Chapter 35
Viability of Using Cassava as Feedstock for Bioethanol Production in Fiji

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Abstract Ethanol production from renewable resources has received attention due to increasing petroleum shortage. One such renewable resource that has been identified is cassava starch. Cassava starch is extracted from root crop, cassava (*Manihot esculenta* (*Crantz*)) and is readily available in Fiji. Many countries such as China, Thailand and India are already having success in producing high starch yielding cassava varieties that can be used for ethanol production. The current paper investigates the viability of producing ethanol from locally available cassava varieties in Fiji. Starch was extracted from the roots of ten different cassava varieties available at two different research stations in Fiji. The sedimentation technique was used to extract starch from cassava roots and some properties of the extracted starch were also determined. In the case of Koronivia Research Station (KRS) the variety Nadelei had the highest starch yield (23.1 %) whereas Coci had the highest starch yield (23.3 %) for Dombuilevu Research Station (DRS). The paper discusses and compares starch yield obtained from Fiji cassava varieties with some other countries and make recommendations on how starch yield from Fiji cassava varieties can be increased. Finally, the paper provides recommendations on enhancing the viability of cassava as a source of bioethanol in Fiji. It also assesses the resources available in Fiji currently to make cassava bioethanol in Fiji a viable proposition.

Keywords Cassava · Starch · Ethanol yield · Bioethanol

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Short Introduction

Recently, cassava starch (extracted from root crop) has received a lot of attention in ethanol production. Many countries such as China, Thailand and India already started to produce ethanol from cassava starch successfully. The current paper investigates the viability of producing ethanol from locally available cassava varieties in Fiji. Additionally, the paper discusses and compares starch yield obtained from Fiji cassava varieties with some other countries and make recommendations on how starch yield from Fiji cassava varieties can be increased.

Introduction

Cassava, *Manihot esculenta* (*Crantz*) is a perennial plant widely grown in many tropical countries including Fiji Islands. The importance of cassava is derived from its diverse use for human consumption, animal feed and industrial application. It is currently the sixth world food for more than 500 million people in the tropical and the sub-tropical Africa, Asia and Latin America (El-Sharkawy 2004).

Cassava generally grows in many soil types. However, cassava does not tolerate saline or persistent water-logged conditions and it also does not tolerate temperature at or below 10 °C (O'Hair 1990). It is usually propagated vegetatively from mature woody stem cuttings however, cassava can also be propagated from seeds. According to Ceballos et al. (2004) seeds are generated through crossing in breeding programs and this result in creating new genetic variation. The use of seeds in commercial cassava production is a promising option to obviate constrains, particularly diseases associated with vegetative propagation (Iglesias et al. 1994).

The roots of cassava typically consists of moisture (70 %), starch (24 %), fibre (2 %), protein (1 %) and other substances which also includes minerals (3 %) (Tonukari 2004). Starch is an important source of carbohydrate that is synthesised by cassava roots and can not only be used as food but also as a source of chemical reagent, feedstock for fermentation processes and adhesive substance. The use of cassava starch as feedstock for ethanol production as fuel is already being exploited and the results shown by many researchers are quite promising.

Therefore, it becomes essential that high starch yielding cassava varieties are identified. The classification of cultivars (variety) is usually based on pigmentation and shape of the leaves, stems and roots (Rogers and Appan 1973). The cassava varieties in Fiji are also identified using these classifications.

Currently, Koronivia Research Station (KRS) in Fiji have identified the following twenty-eight cassava varieties; Vulatolu, Vulatolu 2, Merelesita, Merelesita 2, Yabia Damu,Yabia Vula, Niumea, Coci, Sokobale, Aikavitu, Kasaleka, Katafaga,, Belesilika, Manioke, Yasawa Vulatolu, Malaya (Macuata), Ro Tubuanakoro, Coci (selection), Vulatolu (Dalip Singh), H.165, H.97, Tilomuria No.3, Tavioka Falawa, Navolau, New Guinea, Lomaivuna, Beqa, Hawaii and Kadavu [Nauluvula 2009, pers. Comm.].

