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Studies on the Efficiency of Alcohol Production in Sweet Potato, Cassava, and Potato[1]

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Abstract: Three starchy crops, sweet potato, cassava, and potato, were used to study the efficiency of alcohol production. The results are summarized in the following.

(1) The alcohol yield of starchy crops depends not only upon the starch content, but also on the hectare yield, water content, growth period, and the degree of starch purification.

(2) The simplest method for saccharification and fermentation is to mix the starch material with yeast (Saccharomyces cerevisiae), α-amylase solution, and distilled water at the beginning of the process. It saves energy, as well as labor costs.

(3) Using this method, an alcohol yield of 5.9% for sweet potato, 7.5% for cassava, and 5.2% for potato can be obtained. If purified starch is used, the following alcohol production rates can be reached: sweet potato 9.9%, cassava 10.5%, and potato 9.5%. In the last five years, the hectare yields were averaged 16.0 tons for sweet potato, 15.4 tons for cassava, and 11.7 tons for potato. If calculation is based on purified starch, the following amounts of alcohol per ha can be distilled: 1,856 l (liter) from sweet potato, 2,296 l from cassava, and 760 l from potato. During the purification process, a large amount of material is lost. If this loss is minimized, the alcohol yield from purified starch can be increased by as much as 1.40—1.83 times.

(4) Under local cultivation conditions, sweet potato can be planted in the spring, summer, and autumn, cassava in hilly areas, and potato in winter. Particular attention should be paid to sweet potato, which is more efficient in alcohol production than the other two. However, in case of emergency, all three starchy crops could be used as substitute energy resources.

With petroleum prices increasing at a rate faster than prices of agricultural products, the benefit from food crops export to interchange for fuel petroleum has decreased. In recent years, the use of agricultural products to produce alcohol for fuel has gained worldwide interest. Several economic studies, on the feasibility of growing crops to provide starch for fermentation into alcohol were resulted in optimistic to pessimistic conclusions.

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Alcohol is a very useful liquid fuel. When mixed with petroleum (10% anhydrate alcohol+90% no Pb petroleum), it is called gasohol. Diesohol is a mixture of alcohol and diesel oil. Both have been used in some other countries.[3,9]

In Taiwan, 98% of the petroleum, and 82% of total energy needs are imported.[9] In the event of another energy crisis, renewable energy, including liquid alcohol, will play an important role. Thus, the question of which material is most economical for alcohol production is raised. In Taiwan, sweet potato, cassava, potato, sorgo,[3,11] leucaena,[4] sugar cane,[3,8] and giant brown kelp,[9] etc. all have the potential to meet this purpose. Since sweet potato, cassava, and potato are fast growing and high yielding starch crops in this province, they are to be considered as potential alcohol producing crops. Therefore, it is necessary to evaluate the efficiency and economics in alcohol production for these three plant species.

Materials and Methods

I. Materials

1) four sweet potato lines (C65, C65—46, C65—319, and C65—356)
2) three cassava varieties (Gie-tze-zong, Bai-gu-tze, and I-tze-shiang)
3) five potato lines or varieties (77—054—164, Cardinal, 325, 272, and 16)

II. Methods

1) Analysis of the chemical composition

The water content of the material was determined by heating for three hours at 105°C, the starch content by acid-catalyzed-hydrolysis, amylose content by the automatic amylose determination method, and the shape of the starch grains by microscope at 400X power.

2) Purification of the material

The raw materials were ground, and then filtrated. The protein surrounding the starch grain was removed by 0.2—0.3% NaOH solution. Finally, the fat of the material was removed by 85% methanol solution, leaving purified starch.

3) Saccharification of starch

0.1% and 1.0% α-amylase solution were used for starch saccharification at 38°C, and the two methods of saccharification (acid-catalyzed-hydrolysis with 2.5 % HCl solution, and enzyme-catalyzed-hydrolysis with 1.0% α-amylase solution) have been compared. The glucose content was then determined by the SOMOGYI method.

4) Combination of saccharification and fermentation[13].

A 50ml mixture was made, containing 10g of unpurified starch, 1.0% α-amylase solution from Aspergillus oryzae (6,500 U. E./ml), Saccharomyces cerevisiae (500mg), and distilled water. Citrate was added to adjust the pH-value to 3.5. This starch solution was subsequently fermented at 38°C. The process was also repeated in an identical fashion using purified starch.

