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Ethanol from Babassu Coconut Starch

Technical and Economical Aspects

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ABSTRACT

This study describes a pioneering industrial-scale experience by Tobasa in ethanol production from the amylaceous flour obtained by mechanical processing of the babassu mesocarp. Technical aspects related to enzymatic and fermentation processes, as well as overall economical aspects, are discussed. When produced in a small-size industrial plant (5000 L/d), babassu ethanol has a final cost of about $218/m^3$. The impact of raw materials, production, and processing (enzymes, steam, energy, and so on) on the final product cost is also presented. Babassu coconut ethanol can be produced at low cost, compared with traditional starchy raw materials or sugar cane. The net profitability of ethanol production is about 40% for babassu coconut and just 10% for sugar cane. If the estimated renewable babassu resources were entirely industrially used, 1 billion L/yr of ethanol could be produced, which would roughly correspond to 8% of the current Brazilian ethanol production.

Index Entries: Babassu coconut; amylaceous flour; ethanol; alcohol production.

INTRODUCTION

Babassu coconut is the fruit of a Brazilian native palm (*Orbignya phalerata* Mart.), which is found in the north of the country over a very large area (about 15 million ha) *(1)*. It is a source of fuels and chemicals, mostly lauric oil, starch for ethanol production, and charcoal. The babassu palm exploitation is still carried out on an extractivist basis, but it has a relevant

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social and economical role, assuring the subsistence of about 300,000 families (2). The interest in babassu coconut as an energy source started in the 1970s, but practically all the projects in this field were discontinued. The only exception is the project conducted by Tobasa, currently in operation, and its success can be credited to the utilization of an integrated industrialization approach.

Data concerning babassu coconut productivity are controversial, but a conservative value of 2.5 metric ton/ha/yr may be taken as a representative average of the regions in which these fruits are currently exploited. Considering that only 33% of these native palms are productive, the potential productivity can be estimated as 12.4×10^6 metric ton of coconut/yr.

Babassu coconut is 80–140 mm long and consists of three layers: a fibrous external (epicarp), a fibrous-amylaceous intermediate (mesocarp), and a woody internal (endocarp) where the kernels are enclosed. The average weight contents of babassu coconut are: 12% epicarp, 23% mesocarp, 58% endocarp, and 7% kernels. Traditionally, the exploitation of babassu coconuts is oriented for oil production from kernels, wasting about 93% of the fruit biomass (3). If an integral industrial utilization is performed, a significant production of fuels and chemicals will be obtained, as indicated in Table 1, which illustrates the potential of that biomass. It can be observed that the potential for ethanol production is very high, reaching 1 billion L/yr, corresponding to 8% of the current ethanol production in Brazil. Nowadays, the internal annual consumption of lauric oils is about half of the estimated value indicated in Table 1. Thus, considering exportation of oil and the existing market for the other products, it is possible to establish an economical exploitation of babassu coconut in a large scale.

Integral coconut utilization, which is a new concept of babassu fruit processing, is based on the complete separation of its basic components (epicarp, mesocarp, endocarp, and kernels). After this industrial operation, several interesting products can be obtained by diverse processing routes, as illustrated in Fig. 1. The project implanted by Tobasa at its industrial site located at Tocantinopolis, Tocantins State, Brazil, has an integrated infrastructure from the coconut harvest, transportation, and storage until the industrial processing. Mechanical processing of the coconut fruit involves dehusking (which separates epicarp and mesocarp) and cutting of the fruits, leading to the continuous separation of the kernels and endocarp pieces. In the current project stage, only some of the products shown in Fig. 1 are industrially produced; these are lauric oil and animal feedstock (both obtained from the kernel pressing operation), primary fuel for steam generation (fibrous epicarp), charcoal and gas from the endocarp carbonization process, and amylaceous flour and ethanol from the mesocarp. The production of more sophisticated products (shown in Fig. 1) will require the development of technology and high investment costs.

This work describes an industrial process for ethanol production developed by Tobasa. This development was motivated by the significant starch content found in the coconut mesocarp (about 68%, when a manual

Table 1
Estimated Production Potential and Values of Babassu Coconut and Its Derived Products

Product	Product/ha/yr	Total product/yr	Unit value (US$)	Total value (US$/yr)
Coconut (t)	2.5	1.24×10^7	30	3.7×10^8
Alcohol (L)	200	1×10^9	0.42	4.2×10^8
Charcoal (t)	0.36	1.8×10^6	200	3.6×10^8
Oil (t)	0.10	5×10^5	1000	5×10^8
Gas[a] (m^3)	435	2.2×10^9	0.02	4.4×10^7
Epicarp (t)	0.30	1.5×10^6	30	4.5×10^7

[a] Gas from the carbonization process.

