Trends in Production and Utilization of Cassava in Asia and its Potential as a Bio-Fuel

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ABSTRACT

Over the past decade the cassava planting area in Asia has slightly decreased but yields have markedly increased, resulting in a steady increase in production, from 46.1 million tonnes in 1995 to 60.0 million tonnes in 2004. In most countries cassava is utilized domestically, but in Thailand it is mainly for the export market. China is presently a major importer, importing about 75% of its domestic requirement. In almost all countries in Asia, cassava is principally used in food, while in China and Thailand it is mainly used for animal feed or industrial purposes.

Potential markets for cassava are mainly in the area of starch and starch-derived products, for domestic animal feed, and for processed food. However, recently there has been a renewed interest in the use of cassava as a raw material for the production of ethanol, mainly as a "bio-fuel" to mix with gasoline to produce "gasohol". In this market cassava has to compete with sugarcane in tropical countries and with maize in the temperate zone. Cassava starch can generally compete with other sources of starch on the basis of price in the mass market, and on the basis of its functional properties in certain specialized markets. However, cassava lacks the wide range of intrinsic starch characteristic found in some competing crops like maize and potato. For cassava to enter in a wider range of specialized markets, we need to develop new "high-value" varieties with specific starch or nutritional characteristics required in the processing industry.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) has its origin in Latin America where it has been grown by the indigenous Indian population for at least 4000 years. After the discovery of the Americas, European traders took the crop to Africa as a potentially useful food crop; later it was also taken to Asia to be grown as a food security crop and for the extraction of starch. Thus, in the 19th century cassava became an important food crop in southern India, as well as on Java island of Indonesia and in the southern Philippines, while in Malaysia and parts of Indonesia it was also used for extraction of starch. After the Second World War it became an important industrial crop in Thailand, mainly to produce starch for local consumption, and dried chips and later pellets for the rapidly growing European animal feed market. In Indonesia the crop remains first and foremost a food crop, used in a great variety of dishes, but in southern Sumatra it is now mainly grown for starch extraction.

PRESENT SITUATION

1. Cassava Production Trends

Table 1 indicates that in 2004 about 53% of cassava in the world was produced in Africa, 30% in Asia, and only 17% in Latin America and the Caribbean (LAC). Cassava production in Asia increased at a high rate of 3% annually during the lately 70s and early 80s, slowed down during the 90s, and has been growing quite rapidly again at 2.5% per year during the past nine years. This, in spite of a modest reduction in area, as it was driven solely by a remarkable increase in yields, averaging 3.1% per year; the latter compares with annual yield increases of only 0.7% in Africa and 1.8% in Latin America during the same period.

Figure 1 shows the production and yield in the main cassava producing countries in Asia from 1961 to 2005. In some countries, cassava production kept pace with increases in population, while in others it decreased as a result of rapid urbanization and a more secure supply of the preferred food, rice. A marked exception is Thailand, where cassava production increased rapidly in the 1970s and 80s in response to a rapidly growing demand for animal feed in Europe, as well as a favorable tariff structure. But when the Common Agricultural Policy (CAP) in the EU changed in the late 80s, cassava became less competitive with locally produced barley, and exports of cassava pellets declined rapidly, from a peak of 9.1 million tonnes in 1989 less than 1 million tonne in 2005 (**Figure 2**).

This near-collapse of the export market in Europe was partially offset by accelerated growth in the production of starch and starch derivatives, as well as by increasing demand for cassava chips in

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China. Meanwhile in Vietnam, cassava production was in decline during the 1980s and 1990s as the economy improved and production of rice increased. But during the past five years, cassava production suddenly increased from about 2 million tonnes in 2000 to over 5.7 million tonnes in 2005, in order to meet buoyant internal demand for starch, and for export of chips and starch. This ability to increase production was a result of a substantial increase in planted area, from 235,500 ha in 1998 to 390,000 ha in 2005, as well as a remarkable increase in yield, from 7.53 t/ha in 1998 to 14.61 t/ha in 2005. In both Thailand and Vietnam, the yield increases achieved during the past 10 and 5 years, respectively, are mainly due to a concerted effort to distribute widely the new high-yielding and high-starch varieties, as well as to the adoption of improved cultural practices, such as more balanced fertilizer use and soil conservation measures. In Thailand, new varieties are now planted in nearly 100% of the area, while 80-90% of farmers apply chemical fertilizers; in Vietnam the new varieties are now planted in about 60% of the cassava area while about 80% of farmers apply chemical and/or organic manures. These two factors combined nearly doubled yields in Vietnam over the past seven years.

Table 1. Cassava production, area, and yield in the world, the continents and in various countries in Asia in 2004/05.

	Production (‘000 tonnes)	Area (‘000 ha)	Yield (t/ha)
World	**203,618**	**18,475**	**11.02**
-Africa	108,470 (53%)	12,252	8.85
-LAC	34,727 (17%)	2,696	12.88
-Asia	60,245 (30%)	3,511	17.16
-Cambodia	362	23	16.09
-China	4,216	251	16.81
-India	6,700	240	27.92
-Indonesia	19,425	1,255	15.47
-Laos	56	8	6.81
-Malaysia	430	41	10.49
-Myanmar	139	12	11.30
-Philippines	1,640	206	7.97
-Sri Lanka	221	23	9.54
-Thailand	21,440	1,057	20.28
-Timor-Leste	42	10	4.15
-Vietnam	5,573	384	14.53

Source: *FAOSTAT, April 2006.*

2. Production Systems

Cassava is known to be a very drought-tolerant and water-efficient crop, while the crop is also exceptionally tolerant of high soil acidity and low levels of available phosphorus (P). Thus, cassava can compete with other, more valuable, crops such as maize, soybean and vegetables mainly in areas of acid and low-fertility soils, and those with low or unpredictable rainfall, such as the northeast of Thailand, the central coast of Vietnam and in east Java.