5) Determination of fermentation rate and alcohol production rate

Einhorn fermentation tubes were used to determine the CO_2 quantity in order to find out the fermentation rate. The ethanol alcohol content was determined by G. C. under the following conditions: column temperature of 140° C, injection temperature of 160°C, detector F. I. D. temperature of 160°C, and an H_2 flow rate of 40—50ml/minute.

Results

I. Gross composition of sweet potato, cassava, and potato

The average water contents of sweet potato, cassava, and potato are 67.0%, 61.9%, and 78.4%, respectively (Table 1).

Starch contents on a dry weight basis were found to be 63.4%, 70.0%, and 54.0%, respectively.

Except for special varieties (Cardinal and C65), the difference in amylose content was not very great (sweet potato-12.6%, cassava-14.1%, and potato-16.0%). No close relationship between starch and amylose contents was found.

Furthermore, nearly all the starch grains were spherical or spheroidal in shape.

Table 1 : Gross composition of sweet potato, cassava, and potato starch

Variety or Line	Moisture (%)	Starch (% d. w.)	Amylose (% d. w.)	Granule shape
A) sweet potato				
C65	70.8	60.4	8.5	oval, spherical
C65—46	66.4	68.9	13.0	oval, spherical
C65—319	67.7	63.4	14.1	oval, spherical
C65—356	62.9	60.6	14.8	oval, spherical
Average	67.0	63.4	12.6	oval, spherical
B) cassava				
Gie-tze-zong	53.6	69.8	15.0	oval
Bai-gu-tze	69.4	72.4	13.1	oval
I-tze-shiang	62.6	67.8	14.1	oval
Average	61.9	70.0	14.1	oval
C) potato				
77—054—164	75.0	60.9	17.0	oval
Cardinal	76.5	62.8	19.5	oval
325	77.1	53.9	15.4	oval
272	81.4	47.2	15.5	oval
16	82.0	45.2	12.7	oval
Average	78.4	54.0	16.0	oval

II. Saccharification of starch

Two α-amylase solutions, 0.1%, and 1.0%, were compared. After 17.5 hours, the cassava saccharification rate of the 0.1% α-amylase solution reached 5.0% and after 41.5 hours, 5.6%. With the 1.0% α-amylase solution, they reached 29.4% and 39.2%, respectively. Therefore, the 1.0% α-amylase solution had an effect six times as great as the 0.1% α-amylase solution.

In potato, the effect of the 1.0% α-amylase solution was approximately five times as great as the effect of the 0.1% α-amylase solution. (Table 2)

Table 2 : Effect of enzyme concentration on saccharification

Enzyme and Substrate	Saccharification rate (%)	
	17.5 hr	41.5 hr
A) 0.1% α-amylase solution		
cassava starch	5.0	5.6
potato starch	9.7	10.6
B) 1.0% α-amylase solution		
cassava starch	29.4	39.2
potato starch	51.0	58.4

The results of the two saccharification methods (acid-catalysed-hydrolysis with 2.5% HCl solution and enzyme-catalyzed-hydrolysis with 1.0% α-amylase solution) have also been compared. In both methods, 0.5g of cassava starch was used. Using a 2.5% HCl solution, 88% of the starch could be changed into glucose within four hours.

When a 1.0% α-amylase solution was used, a saccharification degree of only 30% was reached after two days. In neither case could the saccharification amount be increased through longer incubation. Under the first method, 20 samples cost NT$140, while the second method, NT$144 (Table 3).

Table 3. Comparison of two saccharification methods

Methods	Cassava starch (g)	Reaction rate (% hr^{-1})	Total expense for 20 samples
Acid-catalyzed-hydrolysis (2.5% HCl)	0.5	22.01	N.T.$ 140.8
Enzyme-catalyzed-hydrolysis (1.0% α-amylase)	0.5	0.63	N.T.$ 144.4

III. Alcohol yield of sweet potato, cassava, and potato starch

Among the four sweet potato lines tested, line C65—46 had the highest starch content and alcohol production rate of 23.16% and 6.06%, respectively, followed by C65—356, with 22.50% and 5.93%, C65—319 with 20.48% and 4.51%, and C65 with

17.64% and 4.12%, respectively (Table 4). There was a positive correlation between starch content and alcohol production rate (r=0.895).

