THE PRODUCTION OF ETHANOL FROM BANANAS

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Summary

If fuel grade ethanol production from biomass resources is to be competitive with hydrocarbon fuels, it is essential that the raw material cost be minimised. This can be done by utilizing agricultural wastes, one such waste being export market bananas, rejected for poor quality. In the small island states of the Eastern Caribbean, about 20% of their export banana crop is rejected creating a difficult waste disposal problem.

A programme of experimental work has thus been carried out in order to evaluate the feasibility of producing fuel grade ethanol from bananas. This programme was divided into three phases, raw material characterisation, bench scale fermentation studies and small pilot plant scale ethanol production.

A comprehensive raw material analysis showed that banana pulp sugar content increased from about 6% to about 75% dry weight basis during ripening, whilst the starch content reduced from about 75% to about 1%. Similarly, peel sugar content increased from about 6% to about 45% during ripening, whilst the starch content reduced from about 30% to about 3%. The peel also contained about 15% cellulose and hemi-cellulose.

Laboratory scale fermentation studies on puréed and sliced ripe bananas using high ethanol tolerance yeasts of the *Saccharomyces cerevisiae* species showed that ethanol concentrations of about 8 wt % could be produced in about 60 hours.

Production potential from sliced ripe bananas has been demonstrated on a small pilot plant unit comprising 250 litre fermenter, centrifuge and matched atmospheric distillation column.

1. INTRODUCTION

The economies of the small island states of the Eastern Caribbean are based primarily on agricultural production, the major output being geared towards export. In the export marketing of agricultural produce, prime emphasis is placed on quality so there tends to be a significant quantity of rejected material, most of which cannot be utilised on the local market. This can pose a waste disposal problem of major proportions, so all possible means of utilising this waste as a useful raw material should be investigated.

Agricultural crop wastes are usually composed mainly of a combination of cellulose, starch and sugars, in varying quantities. All of these materials can be processed to produce ethanol by appropriate methods thus identifying ethanol production as a potentially attractive means of utilising such wastes. The ethanol produced could be sold as an industrial chemical or utilised as a fuel. The use of agricultural wastes to produce fuel grade ethanol is particularly attractive because it has been shown [1] that if fuel grade ethanol production is to be competitive with hydrocarbon fuels, it is essential that raw material costs must be minimised.

In the design of a plant to produce ethanol from crop wastes it is necessary to have an understanding of the conversion processes involved. Appropriate studies have been carried out for some materials, e.g. cassava, but not for most crop wastes. The major export crop for a number of the Eastern Caribbean states is that of bananas, a material for which little has been published on its use as a potential raw material for ethanol production. The rejection rate for poor quality is about 20%. The work described in this paper is concerned with an examination of the technical feasibility for producing ethanol from bananas. The work was carried out in three phases:

(i) Chemical analysis, in order to characterise it as a potential raw material for ethanol production.
(ii) Bench scale experimentation to study the fermentation characteristics of bananas.
(iii) Pilot plant operation to demonstrate production potential.

The bananas used in the study were of the Gros Michel variety.

2. RAW MATERIAL CHARACTERISATION

Chemical analysis of both peel and pulp for green and ripe bananas were carried out using standard well established methods on five samples. The green bananas were carefully chosen to be full but with no trace of yellow colour on the skin. The ripe bananas were completely yellow with a few brown spots on the skin. The results obtained are shown in Table 1, the reference number giving the text from which details of the method of analysis was obtained.

These results were consistent with previous studies [5] [6] on banana pulp. These previous studies had also indicated that the sugars in banana pulp were composed of approximately one third reducing sugars and two thirds sucrose, the reducing sugars being of roughly equal proportions of glucose and fructose.

3. BENCH SCALE EXPERIMENTATION STUDIES

3.1 Introduction

Reference to Table 1 shows clearly that, during the ripening process, the bulk of the starch in both the pulp and the skin is converted to sugars. Thus, for the pulp, whilst the starch composition, dry weight basis, reduced from about 75% to 1% during ripening, the total sugar concentration increased from about 6% to 76%. In the case of the skin, the starch composition, dry weight basis, reduced from about 30% to 3% during ripening, whilst the total sugar content increased from about 6% to 45%. These figures indicate that ripe bananas are eminently suitable for direct fermentation to ethanol without the need for a hydrolysis stage. The experimental work was therefore concentrated on the direct fermentation of bananas.