Fortunately, there are no economically important pests or diseases in Asia – with the exception of India – so there is no need for the use of pesticides. Fertilizers or organic manures are commonly used on cassava, but not necessarily in adequate amounts or in the right proportions of N, P and K. Usually, responses to organic manures can be greatly enhanced by additional application of chemical fertilizers high in N and K. Production costs vary significantly across the region. Production costs for advanced farmers in Thailand are higher than in Indonesia and the Philippines, but lower than in Vietnam, China and India. When calculated per tonne of fresh roots, production costs in Thailand are slightly higher than in Indonesia or the Philippines, but much lower than in India and China. It is clear that cassava products from Thailand can remain competitive only if farmers increase their yields through the use of improved varieties and better production practices (Howeler, 2001; 2005).

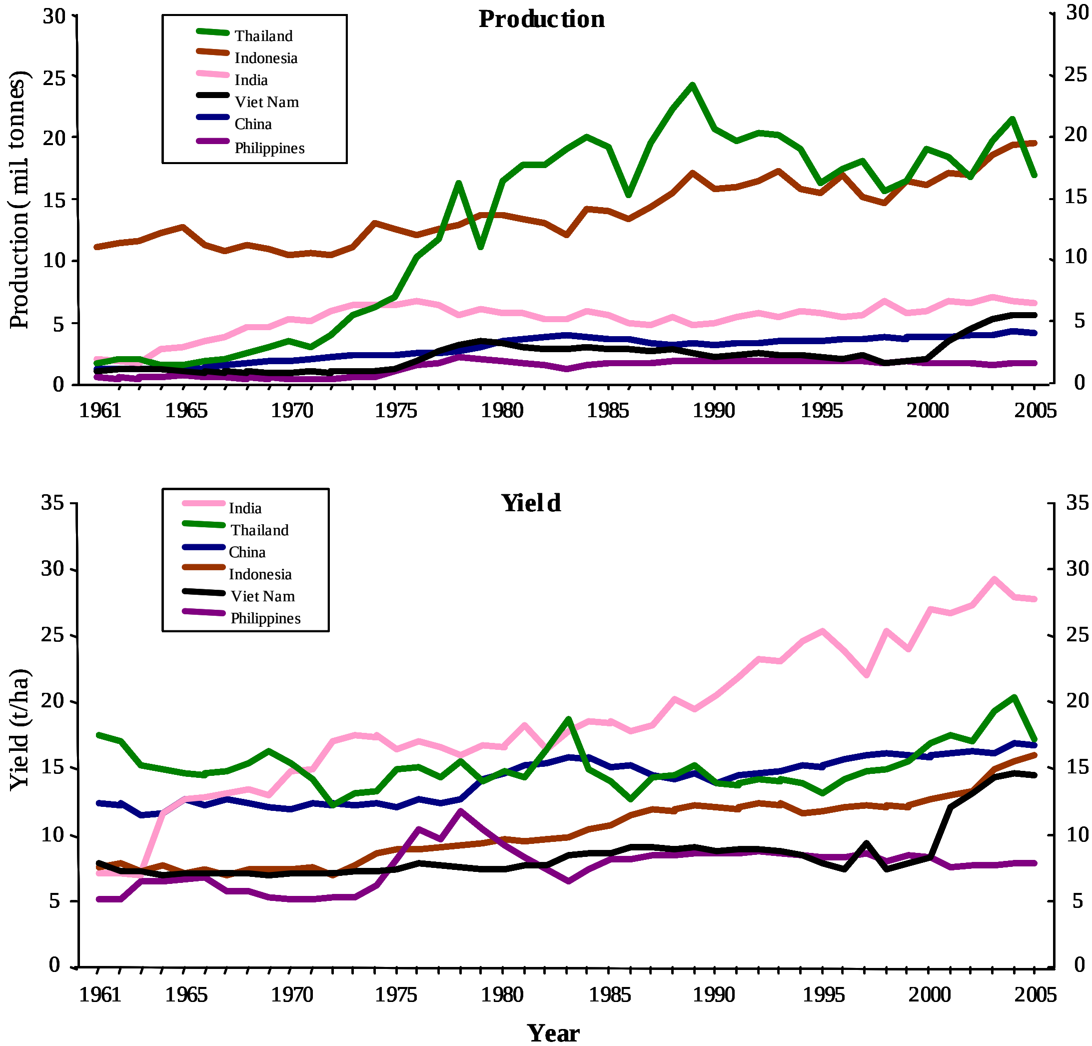

Figure 1. Cassava production and yield trends in Asia's principal cassava producing countries, 1961-2005.
Source: *FAOSTAT, May 2006.*

3. Products and Markets

Both cassava roots and leaves (or young plant tops) have multiple end-uses, including direct human consumption of fresh roots and leaves (after boiling), on-farm animal feeding, commercial production of animal feed, and production of starch or starch derivatives. **Figure 3** shows in more detail the various products made from cassava starch and dried chips, as well as from the peels and pulp, which are by-products from the starch industry.

a. Fresh roots for human consumption

In Kerala state of India, as well as in some areas of China and Vietnam, fresh cassava roots are consumed directly after boiling or roasting. In most other parts of Asia cassava is not consumed as fresh roots, but only after some form of processing.

b. Flour for human consumption

The simplest and most common form of processing, used widely in Indonesia, is to peel the roots, wash and slice and then sun-dry for 2-3 days to produce dry cassava chips or chunks, in Indonesia known as *gaplek*. *Gaplek* can be stored and is traded in village markets. When needed, the dry root pieces are pounded into a flour, which is shaken on a bamboo screen with some water to produce granules, called *tiwul*. The size and shape of these granules is similar to rice grains and the *tiwul* is often cooked together with rice to extend the family's limited supply of rice. Presently, small processing plants in Indonesia buy fresh roots to be processed directly into various flour mixes (supplemented with vitamins and flavors) as well as semi-cooked *instant tiwul*. These are mainly destined for urban consumers.