Table 4. Alcohol production % (V/TV) of four sweet potato lines

Line	Starch content (% f. w.)	Alcohol production rate
C65	17.64	4.12
C65—46	23.16	6.06
C65—319	20.48	4.51
C65—356	22.50	5.93

Among the three cassava varieties (Gie-tze-zong, Bai-gu-tze, and I-tze-shiang), variety Gie-tze-zong, with a starch content of 32.4% was the highest, produced the largest amount of alcohol (7.81%). Variety I-tze-shiang, with a starch content of 25.4%, produced the second highest alcohol amount (7.49%). Variety Bai-gu-tze, with a starch content of 22.2%, produced 7.28% alcohol (Table 5). A highly positive correlation (r=0.991) between starch content and alcohol production rate could be realized.

Table 5. Alcohol production % (V/TV) of three cassava varieties

Variety	Starch content (% f. w.)	Alcohol production rate
Gie-tze-zong	32.4	7.81
Bai-gu-tze	22.2	7.28
I-tze-shiang	25.4	7.49

Among the five potato lines or varieties analysed, line 77-054-164 with a starch content of 15.2%, had the highest alcohol production rate 6.20%. Line 16, which had the lowest starch content of 8.1% reached only an alcohol production rate of 1.37%. (Table 6) A positive correlation of 0.941 between starch content and alcohol production rate could also be realized.

Table 6. Alcohol production % (V/TV) of five potato lines or varieties

Variety or Line	Starch content (% f. w.)	Alcohol production rate
77—054—164	15.2	6.20
Cardinal	14.8	5.20
325	12.4	4.53
272	8.8	2.79
16	8.1	1.37

The alcohol yield of a single plant does not only depend upon its starch and water content, but also upon its yield. For example, the variety "Cardinal", with a starch content of 14.8%, had nearly the same alcohol yield as line "325", which had starch content only 12.4%. This is because variety "Cardinal" had a yield of 700g per plant as compared with 770g in line "325" (Table 7).

When purified sweet potato starch (from line C65—356) was used, the alcohol production rate reached 9.9%, as compared with the 5.9% of unpurified starch. The alcohol rate produced from purified cassava starch (from variety I-tze-shiang) amounted to 10.5%, as compared with the 7.5% of the non-purified starch. In potato (from variety "Cardinal") the alcohol production rate amounted to 9.5% for the purified starch, and 5.2% for the unpurified starch. Obviously, when the starch was purified, the alcohol rate was much higher than that of the non-purified starch. There is a highly significant correlation between starch purification and alcohol yield (Table 8).

Table 7. Theoretical alcohol production per hectare of five potato lines or varieties

Variety or Line	Starch content (% fr. w.)	Moisture (%)	Alcohol (ml/10g starch)	Yield (g/pl.)	Theor. ha Alcohol(1)
77—054—164	15.23	75.0	3.29	562	1,541
Cardinal	14.78	76.5	2.59	700	1,420
325	12.36	77.1	2.40	770	1,411
272	8.80	81.4	1.48	271	228
16	8.14	82.0	0.28	672	113

Table 8. Effect of starch purification on alcohol production rate

Energy crop	Starch content (% d. w.)		Alcohol production (% V/TV)	
	non-purified	purified	non-purified	purified
sweet potato	60.7	89.3	5.9	9.9
cassava	67.8	88.2	7.5	10.5
potato	62.8	88.4	5.2	9.5

Using 10g unpurified sweet potato dry starch (from line"C 65—356"), an alcohol yield of 5.9%, i. e. 3.13ml, was produced. In the past five years (1976—1980), the average sweet potato ha-yield was 15,979 kg/ha (Table 9). After subtracting the water content (62.9%) from the ha-yield (Table 1), 5,928kg unpurified sweet potato starch was obtained, and theoretically, from this, 1,856 1 of alcohol could be produced.