The objective of this study was to identify the starch yield from ten different varieties of cassava found in Fiji and to determine some properties of the starch obtained from these varieties. Another objective was to compare starch yield of Fiji cassava with cassava starch yield in other countries.

Materials and Methodology

The cassava varieties that were used for ethanol production were obtained from two different research stations of the Ministry of Primary Industries in Fiji. One was KRS situated 18° 32′811″ S and 178° 32′133″ E and the other was Dombuilevu Research Station (DRS) situated 17° 33′620″ S and 178° 14′736″ E. These two locations are indicated in the map of Fiji in Fig. 35.1.

The ten cassava varieties obtained were; Niumea, Sokobale, Beqa, New Guinea, Coci, Vula Tolu, Yabia Damu, Merelesita, Nadelei and Navolau. The variety Sokobale was not available at DRS therefore; only nine varieties were used for ethanol production from this location. The cassava varieties obtained from KRS

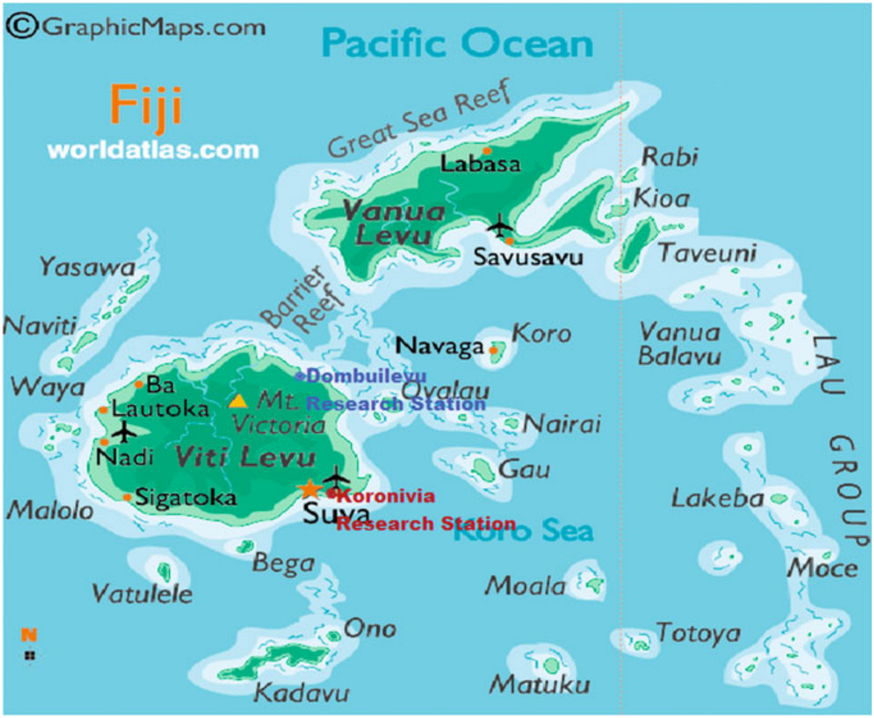

Fig. 35.1 Map of Fiji showing the collection points of cassava varieties (*Source* Fiji Map: http://www.worldatlas.com/)

and DRS were approximately 12 months old. The two sites were chosen to determine whether geographical location played a part in determining starch yield which will then influence the ethanol yield.

Dry Matter Content of Cassava Roots

Dry matter content of cassava roots has become an important character for the acceptance by researchers and consumers who boil or process them (Teye et al. 2011). The percentage of starch and starch yield are closely related to dry matter percentage. Therefore, this is one of the factors that need to be determined in order to identify the best cassava variety for starch and ethanol yield.