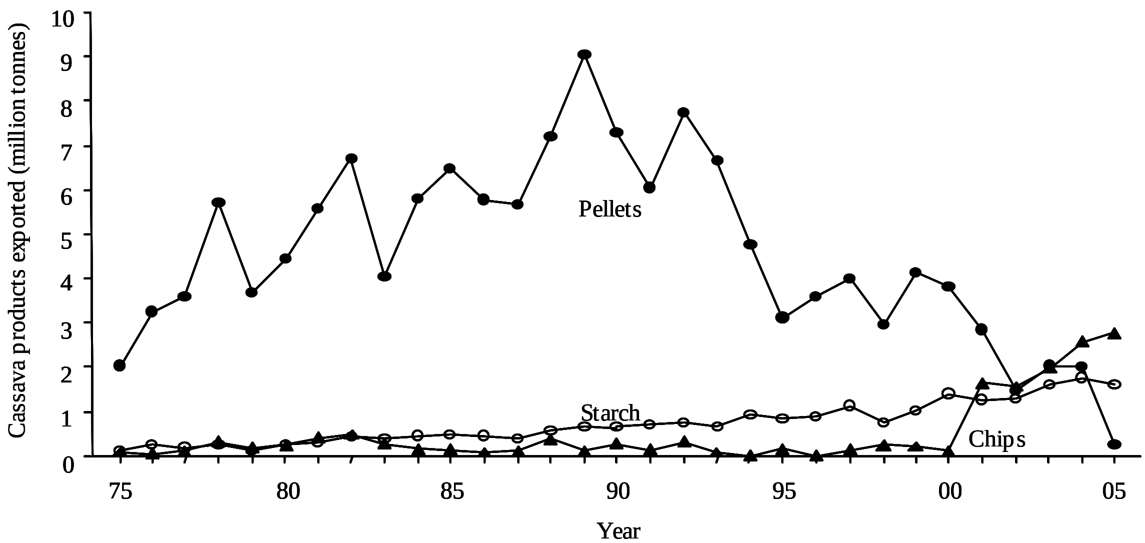

Figure 2. Quantities of cassava products exported from Thailand from 1975 to 2005.
Source: *Adapted from TTTA, 2005.*

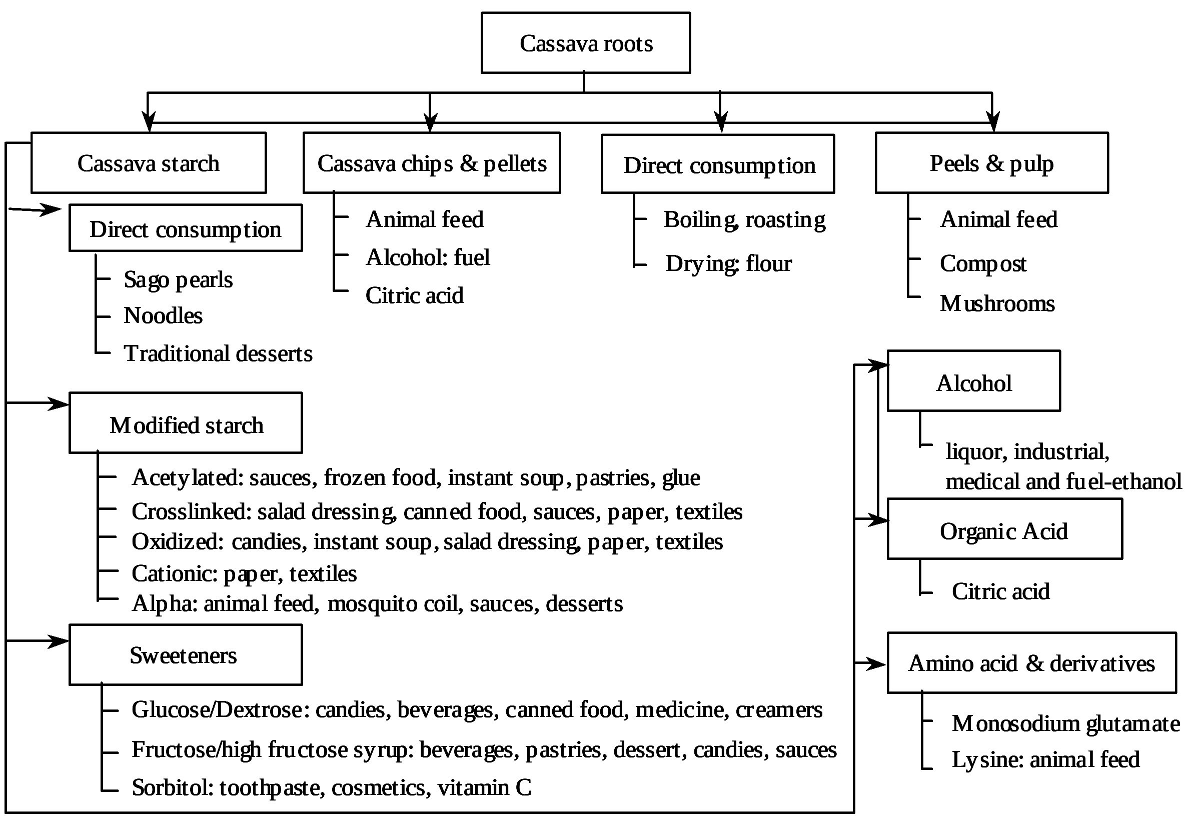

Figure . Cassava root processing into value-added products
Source: *Adapted from TTFITA, .*

c. Chips and pellets for animal feed.