Table 9. The annual yield of sweet potato, cassava, and potato from 1976—1980 in Taiwan

Year	Yield per hectare (kg)		
	sweet potato	cassava	potato
1976	14,959	16,291	11,082
1977	15,551	15,581	11,361
1978	15,964	15,008	11,623
1979	16,476	15,305	12,339
1980	16,949	14,941	12,170
Average	15,979	15,425	11,715

With an average hectare yield of 15,425kg, and a water content of 62.6%, 5,769 kg unpurified starch from cassava variety "I-tze-shiang" could theoretically yield 2,296 1 of ethanol alcohol.

From potato variety "Cardinal" with an average hectare yield of 11,715 kg and a water content of 76.5%, 2,753 kg unpurified starch could be produced. This, in turn, could theoretically yield 760 1 of alcohol.

IV. Factors influencing the fermentation rate and alcohol yield

a. Effect of starch purification on alcohol production

Purified sweet potato starch produced 1.70 times as much ethanol as non-purified starch. Purified cassava starch yielded 1.40 times as much alcohol as unpurified starch. For potato, it was as much as 1.83 times.

b. Effect of pH-value on the fermentation rate

Under acidic conditions (pH 2.5—4.5 adjusted by citrate or phosphoric acid), Saccharomyces cerevisiae performed better than under neutral conditions (pH 5.5—7.0).

c. Influence of the starch concentration on the fermentation rate

To each starch concentration, 0.5g yeast was added. The quickest fermentation rate was obtained by using 5.0g starch/50 ml volume. When a concentration of 0.5g starch/50 ml volume was used, the amount of alcohol was only 12.9% of the 5.0 g starch/50 ml volume, with a concentration of 1.0g starch/50 ml volume, it was 24.5% of the 5.0 g starch/50 ml volume, and with 10.0 g starch/50 ml volume, it was 61.8% (Table 10). Using a higher starch concentration than 10.0 g starch/50 ml volume, the rate of ethanol production decreased because of the increasing difficulty in mixing starch grains, amylase solution, and yeast.

Table 10. Fermentation rate (indicated by CO_2 production) from different amounts of potato starch (using acid-catalysed-hydrolysis and adding 0.5g yeast)

Potato starch (g)	CO_2 production (ml)					Index (%)
	1hr	2hr	3hr	4hr	5hr	
0.5	0.60	0.80	1.25	2.25	2.33	12.9
1.0	0.80	1.30	2.25	3.65	4.45	24.5
5.0	2.00	3.50	6.60	13.90	18.20	100.0
10.0	0.60	1.30	2.95	6.95	11.25	61.8

d. Effect of S. cerevisiae quantity on the fermentation rate

When purified sweet potato or cassava starch were used, the alcohol fermentation rate was increased by larger amounts of yeast.

Discussion and conclusion

Sweet potato, cassava, and potato starch can be saccharified and fermented to produce ethanol alcohol. [3,8,9,10,13] In this study, a higher ethanol production rate (7.5% V/TV) was obtained by using cassava starch than by sweet potato (5.9%) or potato starch (5.2%).

For a high alcohol yield, a high starch content in the plant is the most important criterion. For example, the two potato lines, 77-054-164 and 16, have starch contents of 15.23% and 8.14%, respectively, and from that, an alcohol yield of 1,541 l/ha and 113 l/ha, respectively, could be obtained. The substantial difference is due to the difference in starch content. Varietal variation in starch content within a plant species was obtained : The starch content of sweet potato varied from 8% to 29%, cassava from 22% to 32%, and potato from 8% to 22%. Therefore, varieties with the highest starch contents should be used for alcohol production, and the development of high starch content varieties through breeding should be emphasized.

On the other hand, the growth period of a plant species is equally important. Though the estimated ethanol yield in cassava is as high as 2,296 l/ha, compared with sweet potato's 1,856 l/ha, and potato's 760 l/ha, it must be taken into consideration that cassava's growth period lasts 15—18 months. [14] Potato has a growth period of only three months, but its alcohol yield is low, due to its high water content and low average ha-yield. Furthermore, potato, a cold weather crop, can be planted only once in the winter in Taiwan [12]. Among the three plant species, sweet potato is the most efficient energy crop. Although its alcohol yield of 1,856 1 is lower than that of cassava, its average ha-yield is higher, in addition, it can be planted two or three times a year [6].