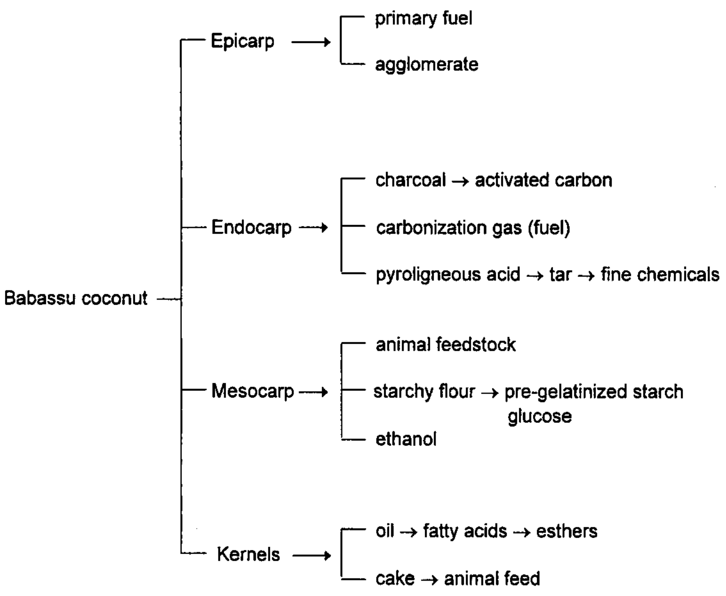

Fig. 1. Potential products obtained from the industrial processing of babassu coconut.

dehusking processing is used), and the relatively low mesocarp cost. Technical results are presented, and an economical evaluation is performed, based on an industrial-scale experience.

INDUSTRIAL PROCESS CHARACTERISTICS

Babassu Starch Characteristics

As mentioned, fruits are dehusked in an industrial machine and the following fractions are obtained: dehusked fruits, fibers (epicarp), and amylaceous flour (mesocarp). When the mechanical process is used, the per-

Table 2
Average Composition of Babassu Mesocarp
(Industrial Amylaceous Flour)

Components	Weight distribution (%)
Moisture	14.0
Starch	50.0
Protein	2.3
Fibers	10.0
Lipids	2.8
Soluble carbohydrates	1.3
Pentosans	3.4
Ash	1.3
Other components	14.8

centage of starch in the flour is about 50% (w/w) and its fiber content is around 10% (w/w). A more detailed composition of industrial babassu amylaceous flour is presented in Table 2. This flour has a brownish color because of tannins. The gelatinization temperature of the starch granules is in the range of 63–73°C, and the Brabender viscosity curves are very similar to those of corn starch. The babassu starch physicochemical properties are close to those of other common cereal starches and are very different from the properties of starches from roots and tubers (cassava, potato, and so on), as remarked by Rosenthal and Espindola *(4)*. Because of its significant amylose content, babassu starch presents a high autoretrogradation trend, thus cooking and liquefaction steps are crucial for the saccharification process, requiring a strict control of cooking and cooling process temperatures *(5)*.

Process Flowsheet

Figure 2 summarizes Tobasa's process for ethanol production from babassu amylaceous flour *(6)*. First, the milled flour is mixed with room temperature water in a 3000-L capacity stirred tank, in a batch process. The resulting slurry has a solid content of 20% w/v. This slurry is supplemented with calcium hydroxide, in order to assure a necessary amount of calcium for enzyme activity, and to adjust the solution to pH 6.0. Some amount of bactericide is also added to prevent contamination. This slurry is pumped to a buffer tank, where 33% of the amount of commercial α-amylase (Termamyl 120 L, Novo Nordisk, Denmark) required for the liquefaction process, is added. This tank assures the continuous operation of the gelatinization step, which is carried out in a specially designed jet-cooker for babassu starch processing, using saturated steam. The gelatinized starch is continuously fed to a flash tank, which promotes an abrupt