Up until very recently, cassava chips and pellets were the mainstay of the Thai "tapioca" trade, mainly for export to Europe (**Figure 2**). However, in 2004, Thailand exported only about 1.7 million tonnes of cassava pellets to Europe, down from 6.0 million tonnes in 1989; but unlike in 1989 it exported considerable quantities of dry chips, almost 2 million tonnes, mostly to China, where it is used for production of commercial animal feed, and alcohol. **Table 2** shows that the export of dry cassava products is still dominated by Thailand, but that Vietnam is also exporting increasing quantities of dry chips and starch, mainly to China. China presently imports about 80% of chips from Thailand and 10% from Vietnam, while it imports 50-60% of starch from Thailand and 15-20% from Vietnam (TTTA, 2004).

Table 2. Total world trade in cassava products in 2004.

	Exports ('000 t)					
	Fresh	Dry products ('000 t)				
	root equivalent	Starch	Tapioca pearl	Chips+ pellets	Flour	**Total**
World	23,895`	1,376	88	6,467	81	**8,012**
-USA	6	1	-	0	-	**1**
-EU(15)	959	6	0	365	3	**374**
-Asia	**22,551**	**1,346**	**86**	**6,006**	**76**	**7,514**
-China	75	3	12	0	-	**15**
-India	6	0	1	0	0	**1**
-Indonesia	1,659	185	29	234	0	**448**
-Japan	1	0	0	0	-	**0**
-Korea (ROK)	1	0	0	0	-	**0**
-Philippines	2	0	0	1	0	**1**
-Thailand	18,259	1,040	27	5,019	76	**6,162**
-Vietnam	1,874	-	-	750	0	**750**

	Imports ('000 t)					
	Fresh	Dry products ('000 t)				
	root equivalent	Starch	Tapioca pearl	Chips+ pellets	Flour	**Total**
World	26,168	1,825	57	6,672	15	**8,569**
-USA	293	21	9	58	0	**88**
-EU(15)	6,701	33	5	2,602	1	**2,641**
-Asia	**18,330**	**1,621**	**40**	**3,995**	**7**	**5,663**
-China	14,142	1,088	4	3,473	0	**4,565**
-India	19	0	4	0	0	**4**
-Indonesia	286	56	1	2	0	**59**
-Japan	741	130	2	30	1	**163**
-Korea (ROK)	1,204	10	0	460	0	**470**
-Philippines	268	46	1	12	0	**59**
-Thailand	4	0	0	0	1	**1**
-Vietnam	-	-	-	-	-	**-**

Source: *FAOSTAT, April 2006.*

d. Starch for food and industry

Cassava starch can be divided into *native starch* and *modified starch*. The production of native starch is a relatively simple process, that can be done at many scales, either at the household level, such as in some villages in north Vietnam, Cambodia and on Java island of Indonesia, up to very large and fully-mechanized starch factories, such as those in Thailand, south Vietnam, and in Lampung province of Indonesia. One tonne of fresh roots usually results in 250-300 kg of starch. During the past decade, the cassava starch industry in Thailand has expanded very rapidly (**Figure 2**), and total production in 2004 was approximately 2.9 million tonnes consuming about 58% of the total (estimated) production of 19.7 million tonnes of cassava roots. In Indonesia the cassava starch industry suffered significant losses after the 1997 economic crisis, but has now mostly recuperated; in 2002, total production was 1.34 million tonnes of starch (P.T. Corinthian, 2004). Practically all cassava starch produced in Indonesia is for the local market. In India, most cassava starch is produced in Tamil Nadu (about 90%) and Andhra Pradesh (10%) with a total annual production of cassava starch and tapioca pearls (or sago) of 330,000 tonnes (Edison, 2001). In China, cassava starch production was about 680,000 t/year (Li Jun, personal communication), in 2005, while an additional 467,000 tonnes of cassava starch were imported, mostly from Thailand (56%) and Vietnam (17%). In Vietnam cassava starch productionit is increasing rapidly and for 2003 it was estimated at about 500,000 tonnes, of which 70% was exported (mainly to China, Taiwan and Korea) and 30% used domestically (Hoang Kim, personal communication).

In China the total annual consumption of starch and derived products in 1998 was about 4.03 million tonnes, of which 3.32 million tonnes (82.3%) was maize starch, 470,000 tonnes (11.7%) cassava starch, 96,000 tonnes (2.4%) each of sweet potato and wheat starch, and 48,000 tonnes (1.2%) potato starch (Tian Yinong *et al*., 2001). In 2004, China imported about 2.76 million tonnes of cassava chips and pellets and 262,360 tonnes of starch from Thailand. Most of the chips and pellets are used for production of alcohol and animal feed, respectively, while the starch is used mainly for production of sweeteners and MSG. It is estimated that China imported an additional 360,000 tonnes of cassava chips and 80,000 tonnes of starch from Vietnam.

e. Modified starch

Native starch can be modified by either physical, chemical or enzymatic processes, producing different forms of “modified” starch with distinctly different properties and different uses. Modified starches are used in many different types of foods as well as in industry, mainly for production of high quality paper, for textile sizing and some animal feeds (**Figure 3**). One of the main users of modified starch is the paper industry. Cationic starches made from cassava starch are particularly suitable for the sizing and coating of paper in high-speed paper making machines (Jin Shuren, 2001). Other main users of modified starch are in the food industry, textiles, in agriculture and in animal feed, while smaller amounts are used in construction materials, in casting, oil drilling and medicines.

f. Starch-based sweeteners

Cassava starch can be used for the production of many types of sweeteners after hydrolyzation by either acids or enzymes, or both. These sweeteners include maltose, glucose syrup, glucose and fructose, which can be further processed into various oligo-saccharides (Jin Shuren, 2001).

g. Hydrogenated sweeteners.