The water content and the yield capacity of tubers are the essential criteria for determining alcohol production levels. The estimated ethanol ha-yield of potato variety "Cardinal" was as low as 760 1, which is only 60% of the amount reported previously [3]. This was primarily due to this variety's high water content. Its ethanol hectare yield was calculated by averaging the 5-year yield of all potato varieties. If the yield per plant of 700g (Table 7) had been used, an ethanol yield of about 1,420 l/ha could have been obtained. This means the higher the ha-yield of the variety, the higher the amount of alcohol produced.

The theoretical ethanol yields of sweet potato and cassava reported from others are 1,875 l/ha and 2,700 l/ha [3], and 1,758 and 2,567 l/ha [9] respectively. These values are very close to the present study's findings of 1,856 and 2,296 l/ha, respectively.

By using NaOH and methanol solution, a purification grade of 90% was obtained (Table 8). This purification process has two advantages : a shorter fermentation period, and a higher alcohol yield. As shown in this study, the purified sweet potato starch produced an alcohol yield 1.70 times greater than that of non-purified sweet potato starch (Table 8). The same effect was observed on cassava, which was as high as 1.40 times, and on potato, as high as 1.83 times. But, during the purification process, a lot of material was lost. It is very important to minimize this loss.

Saccharomyces cerevisiae performs better under acid than neutral conditions, but whether citrate or H_3PO_4 was used made no difference.

Other factors which can affect the results of fermentation are : the fermentation temperature, the removal of inhibiting substances, the agitation of the fermentation tube, and the yeast species [11,13] etc. For example, the yeast species, Zymomonas mobilis, and Saccharomyces formosensis, had positive effects on the fermentation of sorgo [11]. It has yet to be determined whether these two yeast species also have positive effects on sweet potato, cassava, and potato.

In addition to the use of sweet potato, cassava, and potato tubers for ethanol production, their leaves and stems can be used to produce methane gas [2,3]. This aspect should be further studied.

With regard to energy input and output(energy balance)in sweet potato and cassava ethanol production, Prof. Y. C. SU reported that both had a net gain of 760 Kcal [9]. If farming methods and fermentation techniques could be improved, the net energy gain could be as much as 3,260 Kcal.

Other plant species, such as sorgo, leucaena, sugar cane, etc. could be used for partial gasoline substitutes [3,9]. Under local cultivation conditions, they all l ave high yield potential.

The saccharification reaction time was short when HCl solution was used for saccharification, then yeast was added for fermentation, but the alcohol yield was low. This is because the starch concentration was greatly diluted after acid treatment, and this resulted in low glucose concentration [8]. If starch material, α-amylase solution, yeast, and water are mixed for both saccharification and fermentation, the process is not only energy, but also labor saving, as it was indicated in this experiment.

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甘藷、樹薯及馬鈴薯之酒精生成效益研究[1]

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摘　要

甘藷、樹薯及馬鈴薯等三種澱粉作物之酒精生成效益之研究結論摘要如下：

1. 影響澱粉作物酒精生成的要素，不僅在其澱粉含量，其他關係亦大的性狀尚有公頃產量、含水率、生育日數及其澱粉的純化程度。
2. 最簡便的酒精生成法是於操作開始時，混合定量之澱粉原料、澱粉酵素、酵母菌及蒸餾水，使能同時進行醣化及醱酵兩作用，此法同時可節約能源及人力。
3. 利用上法所得之酒精產率，在甘藷爲5.9%，樹薯爲7.5%，馬鈴薯爲 5.2%，如改用純化過的澱粉，則可得的酒精率在甘藷是9.9%，樹薯是10.5%，馬鈴薯爲9.5%；依過去五年的平均公頃產量，甘藷約16.0公噸，樹薯15.4公噸，馬鈴薯 11.7公噸，由之估計每公頃酒精生成量，在甘藷爲1,856公升，樹薯2,296公升，馬鈴薯760公升。澱粉於純化過程中雖量的損失頗大，但純化後其酒精產率可提高爲同量未純化澱粉的1.40—1.83倍。因此，如能改進其純化過程，使澱粉損失量減少，則酒精產量可以大爲提高。
4. 依本省的栽培狀況，甘藷可於春、夏、秋三季依序種植，樹薯可種於山坡地，馬鈴薯可於冬季種植，論酒精生成的經濟效益，甘藷的潛力凌駕於其他二者之上。

總之，這些澱粉作物在非常時期將可被用爲一種替代能源。

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