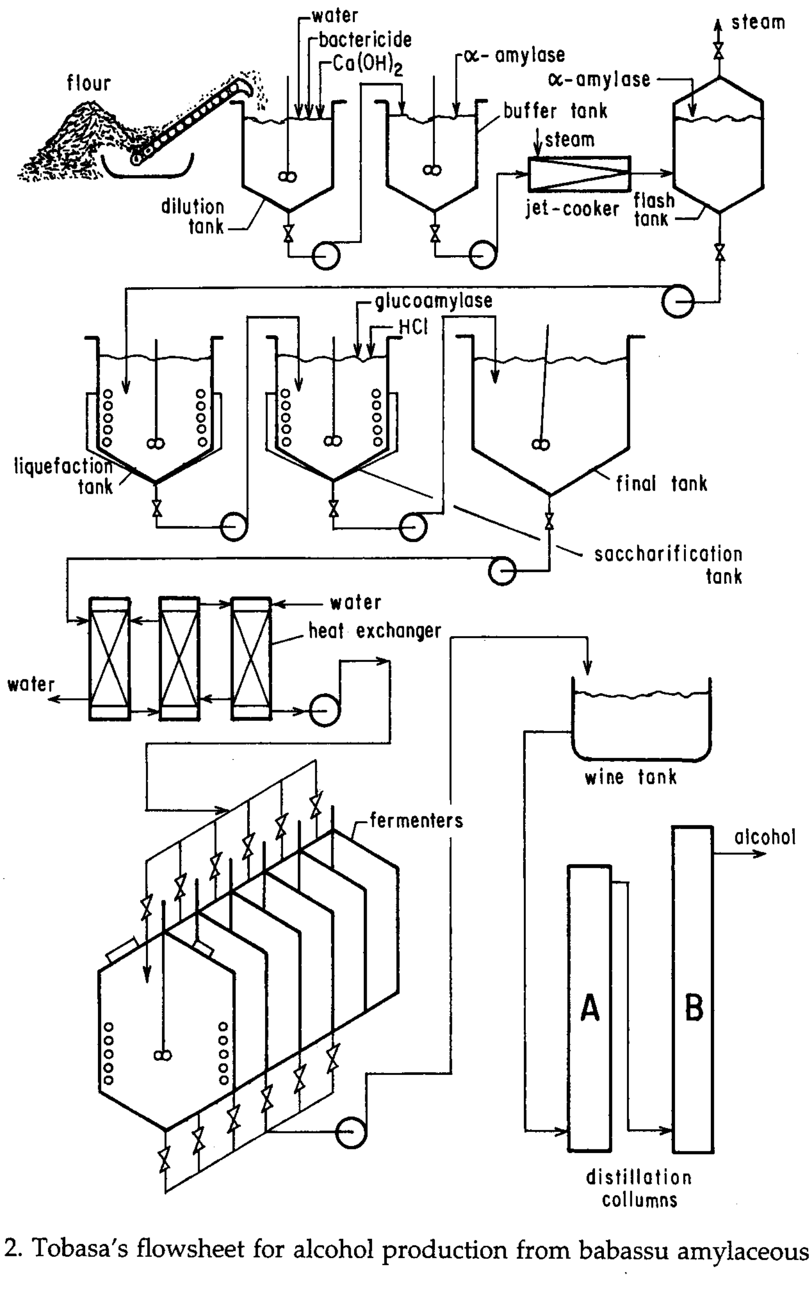

Fig. 2. Tobasa's flowsheet for alcohol production from babassu amylaceous flour.

pressure loss, reducing the liquid temperature to 85–90°C. The enzyme α-amylase (67% of the total amount required) is added to the contents of this tank in an intermittent way. To complete the liquefaction process, an additional 6000-L tank, in series with the flash tank, is necessary. This tank has an internal refrigerating coil and an external heating jacket to keep the correct liquefaction temperature. Partial starch saccharification is conducted in a 6000-L stirred tank, where an intermittent addition of the commercial enzyme glucoamylase (AMG 200 L, Novo Nordisk) is performed. This tank maintains the liquid temperature in the range of 55–60°C. The operation pH value (4.5–4.8) is controlled by the addition of commercial hydrochloric acid. The desired degree of dextrinization is achieved in a downstream 10,000-L stirred tank. The content of this tank is continuously pumped through heat exchangers to reduce the liquid temperature to 30°C, which is used in the fermentation step. This latter process step is performed in conventional open batch vessels, using six 100,000-L capacity fermenters, which are mechanically agitated and coil-refrigerated. Finally, the product is fermented by *Saccharomyces cerevisae*, and is continuously fed to a bubble-cap-tray-distillation column.

