as a new energy source that can substitute non-renewable energy or wood energy. For developing countries such as Madagascar, wood energy takes the first place compared to other energies. However, wood energy creates various socio-economical-environmental problems.
The city of Antananarivo is classified as the most unhealthy city, it generates more than 100 tons of garbage per day, all types of waste (household waste, market waste, industrial waste, ...) while the current landfill sites are beginning to run out, the latter is no longer sufficient in the face of rapid population growth. This is becoming a major national problem due to its negative impact on public health, the main vector of various diseases such as plague, measles,...
The present study consists in the valorisation of banana fruit waste to contribute to the reduction. At the end of this work, the main objective has been reached. We transformed the waste into 80° ethanol which can be used not only as an alternative domestic fuel to wood energy but also for pharmaceutical purposes. In fact, 200 kg of waste allows us to obtain 25 Litres of 80° ethanol, which corresponds to the daily needs of 20 medium-sized households (5 people).

Besides the transformation process of this waste is very flexible, easily achievable and its investment cost is affordable, the price of the raw materials can be to discuss with the operators for a bulk collection. The practical work carried out in the laboratory has allowed us to have satisfactory results of ethanol production.

The profitability indicators for this project show us that the project is profitable. The NPV is positive 27,535,733 MGA, the invested capital is recovered after 2 years 1 month 12 days. The project can support up to 28.46% loan rate if external financing is required. According to these indicators, the project would generate benefits, and its implementation would be beneficial for the study area and also for industrialists in Madagascar and in the Indian Ocean regions.

5. CONCLUSION

This work has highlighted other possibilities for the production of ethanol from waste. For this work, banana fruit waste was used as a raw material. The development of this project has the potential to reduce pollution and protect the environment from deforestation. With a positive environmental record, bioethanol is recommended by various world bodies and also alleviates the demand for non-renewable energy, which is currently tending to become scarce.

This work has made it possible to summarize the essential points relating to bioethanol production, the various processes involved (fermentation, distillation, rectification) and the technical and economic pre-feasibility study of the project. The aim of the experimental part is to transform the fermentable sugars contained in the waste into alcohol under the action of yeast. After the first distillation of the latter, followed by rectification, alcohol at 80°GL was obtained.

This project, on an industrial scale, perfectly met the conditions required by economic evaluation tools to judge the profitability and viability of a project. We generated an Ip of 1.3 or 1MGA of invested capital, generating a profit margin of 0.3 MGA. It is noted that the production of alcohol from banana fruit waste is a profitable project with a very short payback period of 2 years 1 month and 12 days.

In short, the realization of this project provides positive spin-offs for the urban commune of Antananarivo in order to face the problem of reducing the pollution generated by banana fruit waste. The result of this research work could be applied to other types of fruit waste such as lychee, pineapple,...and also considered as a model for the recovery of fermentable waste for energy purposes.

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