Dry matter content was determined according to the procedure described by Benesi (2005). The roots of different cassava varieties were analyzed for dry matter content within 12 h of harvesting. The roots were peeled, cleaned and then shredded into fine slices before 100 g of these were weighed in a Petri dish (w_1). The Petri dish was then placed in an oven at a temperature of 65 °C for 72 h. The samples were removed after 72 h and weighed immediately (w_2). Dry matter content was calculated using the Eq. (35.1):

$$\text{Dry matter content } (\%) = \frac{w_2}{w_1} \times 100\% \tag{35.1}$$

Starch Extraction from Cassava Roots

The extraction of starch from cassava was done according to the method described by Birse and Cecil (1980). However, some parts of the method were modified. A flowchart of starch extraction is shown in Fig. 35.2. Cassava roots were washed, peeled then washed again before the roots were chopped into approximately 1 cm cubes. The weight of the chopped cassava (w_3) was taken before pulverizing it in a high speed blender for 5–10 min. The pulp was then suspended in ten times its volume of water, stirred for about 5 min before filtering using a double fold cheese cloth. The filterate was left to stand for about 6 h before the starch settled and the liquid portion discarded. The water was then added to the sediment and the whole process was repeated. The starch was then dried at 50 °C for 24 h and its weight measured (w_4).

The starch yield was determined using the Eq. (35.2):

$$\text{Starch Yield } (\%) = \frac{w_4}{w_3} \times 100\% \tag{35.2}$$

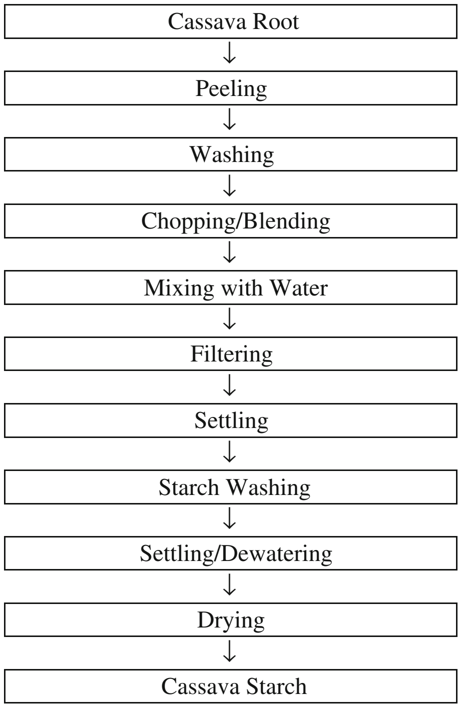

Fig. 35.2 Flowchart for Cassava starch production

Moisture Content of Starch

Moisture content of the extracted starch was determined according to the method described by Benesi (2005). However the quantity of cassava starch to be analyzed was increased.

Approximately 10 g of cassava starch (w_5) was dried in an oven at 105 °C for 24 h. After 24 h the samples were cooled in a desiccator and weighed immediately (w_6). The moisture content was determined using Eq. (35.3):

$$\text{Moisture content }(\%) = \frac{w_5 - w_6}{w_6} \times 100\% \tag{35.3}$$

Ash Content of Starch

Ash content was determined according to the method described by International Starch Institute (1999a). Clean ashing crucibles were heated in the furnace for approximately half an hour at 900 °C. The crucibles were cooled in a dessicator to room temperature and weighed (w_0). Approximately 5 g of the starch sample was uniformly distributed in the ashing crucible and weighed (w_7). The samples were then incinerated on a bunsen burner until it completely carbonised before placing the ashing crucibles in the furnace for 5 h at 900 °C. After incineration the samples were cooled to room temperature in a dessicator and weighed (w_8). Ash content of starch was determined using Eq. (35.4):

$$\text{Ash content } (\%) = \frac{w_8 - w_0}{w_7 - w_0} \times 100\% \quad (35.4)$$

pH determination of Starch

The pH of starch was determined according to the method described by International Starch Institute (1999b). Approximately 5 g of starch was mixed with 20 ml of distilled water. The starch was then allowed to settle for 15 min before the pH of the water phase was measured using a calibrated pH meter.