BABASSU ETHANOL QUALITY

The characteristics of babassu ethanol are similar to those of other cereal alcohols, presenting a density of 0.78 g/mL, total acidity in the range of 3–8 mg/L, and a very pleasant smell. Table 3 compares babassu alcohol produced by Tobasa with other cereal and sugar-cane alcohols found in the Brazilian market, in terms of minor components. These chromatographic results indicate that babassu alcohol has nondetectable levels of propanol and isobutyl alcohol, in contrast with sugar-cane alcohols, which present very high levels of these components. However, it presents higher amounts of ethyl acetate and acetaldehyde, compared with commercial cereal alcohols, because the distillation step at Tobasa industrial plant is not yet completely optimized. Improvements in babassu alcohol quality are expected in the near future.

ECONOMIC ASPECTS OF BABASSU ETHANOL PRODUCTION

Figure 3 shows the contribution of itemized costs on the final product cost. Raw material is the major contribution for alcohol production cost, followed by enzymes, manpower, electricity, chemicals, steam, and mechanical maintenance. Steam generation costs are quite insignificant because of epicarp utilization as solid fuel for boilers. This is a favorable aspect for the net energy balance of the industrial plant, as remarked by Menezes *(7)*.

The results obtained in Tobasa's industrial plant enable us to compare production costs and profitabilities for ethanol production from babassu starch, conventional amylaceous raw materials, and sugar cane. Table 4 summarizes technical and economical data concerning raw material market prices and its starch content, ethanol yield (based on an starch–ethanol production of 0.60 L of ethanol/kg of starch for all the amylaceous materials), conversion costs, processing costs (considered 30% of the ethanol price for amylaceous raw materials and 24% for sugar cane), and final production costs and profitabilities.

Table 3
Minor Components of Commercial and Babassu Coconut Alcohols

Alcohol type	Propanol (mg/L)	Isobutyl alcohol (mg/L)	Methanol (mg/L)	Acetaldehyde (mg/L)	Ethyl acetate (mg/L)
Babassu coconut (Tobasa)	nd	nd	84	51	226
Cereal (Trade mark A)[a]	nd	nd	51	23	10
Cereal (Trade mark B)[b]	20	nd	25	14	80
Sugar-cane (Trade mark B)	640	270	5	52	913
Sugar-cane (Trade mark C)[c]	110	32	8	110	1350

[a,b,c] Correspond to samples of commercial Brazilian alcohols (for ethical reasons, true trade marks were preserved). Component determination was performed by gas chromatography using the following conditions: FID detector, column temperature (75°C), detector temperature (150°C), stainless steel column-PAC 3334, and injection volume (5 μL).

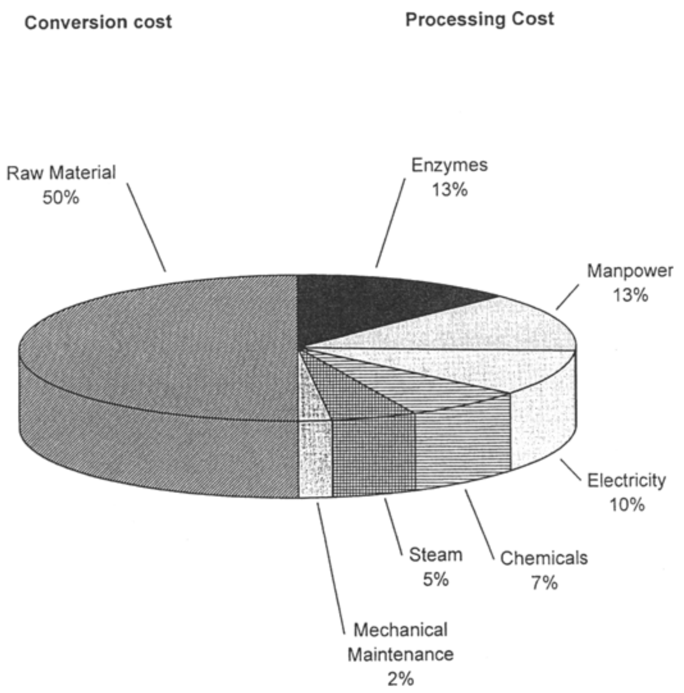

Fig. 3. Contribution of production costs on the final babassu coconut alcohol cost.