These include sorbitol, mannitol and maltol. They are produced by treating starch with hydrogen gas in high-pressure tanks, using a special catalyst and ion-exchange resins. Sorbitol is used mainly for the production of vitamin C and as a moisture conditioner in toothpastes (Jin Shuren, 2000).

h. Ethanol

In some countries cassava is used for the production of ethanol. In the late 1970s several alcohol distilling factories were set up in Brazil using fresh cassava roots as raw material. The alcohol was used as automotive fuel, either mixed with gasoline (up to 20% alcohol) for which no motor modification is required, or as pure anhydrous ethanol, in which case the carburator and some other parts need to be modified (de Souza Lima, 1980). Both result in less atmospheric pollution than the use of 100% gasoline.

In China, several factories in Guangxi are now using the solid waste (pulp) of the cassava starch industry for the production of ethanol (Gu Bi and Ye Gozhen, 2000). Other alcohol factories in China are switching from the use of molasses to that of cassava chips for alcohol production, because of strict pollution control requirements that makes the use of molasses uneconomical. In Guangxi there are now about 200 alcohol factories, most of which still use molasses as the raw material. But about 20 factories use mainly cassava fresh roots, supplemented with cassava dry chips and molasses when no fresh roots are available. These produce about 20,000-30,000 tonnes/year of hydrous ethanol (95% ethanol), mainly for export or industrial use.

Since about 2002 the Chinese government has promoted the use of “gasohol” instead of gasoline, in order to reduce the importation of oil and reduce air pollution from greenhouse gasses. There are presently four large companies producing anhydrous or fuel-ethanol in four provinces, mostly located in the north and northeast. Three of these use maize and one uses wheat as the raw material. Together they produce about 1 million tonnes of fuel-ethanol per year, or 3.35 million liters per day. Since maize and wheat can be better utilized as food or animal feed, the government is planning to phase out the use of these crops for production of fuel-ethanol. Instead, they want to promote the use of sweet sorghum in the northern provinces and cassava in the south. Thus, it is likely that in the southern provinces of Guangxi, Guangdong, Hainan and Yunnan, major investments will be made in the construction of large factories to produce anhydrous (99.5%) ethanol for the production of "gasohol E10", i.e. 10% ehtanol mixed with 90% gasoline.

In Thailand "gasohol", containing 10% ethanol, is presently available in most gas stations and this has become the most popular fuel because of its lower price. The ethanol is still mostly made from molasses, but one factory in Khon Kaen is now producing ethanol from cassava while another factory is nearing completion. According to an intensive study by Kasetsart University (Piyachomkwan *et al*., 2002) dry cassava chips would be the cheapest and most convenient raw material for large-scale production of ethanol for automotive fuel in Thailand.

i. Degradable plastics

Various types of starches are being used for the production of bio- or photo-degradable plastics, either by mixing starch or modified starch with polyvinyl hydrocarbons, or by polymerization of starch, which is then blended with various other polymers (Klanarong Sriroth *et al*., 2001). The use of cassava starch for these processes still requires much research.

j. Organic acids

Organic acids made from cassava starch include citric acid, acetic acid, lactic acid and itaconic acid, which are used in the food industry as well as for the production of plastics, synthetic resins, rubber products etc. Lactic acid is produced by the fermentation of starch with *Lactobacillus amylovorus* (Wang Xiaodong *et al*., 1997; 2000).

k. Monosodium glutamate (MSG) and Lysine

MSG is a well-known flavor-enhancing agent used in many Asian kitchens. It is made through the microbial fermentation of starch or sugar (molasses) in the presence of ammonium salts. In Thailand, MSG production is one of the main consumers of native cassava starch. Lysine is an important amino-acid used as a supplement in animal feed, especially for pigs.

FUTURE POTENTIAL

Cassava-based products can only be competitive in the world market if the cost of processing and the cost of the raw materials is lower than those of competing crops. The competitiveness also depends on government policies, on import duties, tariffs and other trade barriers. Thus, during the 1970s and 80s the Thai tapioca export industry benefited from relatively low import duties into the European markets as well as artificially high prices of domestic coarse grains; but those policies changed in the late 80s. With ever increasing trade liberalization, products will more and more have to compete on the basis of price and quality characteristics. **Table 3** shows the relative potential for growth of various cassava-based products in the seven major cassava producing countries in Asia.

1. Food

Fresh cassava for human consumption does not have major growth potential as rice remains the preferred food in the region. Total food demand may increase due to increases in population, but as Asian societies become more affluent, they are likely to reduce their consumption of high-energy staples like rice and cassava in preference for meat products or convenience foods. Moreover, in Asia, as in other parts of the developing world, there is an unrelenting trend for rural populations to move to the cities. It is expected that after 2020 more than 50% of the population in Asia will be urban rather than rural. This will have profound effects on food consumption patterns as urban populations have to buy all their food, and they prefer clean, attractively packaged and convenient foods. For that reason, there is likely to be a greater future potential for processed foods and snack foods, where cassava-based products may find a niche market.

Table 3. Summary of market potential[1)] for cassava by country in 2000.

	Food		Animal feed		Starch and starch-based products	Ethanol
	Fresh	Processed	Domestic	Export		
China	*		**		***	***
India -Kerala	*	**				
- Tamil Nadu					***	
Indonesia	*	**	**	*	**	**
Malaysia		***	**		**	
Philippines	*	**	**		***	**
Thailand			***	*	***	***
Vietnam-North	*	**	**	*	***	
-South		**	**	*	***	

1) * = maintenance of existing consumption levels
** = growth in existing markets
*** = unexploited growth potential

2. Feed

Table 3 shows that in all countries in Asia except India there is likely to be a substantial growth in the domestic animal feed market. This market is still largely untapped in Thailand, which has traditionally concentrated on the export of cassava-based animal feed. However, since the export of cassava pellets to Europe becomes increasingly more difficult, there is a large potential to develop the use of both cassava roots and leaves for the domestic animal feed market, adding value to an otherwise cheap export product. Previously, this was unattractive due to large domestic supplies of other sources of feed ingredients, such as maize, rice bran and soybean. But, starting in the 1990s Thailand became an importer of maize and especially soybeans. While world soybean prices have been in decline since 1997, they are markedly increasing since 2004 due to high demand in China. Cassava leaves may be a good alternative source of protein, which could be incorporated, together with root meal, into animal feed rations. When cassava is grown specifically for leaf production and is well-managed, cassava tops can be cut five times in a one-year crop cycle producing 13-15 t/ha of dry leaves and 2.5-2.8 t/ha of crude protein; this is 3-4 times higher than a good crop of soybean!!! Roots can still be harvested at 11-12 months with yields of 15-20 t/ha.