Component	Ref. No. for Test	Composition of Pulp in Wt %		Composition of Peel in Wt %	
		Green Stage	Ripe Stage	Green Stage	Ripe Stage
Moisture	2	72–75	71–76	85–89	80–83
Total Sugars	2	1.7–2.0	15–21	0.8–1.1	7–11
Starch	3	21.0–23.0	0.2–0.4	4.3–5.1	0.5–0.7
Protein	2	1.4–1.9	1.5–1.9	1.3–1.7	1.6–1.7
Fat	2	0.2–0.3	0.1–0.3	0.1–0.2	0.2–0.4
Ash	2	0.6–0.8	0.7–1.0	1.2–1.6	2.0–2.8
Lignin	4	0.2–0.3	0.7–0.9	1.0–1.1	0.9–1.0
Pectic Substances	4	0.7–0.8	0.5–0.7	1.0–1.2	0.7–1.0
Hemi-cellulose	4	1.5–1.6	0.9–1.0	1.5–1.6	0.8–1.1
Cellulose	4	0.1–0.2	0.4–1.0	2.0–2.5	1.8–2.2

TABLE 1 Chemical Composition of Bananas

3.2 Choice of Yeast

Since raw material analyses have indicated that the fermentable materials in ripe bananas were basically glucose, fructose and sucrose, a yeast of the *Saccharomyces cerevisiae* species was considered to be the most appropriate for promoting the fermentation. A number of different strains were obtained and tested for glucose, fructose, sucrose and ethanol tolerances and one strain chosen accordingly.

3.3 Bench Scale Fermentation Studies

3.3.1 Experimental Methods

Bench scale fermentation studies were carried out at ambient temperature (about 30°C) in 5 litre sealed concial flasks using magnetic stirrers to assist agitation. There was provision for taking substrate samples during the course of each run.

The two variables investigated in the experimental programme were:

(i) The means of raw material preparation.
(ii) The quantity of water added prior to fermentation.

Thus, two sets of runs were carried out, one where the medium was blended with water to form a purée prior to fermentation, and the second where the bananas were initially sliced prior to mixing with water and charging to the fermenting flasks. The second variable investigated was that of the quantity of water added to the fermenter broth. Thus, for each means of raw material preparation, runs were carried out at banana/water weight ratios of 0.3, 0.5, 0.6, 0.7, 0.8 and 0.9. Fermentation was difficult above a ratio of 0.8 because of the high viscosity of the medium.

During the course of each run, samples were taken at various time intervals and analysed for total sugars content, ethanol concentration and cell counts.

3.3.2 Experimental Results

Each run continued for about 72 hours by which time the total sugars concentration reduced to a very low value. Fermentation was vigorous at the low solid to liquid ratios but became patchy and difficult at the highest ratio, 0.9, when the viscosity of the medium was high and mixing inadequate.

The results for ethanol production utilising sliced bananas are shown in Figure 1 as a function of solid/liquid ratio. Similar results were obtained with the substrate in purée form. Reference to these results shows that the rate of increase of ethanol concentration was very high at the beginning of each fermentation, but the curves began to level off after about 48 hours. Total sugars concentration dropped off sharply at the beginning of each run tending normally to drop off to below 1% after about 48 hours, indicating that fermentation was almost complete.

3.4 Implications of Bench Scale Experimentation

The results shown in Figure 1 clearly demonstrate that ethanol production from a banana based substrate is quite feasible. The major problem in implementing the results is in choosing a solid/liquid ratio which will give an acceptably high ethanol concentration whilst ensuring that the substrate viscosity is not so high as to give problems in mixing and hence fermentation. On the basis of the results obtained, in conjunction with experimental observation, a solid/liquid ratio of 0.8 was considered to be the most appropriate. This ratio was used in the Pilot Plant Demonstration run.

It may be expected that slicing the bananas would be more appropriate to a production plant operation than preparing a purée. Since the bench scale fermentation results showed no advantage in puréeing, sliced bananas were used for the pilot plant run.