Table 4
Ethanol Production from Amylaceous Raw Materials, Babassu Coconut, and Sugar Cane: an Economical Comparative Evaluation

Parameter	Rice	Cassava	Corn	Sorghum	Babassu mesocarp	Sugar cane
FOB price (US$/metric t)[a]	85	30	120	100	32	19
Starch content (w/w%)	35	15	65	63	50	–
Ethanol yield (L/metric t)	208	90	400	370	290	80
Conversion cost (US$/m^3)[c]	408	330	300	270	109	238
Conversion cost/ethanol price (%)[b]	112	91	83	74	30	66
Processing cost (US$/m^3)[d]	109	109	109	109	109	87
Processing cost/ethanol price (%)[b]	30	30	30	30	30	24
Final production cost (US$/m^3)[e]	515	439	410	377	218	326
Final prod. cost/ethanol price (%)[b]	142	121	113	104	60	90
Profitability (US$/m^3)[f]	−152	−76	−47	−15	145	36
Profitability/ethanol price (%)[b]	−42	−21	−13	−4	40	10

[a] Raw materials prices based on current market prices of April, 1996.
[b] Ethanol established government price (free taxes): US$ 362.68/m^3 (April, 1996).
[c] The conversion cost is the result of the division of FOB price per ethanol yield.
[d] The processing cost was estimated as 30% (starchy materials) and 24% (sugar cane) of the ethanol price, based on Tobasa's experience.
[e] The final production cost is the sum of conversion and processing costs.
[f] The profitability value is the difference between the ethanol price and the final production cost.

Data from Table 4 show that ethanol production from conventional amylaceous raw materials does not present economical viability, as indicated by the negative profitability values obtained for rice, cassava, corn, and sorghum. The high profitability of ethanol production from babassu coconut is strongly linked to the pronounced starch content of its mesocarp, and the relatively low price allocated for this coconut fraction. Obviously, if the coconut fruit was purchased only for ethanol production, the profitability would become negative, as for the other starchy raw materials. Thus, only the integral utilization of the fruit allows a profitable production of alcohol. It is important to note that babassu coconut is also a source of oleaginous, proteinaceous, and carbonaceous materials, as well as fibrous material (epicarp), which, used as a primary fuel, has a major contribution for the process energy balance.

Sugar cane is considered the most competitive source for ethanol production in Brazil, mostly because of its low raw material and processing costs, compared with conventional starchy raw materials. However, as shown in Table 4, when these costs are compared with those of babassu mesocarp, a new picture is established, as conversion costs of sugar cane and babassu coconut are 66 and 30% of the alcohol price, respectively. This advantage overcomes the higher processing costs of babassu coconut. Thus, the final ethanol production cost is $326/m^3 for sugar cane and $218/m^3 for babassu coconut ethanol, resulting in profitability values of $36/m^3 and $145/m^3 respectively.

CONCLUSIONS

The production process of ethanol from babassu coconut mesocarp was developed and implanted on a small industrial scale (5,000 L ethanol/d). This process, consisting of physicochemical, enzymatic, and fermentation steps, reaches an ethanol yield of 0.60 L ethanol/kg starch, which is similar to those obtained in conventional plants processing other amylaceous materials. For babassu mesocarp, this yield corresponds to 290 L alcohol/metric ton amylaceous flour.

Alcohol production from amylaceous raw materials seldom is economically viable, because of starchy flour costs, which have increased their market prices. The production of ethanol from babassu coconut starch will be economically viable if, and only if, an integral fruit-processing approach is adopted. Babassu ethanol can be produced at a final cost of $218/m^3 which is a low value in comparison with ethanol produced from other starchy raw materials, and even sugar cane. Furthermore, it can be produced with a profitability that is significantly higher than that currently presented by sugar-cane alcohol.

The results presented in this work indicate that a rational and intensive utilization of babassu coconut can be economically performed on an industrial scale. Furthermore, babassu palms are an important native and renewable forest resource, which assures fuel and chemical production without developing new agricultural frontiers, and avoids the substitution of traditional food crops by sugar cane or other energetic crops.

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REFERENCES

1. Amaral Filho, J. (1990), *A Economia Política do Babaçu*, Sioge, São Luiz.
2. Anderson, A. B., May, P. H., and Balick, M. J. (1991), *The Subsidy from Nature: Palm Forests, Peasantry and Development on an Amazon Frontier*. Columbia University Press, New York.
3. Pinheiro, C. U. B. and Frazão, J. M. F. (1995), *Econ. Botany* **49,** 31–39.
4. Rosenthal, F. and Espindola, A. C. (1975). *Revista Brasileira de Tecnologia* **6,** 307–315.
5. Rosenthal, F., Espindola, L., Nakamura, T., Nakamura, L., Ghiotti, A., Lima, M., and Silva, S. (1978). *Informativo do INT* **XI,** 19, 3–16.
6. Baruque Filho, E. A. (1996), Tocantins Babaçu S. A. (Tobasa), Technical Report, Tocantins, Brazil.
7. Menezes, T. J. B. (1982), *Proc. Biochem.* **17,** 32–35.