Results and Discussion

The starch yield from different cassava varieties obtained from two different locations in Fiji is shown in Table 35.1. The starch yields for cassava varieties obtained from both the stations ranges from 17 to 23 %.

The results show that the yields are dependent on the sites of the plantations. They show that Beqa, New Guinea, Yabia Damu, and Nadelei are more suited to the Koronivia site with regard to their starch yields. On the other hand Niumea, Coci, Vula Tolu and Navolau performed better at the Dombuilevu site for their starch yields. The Merelesita starch yield did not show much variation with site. Therefore, it is seen that location is one of the factors that influence starch yield.

Table 35.1 Starch yield from cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Starch yield (%)	Starch yield (%)
Niumea	18.3	19.9
Sokobale	17.7	
Beqa	21.9	17.0
New Guinea	20.9	19.5
Coci	20.5	23.3
Vula Tolu	17.3	18.1
Yabia Damu	19.6	17.9
Merelesita	18.6	18.8
Nadelei	23.1	22.1
Navolau	17.0	19.8

Table 35.2 Dry matter content of cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Dry matter content (%)	Dry matter content (%)
Niumea	37.9	36.2
Sokobale	36.3	
Beqa	41.2	32.2
New Guinea	41.5	32.3
Coci	37.0	36.8
Vula Tolu	31.1	35.6
Yabia Damu	35.7	36.0
Merelesita	40.9	35.6
Nadelei	40.8	38.0
Navolau	33.7	33.8

Benesi's (2005) result indicated that the genetic constitution of the plant is the most influential factor. However, sites, rounds of starch extraction and their interaction also have appreciable influence. Similar observations were also made by Ngendahayo and Dixon (2001) who found that after six months, the starch content in plants are influenced by genotype, harvesting time and rainfall pattern.

The dry matter content obtained from two different locations is shown in Table 35.2. The cassava from Koronivia had a dry matter content as high as 41 % (New Guinea and Beqa) whereas the ones from Dombuilevu had a maximum of 38 % (Nadelei).

Dry matter content is very much related to rainfall during six to eighteen months of plant growth (Ngendahayo and Dixon 2001). This suggests that the difference in dry matter content between the sites could be contributed to the rainfall received during plant growth. However, Benesi et al. (2004) have reported that the root dry matter content of cassava in Malawi is in the range 38.24–46.48 % and that dry matter content was not as much influenced by the environment as by the genetic differences.

The mineral elements and inorganic salts present in starch are referred to as ash. Table 35.3 shows that the ash content for cassava varieties obtained from Koronivia is 0.10 to 0.17 % and for Dombuilevu it was 0.1 to 0.21 %.

According to Thomas and Atwell (1999) ash content is typically less than 0.5 % of dry mass and this agrees with the results obtained for all the cassava varieties obtained from Koronivia and Dombuilevu. Variations in ash content depend upon source of raw material, agronomic practices, extraction and milling procedures and types of chemical modifications (Benesi 2005).

The pH of cassava starch as reported in Table 35.4 ranged from 4.07 to 5.23 for the varieties obtained from Koronivia and 5.03 to 6.20 for those varieties obtained from Dombuilevu. Benesi (2005) indicated a pH range of 5.0–5.5 for the native starch obtained from ten elite Malawian cassava genotype. The recommended pH range stated by the National Starch and Chemical Company is between 4.5 and 7.0 (National Starch and Chemical Company 2002).