During the past four decades both chicken and pig production in Asia increased markedly as increasing affluence in many countries increased demand for meat products, and thus for animal feed. Even though production of the major food and feed crops, i.e. rice, maize and cassava, increased dramatically in Asia, this still could not satisfy the high demand for feed ingredients, resulting in major increases in grain imports, especially of maize and soybeans. Whether or not locally produced cassava chips and pellets can compete with maize as a major feed ingredient depends largely on the prices of maize, cassava chips and soybean, as the latter will need to be mixed with cassava at a ratio of about 85:15 to obtain the same protein content of a maize-based feed (**Table 4**). Since the mid 1990s the prices of nearly all feed ingredients (not adjusted for inflation) have shown a downward trend, but during the past four years these prices have increased substantially, especially the price of soybean. While the cassava–soybean mix tended to be cheaper than locally produced barley in Europe during the 1990s, this is presently not the case.

Using a linear-programming model and average commodity prices during 1991-2001, Fuglie (2004) found that, unlike most other countries in Asia, in Thailand the cassava-soybean mix provided the lowest-cost animal feed, considerably lower than the traditional maize-soybean mix, both for manufactured and farm-grown feed. In spite of recent price increases of all three crops, the cassava-soybean or cassava chips-leaf meal-soybean mixes are now considerably cheaper than maize-soybean mixes with the same crude protein contents (**Table 4**). Further research is urgently needed concerning the large-scale production and utilization of cassava leaves as a protein source in commercial feeds.

Table 4. Approximate prices of various feed ingredients and the final cost and protein content of feed mixes in Thailand in 2004.

	Protein (%)	Price (baht/tonne)	Price (US$/tonne)
Ingredients			
-Maize	8.5	4,920	123
-Cassava chips or pellets	2.5	2,563	64
-Soybean meal	44.0	9,310	233
-Cassava chips (85.5%) + soybean meal (14.5%)	8.5	3,643	91
-Cassava leaf meal-1	20.0	5,000	125
-Cassava leaf meal-2	25.0	6,000	150
Feed mixes			
-Milk cows:			
Maize (82%) + soya (18%)	14.9	5,710	143
Cassava chips (70%) + soya (30%)	15.0	4,587	115
Cassava chips (56%) + leaf meal-1 (24%) + soya (20%)	15.0	4,497	112
Cassava chips (59%) + leaf meal-2 (24%) + soya (17%)	15.0	4,535	113
-Pigs:			
Maize (76%) + soya (24%)	17.0	5,974	149
Cassava chips (65%) + soya (35%)	17.0	4,924	123
Cassava chips (61%) + leaf meal-1 (7%) + soya (32%)	17.0	4,892	122
Cassava chips (62%) + leaf meal-2 (7%) + soya (31%)	16.9	4,895	122
-Chickens:			
Maize (73%) + soya (27%)	18.1	6,105	153
Cassava chips (63%) + soya (37%)	17.9	5,059	126
Cassava chips (60%) + leaf meal-1 (5%) + soya (35%)	17.9	5,046	126
Cassava chips (60%) + leaf meal-2 (6%) + soya (34%)	18.0	5,063	127

1 US$ is 40-42 baht in 2003

3. Starch and Derivatives

Table 3 indicates that most countries foresee the greatest future potential for cassava in the area of starch and starch-based products. This is due to the increasing demand for starch in processed food, in the paper and textile industry, as well as a very large potential demand for biodegradable plastics. In most of these markets cassava has to compete with maize, wheat, and potato. **Table 5** indicates that Thai cassava starch is very competitively priced in comparison with maize, wheat or potato starch in the US market. Thus, for products where cassava starch can substitute for these other starches in terms of starch characteristics, there is little doubt that cassava starch is the cheapest source. However, in cases where specific starch characteristics, such as low-amylose content, are required, as in the production of biodegradable plastics, cassava starch may lose its competitive edge to waxy (low-amylose) maize or potato starches. Intensive research will be required to breed for low-amylose cassava or to produce these varieties through genetic transformation. On the other hand, cassava starch is characterized by a neutral taste and odor, and the transparency, smoothness and viscosity of the gel, making it particularly suitable for many processed food items. Native cassava starch is also very resistant to acid conditions, it is intermediately resistant to freezing but very unstable during heating (sterilization), making it suitable for some and unsuitable for other applications (Dufour *et al*., 2000).

4. Fuel-Ethanol

Due to the dramatic increases in world oil prices in 2006, and the growing concern about global warming as a result of the production of greenhouse gases, especially from car exhausts, many governments are looking for alternative energy sources, especially renewable and domestically produced bio-fuels. These include mainly ethanol, made mostly from maize, wheat, sugarcane or molasses and cassava, as well as bio-diesel, made mostly from soybean and palm oil. The fuel ethanol is usually mixed with gasoline in a ratio of 1:9 or 2:8 to produce “gasohol” E 10 and E 20, respectively. However, “flexifuel" cars can run on E 85, while "total-flex" cars, made in Brazil, can run on anything between pure gasoline and pure ethanol (E 100).

Table 5. Price (US $ per tonne) trends of cassava, potato, maize and wheat starch in the US market; 1996-2003.