4. PILOT PLANT OPERATION

4.1 Equipment

The small scale pilot plant used to demonstrate the technical feasibility of ethanol production from bananas is shown in flow sheet form in Figure 2.

Fermentation was carried out in a 250 litre open stainless steel tank under ambient conditions with intermittent agitation by paddle.

After completion of fermentation, the fermenter liquid was separated from the remaining solid by means of a basket centrifuge with a 30cms diameter by 12cms deep basket.

After separation the liquid was held in a 400 litre tank prior to continuous distillation in a 10cms diameter column with 5 metres of 0.6cm Rasching ring packing. Operation was at atmospheric pressure.

4.2 Results of Pilot Plant Run

About 225kgs of bananas were initially sliced. An appropriate amount of water was added to give a solid to liquid ratio of 0.8 and the mixture sterilised prior to charging to the fermentation tank. When the mixture had cooled down to 35°C, the yeast broth was added to initiate fermentation. Samples were taken at regular intervals from this point for total sugars analysis, ethanol composition determination and cell counts. Fermentation was terminated after 100 hours when the total sugar concentration had reduced to well below 1% w/w and the ethanol concentration levelled off at about 8% w/w.

The curves of wt % total sugars and ethanol concentration against time are shown in Figure 3. Comparison with the appropriate bench scale experiment presented in Figure 1 shows the rate of fermentation to be slightly lower for the pilot plant run, but the final ethanol concentration achieved compared favourably with that found on the bench scale.

The form of the fermentation product was such that solid/liquid separation had to be carried out by centrifuge.

There was no difficulty in distilling the liquid portion to give an ethanol concentration (94% w/w) close to that of the azeotrope under atmospheric (96% w/w) conditions.

5. DISCUSSION

The raw material analysis can be used to calculate the initial total sugar concentration and final expected ethanol concentration as a function of solid/liquid ratio. The results are shown in Table 2 where the lower values are based on the lower values of total sugars in Table 1 and the higher values based on the higher value of total sugars in Table 1. When comparing the expected final ethanol concentrations with those determined experimentally in the bench scale experiments as shown in Figure 1, it is seen that there is reasonable agreement expect that for ratios of 0.5 and 0.6 the measured ethanol concentrations do not reach the expected minimum. In addition, for ratios of 0.3 and 0.7, final ethanol concentrations of slightly more than the maximum predicted were measured. The final ethanol concentration reached in the pilot plant run was also slightly more than the anticipated maximum. This may have been due to some evaporation from the open tank.

The results obtained both at bench scale and at pilot plant scale show that the production of ethanol by direct fermentation of ripe bananas is quite feasible technically. Use of the raw material analysis to calculate the expected yield indicates that somewhere between 80 and 120 litres of ethanol should be produced per tonne of bananas. In determining the expected output in a particular situation it would therefore seem reasonable to use a rule of thumb figure of about 100 litres per tonne of bananas. Thus in the case of St. Lucia which exports about 60,000 tons of bananas each year and may expect to produce about 10,000 tons per year of reject material, the potential production of ethanol is about 10^6 litres.

BANANA/WATER RATIO BY WEIGHT	% TOTAL SUGARS BY WEIGHT	% EXPECTED ETHANOL CONCENTRATION BY WEIGHT
0.1	1.75—2.10	0.81—0.97
0.2	3.50—4.20	1.61—1.93
0.3	5.25—6.30	2.42—2.90
0.4	7.00—8.40	3.22—3.86
0.5	8.75—10.50	4.03—4.83
0.6	10.50—12.60	4.83—5.80
0.7	12.25—14.70	5.64—6.76
0.8	14.00—16.80	6.44—7.73
0.9	15.75—18.90	7.25—8.69
1.0	17.50—21.00	8.05—9.66

TABLE 2: Expected Final Ethanol Concentration as a Function of Solid to Liquid Ratio

It is important to note that the total sugars composition of the ripe bananas, being generally >15wt% as shown in Table 1, compares very favourably with that for other sugar crops, such as sugar cane with a fermentable solids composition of 12.3wt% [7] and sweet Sorghum with a fermentable solids composition of 9.6wt% [7].

It is however unlikely that a plant would be built just to process bananas alone. It is more likely that a plant would be designed to handle a variety of agricultural wastes, thereby necessitating additional equipment for the hydrolysis stage.