Table 35.3 Ash content of cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Ash content (%)	Ash content (%)
Niumea	0.17 ± 0.01	0.19 ± 0.03
Beqa	0.17 ± 0.03	0.21 ± 0.02
Sokobale	0.11 ± 0.02	
New Guinea	0.09 ± 0.01	0.15 ± 0.04
Coci	0.14 ± 0.02	0.13 ± 0.01
Vula Tolu	0.10 ± 0.02	0.12 ± 0.02
Yabia Damu	0.10 ± 0.02	0.17 ± 0.03
Merelesita	0.12 ± 0.02	0.13 ± 0.01
Nadelei	0.10 ± 0.02	0.10 ± 0.02
Navolau	0.14 ± 0.02	0.16 ± 0.04

Means of three replicates (±SD)

Table 35.4 pH of Cassava varieties

Cassava variety	Koronivia (pH)	Dombuilevu (pH)
Niumea	4.07 ± 0.02	5.98 ± 0.05
Sokobale	4.18 ± 0.02	
Beqa	4.89 ± 0.01	5.81 ± 0.04
New Guinea	5.23 ± 0.02	5.03 ± 0.02
Coci	4.47 ± 0.01	5.04 ± 0.03
Vula Tolu	4.63 ± 0.03	5.17 ± 0.01
Yabia Damu	4.44 ± 0.01	6.20 ± 0.02
Merelesita	4.53 ± 0.03	5.21 ± 0.03
Nadelei	4.53 ± 0.02	5.48 ± 0.03
Navolau	4.37 ± 0.01	5.34 ± 0.02

Means of three replicates (±SD)

Table 35.5 Moisture content of Cassava varieties

Cassava variety	Koronivia	Dombuilevu
	Moisture content (%)	Moisture content (%)
Niumea	12.6 ± 0.5	12.9 ± 0.9
Sokobale	14.7 ± 0.6	
Beqa	14.1 ± 0.8	14.5 ± 0.4
New Guinea	13.9 ± 0.6	13.6 ± 0.9
Coci	13.1 ± 0.5	12.5 ± 1.0
Vula Tolu	13.9 ± 0.6	13.7 ± 1.2
Yabia Damu	12.9 ± 0.3	12.8 ± 0.5
Merelesita	12.4 ± 1.0	13.0 ± 0.4
Nadelei	13.7 ± 0.4	13.6 ± 0.9
Navolau	12.5 ± 1.0	12.0 ± 1.2

Means of three replicates (±SD)

The moisture content for Koronivia cassava variety as shown in Table 35.5 ranged from 12.4 to 14.7 % whereas for Dombuilevu it was from 12.0 to 14.5 %. The results obtained are consistent with the results reported by Nuwamanya et al. (2008)

and Benesi (2005). Nuwamanya et al. (2008) reported moisture content ranged from 14.09 to 16.49 % for the parental lines and 14.80 to 16.11 % in the progenies. The native cassava starch moisture content that Benesi (2005) found for the ten varieties investigated ranged from 10.47 to 12.83 %. High moisture content in cassava starch is not a desired property. High moisture content in cassava starch leads to growth of micro-organisms that are capable of degrading starch (Nanda et al. 2010). Moorthy (2001) reported that high moisture content affects the pasting properties of cassava starch and Willett and Doane (2002) stated that the tensile properties and overall granular structure of starch are also affected by high moisture content.

Comparison of Starch Yields from Fiji Cassava with Other Countries

In Fiji, cassava has primarily been cultivated for food. More recently, cassava has gained importance as a possible fuel commodity in countries such as China, Thailand, Indonesia, and other countries which have more advanced national biofuel programs. The Fiji government is also looking at improving the country's energy security by developing biofuels to reduce the dependence on diesel and petrol. Some renewable resources that have been identified for bioethanol production in Fiji include sugarcane, molasses and cassava.