	Cassava starch[1)]	Potato starch [1)]	Maize starch [2)]	Wheat starch [1)]
1996	449	595	468	416
1997	403	500	449	441
1998	412	440	499	457
1999	357	424	437	305
2000	347	406	460	363
2001	370	402	427	349
2002	325	398	392	483
2003	291	396	410	596

[1)] CIF port of arrival in US
[2)] FAS (free alongside ship); this does not include ship loading charges
Source: *International Trade Commission, US Department of Commerce*

In the US and Canada most fuel-ethanol is made from maize or wheat, in Brazil it is made almost entirely from sugarcane; in Argentina from sugarcane and maize; in Europe mainly from wheat, rye and barley, in China from maize and wheat; and in Thailand from sugarcane (or molasses) and cassava. While India is presently not producing much fuel-ethanol, it is likely that in the future it will use both maize and sorghum. China, on the other hand, plans to phase-out fuel-ethanol production from maize and wheat and switch to sweet sorghum and cassava. In Indonesia there are also many plans for the construction of fuel-ethanol factories, mainly on Kalimantan island, while at least one factory is making ethanol from cassava in East Java with a capacity of 40,000 tonnes of ethanol per year.

The choice of crops to be used depends mainly on what crop is readily available for year-round production, and at a competitive price. **Table 6** shows that in the US sugarcane would produce the highest ethanol yield per ha, but cassava fresh roots or molasses would be the cheapest raw materials for production of ethanol. But, since none of these are abundantly available, maize is the preferred raw material. In contrast, **Table 7** shows that in Thailand molasses and dry cassava chips are the cheapest raw materials for production of ethanol, followed by fresh cassava roots. Since dry chips can be readily stored and cheaply transported, while the supply of molasses is limited and seasonal, cassava dry chips are considered the most promising raw material for ethanol production in Thailand. However, **Table 8** shows that while cassava is clearly the cheaper source of raw material for ethanol production than maize in both the US and Thailand, the lower processing cost of maize as well as the greater value of its high-protein by-products, results in a lower total cost of production of ethanol from maize as compared to cassava in the US, but a lower production costs for cassava as compared to maize in Thailand. Thus, in different countries different crops may have a comparative advantage. It seems, however, that in southeast Asia, where cassava yields are relatively high and production costs are relatively low, cassava will have a cost advantage over most other crops. Moreover, cassava can be grown on poor soils and under drought conditions where other crops may perish. Also, cassava roots – either fresh or as dry chips – are available during most of the year and the waste water ("stillage") and solid residues resulting from cassava processing into ethanol are much less polluting than those from molasses; they may even be used to produce valuable by-products such as biogas and animal feed.

Thus, it appears that the production of fuel-ethanol opens a huge new market for cassava. **Figure 4** shows the current and future expected demand for various cassava products in Thailand. To keep up with this increasing demand, cassava production will need to increase from the current level of 16.9 mil. tonnes to 27.5 mil. tonnes over the next three years, as the demand for cassava roots for ethanol production increases from 0 in 2004/05 to 4.7 mil. tonnes in 2007/08 when an expected eight factories will be producing 1.95 mil liters/day or 570,000 t/year.

Similarly, in China the current installed capacity for cassava processing into starch and derived products, including hydrous alcohol, will require about 13 mil. tonnes of fresh roots in 2005/06. This is likely to increase by another 7.2 mil. tonnes to a total of 20 mil. tonnes fresh roots with the production of 1 mil. tonnes (1.2 bil. liters) of fuel-ethanol from cassava in the next 3-4 years. This is still only a fraction of the 5 mil. tonnes of fuel-ethanol that China is expected to need when all cars are running on gasohol E 10.

Table 6. Ethanol yield and raw material costs of various crops potentially used for ethanol production in the US

	Yield (t/ha)	Market price (US$/t)	Gross income (US$/ha)	Ethanol yield (liter/t)	Ethanol yield (liters/ha)	Raw matrial costs US$/1000 l	Valuable co-products
Maize	8.5-9.0	70-100	595-900	385-400	3,272-3,600	175-260	DDGS[1)]
Wheat	2.5-4.9	114-118	285-578	378-390	945-1,911	292-312	Gluten, yeast, bran
Sugarcane	70-75	15-20	1,050-1,500	90-100	6,300-7,500	150-222	Bagasse, yeast
Molasser	3.2-3.4	35-40	112-136	250-300	800-850	116-160	-
Cassava -fresh roots	20-30	20-30	400-900	160-180	3,200-5,400	111-187	DDGS[1)]
-dry chips	9-13.5	60-70	540-945	330-400	2,970-5,400	150-212	DDGS[1)]

[1)]DDGS = distillers dry grain with solubles
Source: adapted from Shetty *et al*, 2006, by R. Howeler.

Table 7. Raw material costs per liter of ethanol produced from various crops potentially used for ethanol production in Thailand.

Crop	Planted area (‘000 ha)	Production (‘000 t)	Yield (t/ha)	Con version ratio (kg/liter ethanol)	Price of raw material (US $/t)	Raw material cost (US$/1000 l ethanol)
Maize	1,258	4,461	3.55	2.7	104	281
Rice	9,761	25,608	2.62	-	-	-
Broken rice	-	-	-	2.7	150	405
Sugar cane	1,065	62,828	58.99	14.3	17	243
Molasses	-	3,000	-	4.0	37	148
Cassava -fresh roots	1,101	18,265	16.59	6.5	26	169
-dry chips	-	-	-	2.5	62	155

Source: adapted from Piyachomkwan, 2005, by R. Howeler

Table 8. Cost of production of ethanol using either dry maize grain or fresh cassava roots as the raw material for ethanol production under US and Thai conditions.