6. CONCLUSIONS

It may be concluded that ripe bananas could constitute the basis of a suitable substrate for ethanol production by direct fermentation. In such a process for a banana to water ratio of 0.8 by weight, the results obtained show that an ethanol concentration of about 7½% should be obtained in a 60 hour fermentation period. Ethanol yield per tonne of bananas may be as high as about 100 litres.

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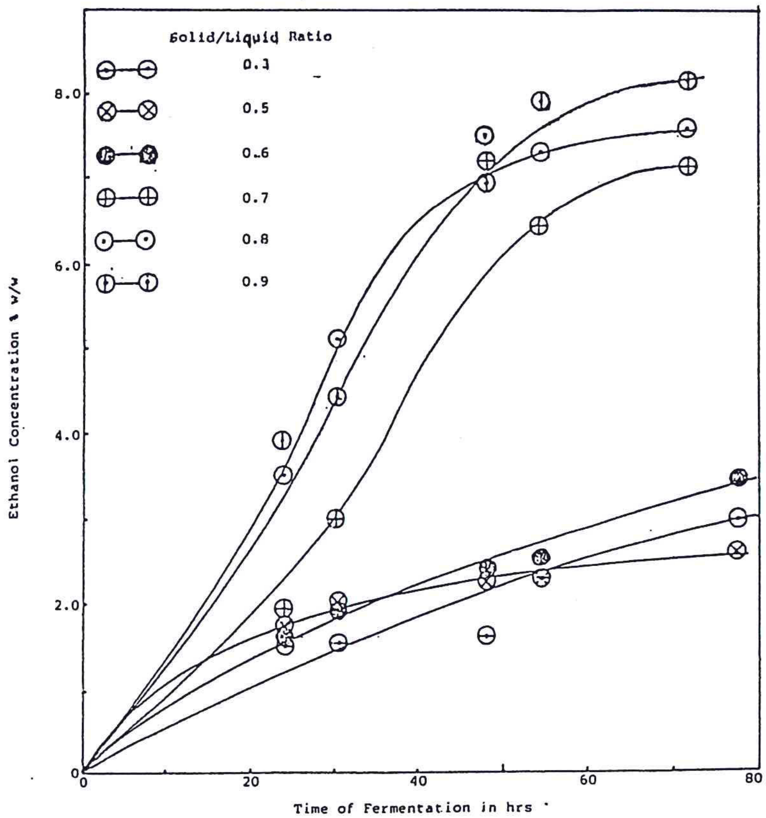