Cambodia (Jie 2002)

In Cambodia cassava is mostly used for human consumption while little is used for animal feed and industrial purposes. Cassava is usually harvested 6–8 months after planting in flood plain regions. Farmers usually plant the cassava stems into the soil during November and harvest the crop before flooding in June. In the upper lands cassava is planted during wet season and harvested 9–12 months later. Results obtained from major cassava factories in Cambodia showed an average starch content of 24–28 % in roots. Most provinces in Cambodia plant cassava for human consumption therefore cultivation practices are limited to minimum land preparation, weeding and fertilizer. However, there are provinces where farmers earn money by selling cassava and cultivation is intensive giving high average yield and production.

China (Wang 2002; Yinong and Kaimian 2002)

In China more than 60 % cassava is used for industrial purposes, 30 % for animal feed and 10 % for human food. Planting of cassava is usually done in the tropical/subtropical extremes of the southeast corner of the country (Onwueme 2002).

The mean temperatures in this region are 20–24 °C with clay Oxisols or Alfisols soil of low fertility and pH of 4.5 to 6.6 being used (Onwueme 2002). Crops are grown on flats or ridges and usually intercropped with groundnut or rubber. Stem cutting are placed horizontally (Onwueme 2002). The roots can be processed to make different products due to their high starch content of 28–35 %. Over the past years China has been successfully able to introduce new varieties to replace older ones. These new varieties have high starch content and high yield fulfilling the most important breeding objectives in response to China's fast development of cassava processing industry. Most owners of starch factories in China have recognized the importance of raw materials supply. Therefore, they have started to support cassava cultivation with farmers by signing contracts and introducing farmers to varieties that have high starch content and high yield.

India (Edison 2002; Unnikrishnam et al. 2002)

India has a unique status on the cassava map for its high yield per hectare among the Asian countries. This has been made possible due to the availability of high yielding varieties, willingness of farmers to adopt these varieties and improved management practices. A large number of varieties are grown in different regions of India and the starch content for these varieties range from a minimum of 22 % to as high as 48 %. Cassava is grown in India under varying agro-climatic conditions and different soil types. In most states it is grown as rain-fed crop but in some districts like Tamil Nadu it is grown as irrigated crop. Previously, cassava was mostly grown in uplands either on open slopes or in coconut-based cropping systems. However, in the recent years it has shifted to lowland rice-based cropping systems.

Thailand (Sarakarn et al. 2002)

Thailand over the years has been trying to look for varieties that are most suitable to the environment and with good traits. The desired varieties should have high yield capacity, high harvest index, high root starch content and early harvest time. Thailand had limited cassava genetic diversity therefore, to improve those local varieties and to widen the genetic base, the country introduced many varieties from abroad. Varieties that are present in Thailand have a high starch content of 27.6 %. Most of these varieties have other good characteristics such as high fresh root yield, can be planted in late rainy season and more.

Cassava in Thailand is mostly grown as a sole crop (Howeler 1988). However; occasionally it is intercropped with maize, groundnut, rubber or coconuts. Planting occurs during May to November with most planting done between May to June (Onwueme 2002). Planting is done on flat or ridges by placing the stems vertically in soil. The soil in which cassava is grown is mostly Ultisols of loamy sand or sandy loam texture (Onwueme 2002). Temperatures are usually 27 °C with rainfall of 1,100–1,500 mm in central plain and 900–1,400 mm in the northeast region (Onwueme 2002).

Vietnam (Bien et al. 2002)

Vietnam is one of the major exporters of cassava. This has been made possible due to their extensive research in identifying varieties that are suitable to the agro-climatic condition and varieties that are high yielding as well as adopting sustainable production practices. The use of farmer participatory research in development and transfer of new technologies to cassava households have been a success. With introduction of high yielding cassava varieties and improved or sustainable production practices have raised the economic effectiveness of cassava production especially in Southeastern region of Vietnam. Several cassava cultural practices have been developed which include, (1) erosion control by growing vetiver grass and other plant species, (2) balanced fertilizer application, (3) intercropping cassava with peanut and/or mungbeans, (4) planting new high yielding varieties, (5) using the herbicide Dual, (6) using silage of cassava leaves and roots to feed animals. All these practices are supported by farmers. In most areas cuttings are planted vertical however, in sandy soils horizontal planting is practiced. Cassava roots in Vietnam can give high starch contents of 25–30 %.