	USA		Thailand	
	Maize	Cassava	Maize	Cassava
Crop yield (t/ha)	11	35	3.5	20
Crop price ($/tonne)	81	25	104	26
Ethanol yield (liters/t raw material)	379	180	379	180
Substrate costs ($/liter ethanol)	0.21	0.14	0.27	0.14
By-product credit ($/liter ethanol)	-0.063	-0.004	-0.063	-0.004
Processing costs ($/liter ethanol)	0.16	0.21	0.16	0.21
Ethanol production costs ($/liter)	0.31	0.35	0.37	0.35

Source: adapted from Shetty *et al.*, 2006, by R. Howeler

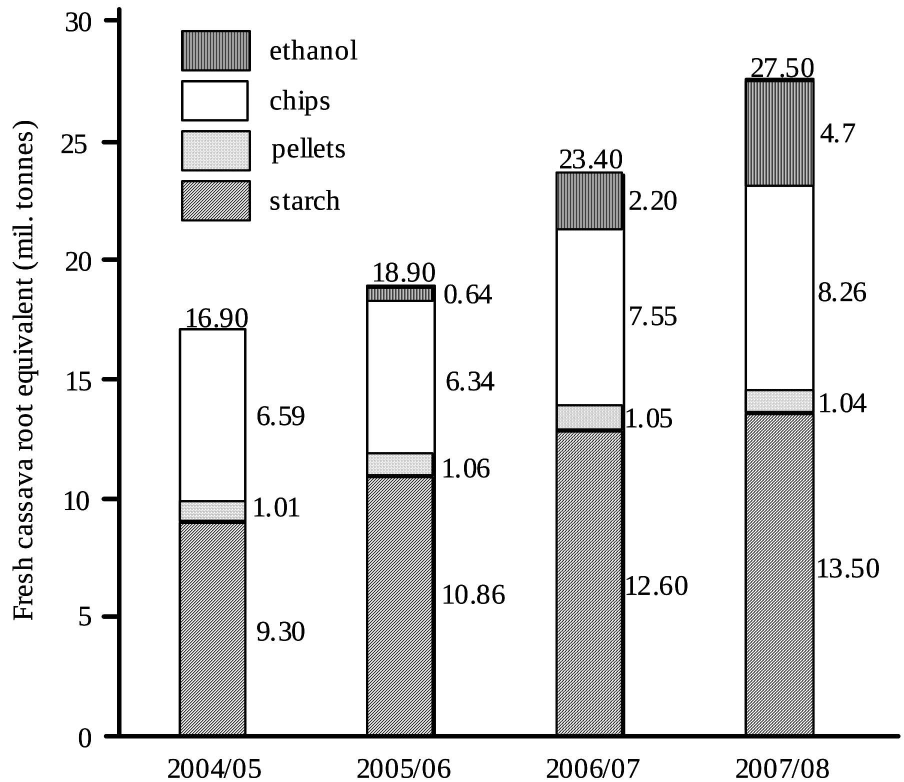

Figure 4. Current and expected future market demand for various products made from cassava in Thailand from 2004/05 to 2007/08.

Since the cassava harvested area can not expand to keep up with increasing demand, this will require major increases in cassava yields, from the current levels of 19-20 t/ha in Thailand and 18-19 t/ha in China to about 30 t/ha in both countries. This will require major efforts to develop new higher yielding varieties with a higher starch content and a higher conversion efficiency to ethanol (from the current 160-180 liters/tonne fresh roots to at least 200 l/t), as well as improved agronomic practices that will allow these varieties to reach their full yield potential. Both the Thai and Chinese governments are fully committed to support the necessary research and extension activities, while the public and private sector will have to work closely together in support of cassava farmers to make this a reality.

MAINTAINING A COMPETITIVE EDGE

To keep cassava-based products competitive in domestic as well as world markets is a real challenge. While cassava has many favorable attributes in the area of production, it also has some negative attributes, especially in terms of post-harvest handling due to its high water content and rapid deterioration. The content of cyanogenic glucosides in the roots is an important consideration in the use of cassava for direct human consumption, but is of less importance for production of processed food, animal feed or starch. The low content of protein in cassava roots increases the efficiency of starch extraction, but also means the absence of a valuable high-protein by-product, as is the case for maize starch. Finally, since cassava cannot be grown in temperate climates, it has never received the same research attention in developed countries as for instance maize, rice, wheat, soybean and potato. Research on cassava had been minimal until the early 1970s when the international research centers – CIAT in Colombia and IITA in Nigeria – received the mandate for cassava research and development, which in turn triggered the formation of many national cassava research programs. Nevertheless, the number of researchers working on cassava, and the research budgets dedicated to this crop, are minimal in comparison with those for most of the competing crops.

Still, cassava thrives in Asia because of the ability of farmers, processors, traders, researchers and policy makers to adapt to rapidly changing physical, biological, economic and social conditions. To maintain this competitive edge will require special attention in three areas: 1) improving the production system in order to reduce the cost of raw material while maintaining reasonable profit margins for farmers; 2) adding post-harvest value by the development of new products and more efficient processes; and 3) stimulating higher demand for cassava-based products by market development. To be really successful, these three research streams should not work independently, but should closely coordinate their activities, seek collaboration between institutions and forge a strong partnership between the public and the private sector.

Participatory Approaches and Institutional Collaboration

Cassava yields in Asia have increased more than in other continents mainly by the widespread adoption of higher yielding varieties, which in turn responded to improved crop management practices. This widespread adoption was achieved through the close and effective collaboration between national research and extension institutions working together with local and provincial government officials. The use of farmer participatory research (FPR) and extension (FPE) methodologies, in which farmers become directly involved in the testing, selection and dissemination of new technologies, played a major role in enhancing the adoption of these technologies. This participatory approach need to be further developed and become part of the institutional culture. Moreover, the active collaboration between various institutions within each country need to be strengthened, and an effective partnership between the public and private sector need to be created if we want to maintain cassava's competitive edge in world markets, while helping farmers to improve their livelihood and maintain our natural resources for future generations.

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