FIGURE 1 BENCH SCALE FERMENTATION RESULTS

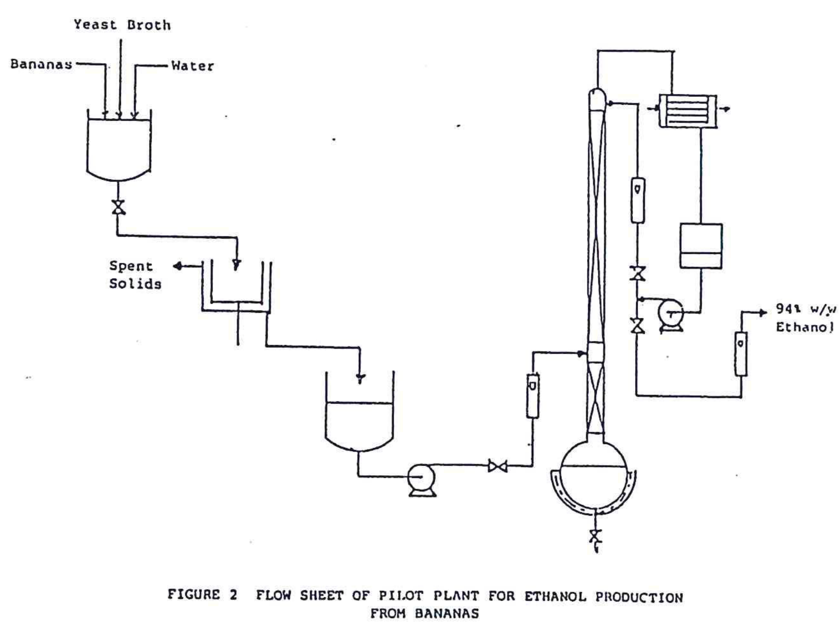

FIGURE 2 FLOW SHEET OF PILOT PLANT FOR ETHANOL PRODUCTION FROM BANANAS

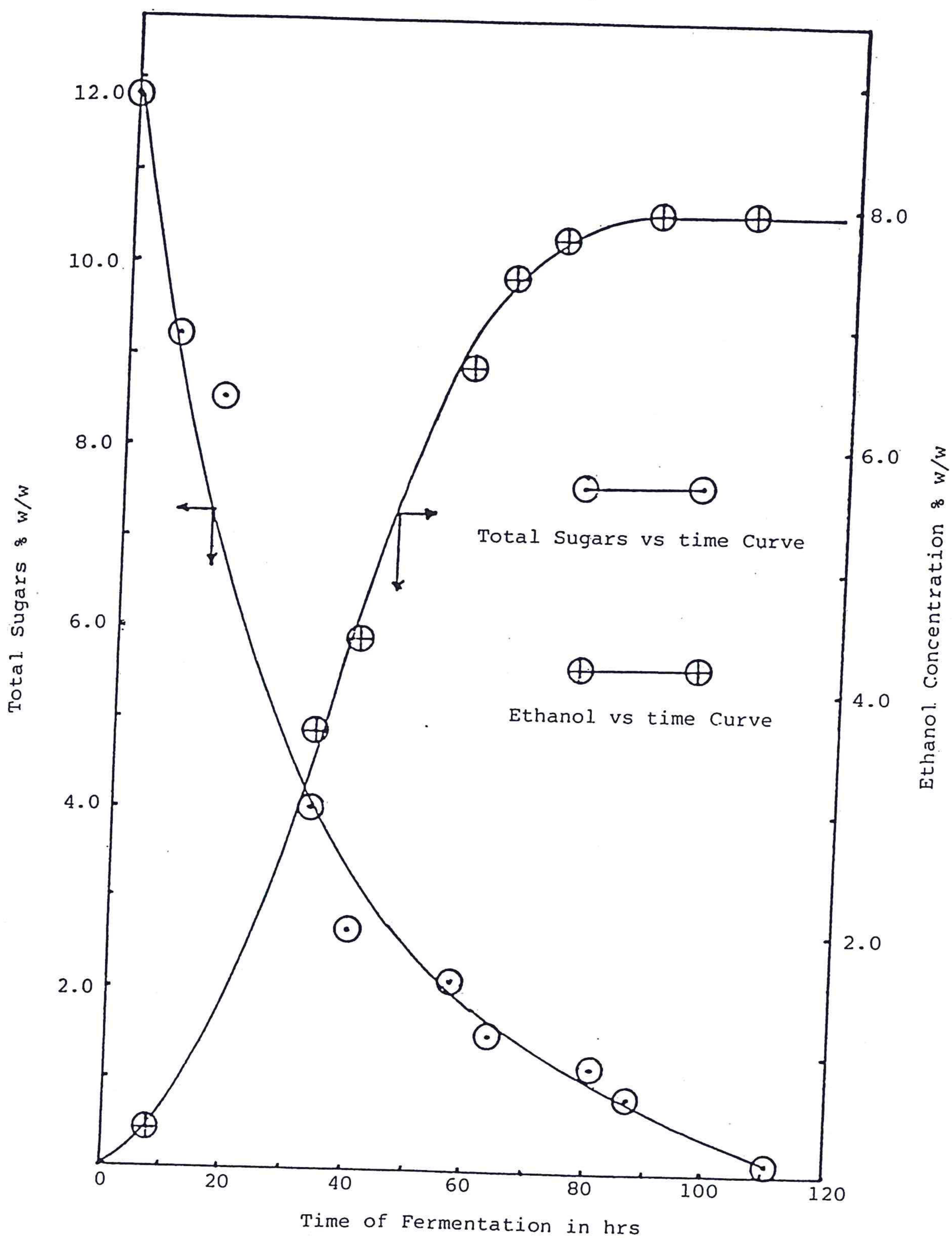

FIGURE 3 PLOTS OF TOTAL SUGARS AND ETHANOL CONCENTRATION WITH FERMENTATION TIME FOR PILOT PLANT RUN