Fiji

In Fiji cassava is predominantly grown for human consumption. There is almost no processing of cassava into dried form for human or animal use. However, apart from food cassava is exported to Australia and New Zealand as frozen tubers. Cassava is grown in most parts of Fiji. As it is tolerant to a range of climatic conditions as well as growing in marginal land, limited effort is currently being placed in improving conditions for planting. There is minimum land preparation, weeding is hardly done and limited fertilizer applied. In 2007 cassava yield was 13.80 t/ha (Krishna et al. 2009). This yield can be increased with sustainable cultivation practices and also by identifying high yielding varieties. Cassava research in Fiji is mostly done by KRS and other stations of the Ministry of Agriculture, Fisheries and Forest. The maximum starch yield obtained from cassava available in Fiji was 23.3 % and a minimum of 17 %.

Bioethanol is produced by fermenting sugars or substances that contain sugar. Cassava roots contain starch that can be converted to sugar. As seen in the starch results obtained, cassava in Fiji can be used for bioethanol production. The Fiji Government has plans to produce bioethanol from agricultural sources available in

Table 35.6 Comparison of ethanol yield made from various energy crops (Rao 1997)

Crop	Yield (t/ha/year)	Conversion rate to sugar or starch (%)	Conversion rate to ethanol (L/t)	Ethanol yield (kg/ha/year)
Sugarcane	70	12.5	70	4,900
Cassava	40	25	150	6,000
Carrot	45	16	100	4,500
Sweet sorghum	35	14	80	2,800
Maize	5	69	410	2,050
Wheat	4	66	390	1,560
Rice	5	75	450	2,250

Fiji namely sugarcane, molasses and cassava. Experts have pointed out that cassava is the best crop to be used for bioethanol production. The reason being that ethanol yield of cassava per unit land area is higher than any other known energy crop as seen in Table 35.6, it is also much cheaper to set up a cassava ethanol factory because of lower investment and much simple processing technology due to special characteristics of starch (Wang 2002). The cost of cassava ethanol can be lowered due to production of useful by-products from different parts of cassava plant (Wang 2002).

However, since cassava is primarily produced in Fiji for food by the people, an approach needs to be taken that would balance out the use of agricultural land for food and fuel. The use of food crops for fuel usually drives the prices of these crops. For this reason governments in many countries are now ensuring that biofuels do not increase the price of staple foods. The Fiji Government has dismissed the threat to food security on the grounds that more than half of Fiji's almost 2 million hectares of land is idle according to FAO 2006 figures (Krishna et al. 2009). As stated in the FAO report (Krishna et al. 2009), promoting diversification and setting aside land for food production is one strategy. However, governments need to make a national-level decision as to what extent staple crops should be used for biofuel production.

Conclusions

Cassava roots have a number of end-uses, such as for food and feed processing, starch industry, bioethanol production and for export. The ten varieties of Fiji cassava showed difference in starch yield and dry matter content suggesting that high starch yields could be obtained by selecting suitable varieties for starch extraction. Cassava can be grown in poor soil conditions and in many areas. However, with suitable farming practices cassava root yields as well as starch yield can be increased.

Further research on starch yield and dry matter content needs to be carried out on the other varieties of cassava that are available in Fiji and from various other locations. Also other possible root crops such as yams should be considered for starch and bioethanol production. The Ministry of Agriculture in Fiji should do research on new and better varieties of cassava that are more suitable to the climatic condition and are high yielding. They should also monitor the new varieties released on large scale farming and promote the use of the superior varieties of cassava to farmers.

Finally, in order to consider cassava for bioethanol production a comprehensive feasibility study needs to be conducted. Bioethanol production should only be considered if food versus fuel crisis does not arise.

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