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Root Crops, Starch and Agro-industrialization in Asia

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Abstract

Starch is a heterogeneous commodity used in the manufacture of many food and non-food products. Market demand for starch is strongly and positively correlated with average per capita income. In Asia, root and tuber crops (cassava, sweetpotato and potato) supply most of the starch used by industries. Because starch processing of root and tuber crops is usually done in rural areas due to their perishability and bulkiness, starch processing is an important rural agro-industry. Small firms coexist with large starch mills to provide intermediate processing despite diseconomies of scale. Policies also influence trade in starch and industrial organization of starch processing.

Key words: cassava, industrial organization, maize, market demand, potato, sweetpotato, China, Indonesia, Thailand.

Root Crops, Starch and Agro-industrialization in Asia

INTRODUCTION

The extraction and processing of starch from agricultural commodities is one of the most important agro-industries in Asia, if not worldwide. By 2002, Asia probably accounted for more than one-third of global starch production for an annual worth of at least US$ 6 billion. But the starch industry in the developing countries of Asia differs in important ways from its counterpart in the industrialized world, especially in terms of rate of growth, industrial organization, pattern of commodity utilization, and influence of government policy. The purpose of this paper is to examine the dynamics of starch supply and demand in selected countries of Asia.

The importance of starch in agro-industry derives from its heterogeneity and versatility that gives it wide usage in the manufacture of many food and non-food products. Almost all major industries have found some applications for starch. In food industries, starch is used to impart "functional" properties to processed foods such as thickening, binding, filling, and taste. Starch is also converted into sugars and sweeteners. Uses of starch in non-food industries are just as numerous. Major users include the textile, paper, plywood, adhesive, and pharmaceutical industries. Starch is also used to make beverage and fuel alcohol.

Despite the importance of the starch industry, information about starch production, utilization and prices is sparse and incomplete, especially for developing countries. Much of these data are held privately by firms that may be reluctant to share them due to market advantages that such data may impart. The work may also be carried out in the informal sector by small enterprises. What information is publicly available from government bodies or industrial associations usually focuses almost exclusively on the large-scale modern sector, ignoring starch extraction and use by small firms. In developing countries, small-scale firms are important players in the starch industry, especially for root and tuber crop starch processing and utilization. The bulkiness and perishability of root and tuber crops often requires that these crops be processed close to the farm and soon after harvest.

One objective of this paper is to review recent trends in starch markets for several countries in Asia. Ostertag (1996) provides one of the few attempts to assess the significance of starch production in developing countries, drawing together data from the early 1990s. We update these data on starch production in Asia and reexamine the importance of root and tuber crops in the Asian starch industry, which we believe has been significantly underreported. Second, we assess the prospects for future growth of starch demand in Asia. Since many of the products that involve starch in their manufacture are income elastic, per capita starch demand is likely to be positively correlated with per capita income. Moreover, since the mix of goods consumed also changes with per capita income, the quality or kind of starch demanded may also change as a country develops. We quantify some of these demand relationships by estimating Engel functions from cross sectional and time series data on starch consumption from various Asian countries. Third, in order to understand the heterogeneous nature of the market for starch, we examine price relationships among five different kinds of starch (starch from maize, potato, sweetpotato, cassava, and canna) using seasonal wholesale price data collected over a two-year period in Sichuan, China. This is a unique market because so many types of starches are available year-round. Finally, we investigate industrial organization and producer-processor relationships in the starch extraction agro-industry, drawing upon interviews with sweetpotato starch processors conducted by the authors in two provinces of China and other studies from Indonesia and Thailand.

SUPPLY AND TRADE OF STARCH

Globally, the commodities from which most starch is derived are maize, cassava, sweetpotato, potato and wheat. In developing countries, root and tuber crops are relatively more important as sources of starch than cereal crops. Worldwide, the biggest user of starch is the sweetener industry. In low-income countries, most starch is used to make food products. As a country's economy develops, non-food industries tend to make up an increasing share of total starch consumption.

Commodity supply of starch

Statistics on starch production, prices, and demand are not widely available. Unlike for agricultural commodities, government agencies generally do not collect and publish reports on starch markets. However, statistics on international trade in starch are often reported. International trade in starch is mostly within regional markets. But with the gradual reduction in trade barriers, global trade in starch is becoming more important.

Table 1 presents estimates of global annual starch production with particular focus on Asia. These estimates are drawn from a number of sources and include starch produced by small-scale and household firms. The estimates indicate that by 2002 Asia probably accounted for about 37 percent of world starch production. While nearly 70 percent of world starch production was derived from maize, maize accounted for only 45 percent of starch production in Asia. Root and tuber crops supplied more than half of Asia's starch needs, especially cassava (24.7 percent), sweetpotato (23.5 percent) and potato (6.0 percent).

Table 1. World production of starch in 2002 with special reference to Asia (million tonnes starch content)

Region or country	Maize	Wheat	Sweet Potato	Cassava	Potato	Other	Total Production
China	5.45	0.03	4.82	0.42	0.99		11.71
Japan	2.61	0.03	0.09		0.27		3.00
Taiwan	0.05	0.02	0.02				0.08
South Korea	1.07	0.00	0.03				1.10
Thailand				2.59			2.59
Indonesia	0.08			1.27		0.03	1.38
Vietnam				0.50			0.50
Philippines	0.08			0.02			0.09
Malaysia				0.07		0.03	0.10
India	0.20			0.35			0.55
ASIA	9.53	0.08	4.96	5.21	1.26	0.06	21.10
NAFTA (US, Canada, Mexico)	24.60	0.30					24.90
EUROPEAN UNION (15)	3.90	2.80			1.80		8.50
EX-USSR & E. EUROPE	0.30				0.30		0.60
AUSTRALIA	0.05	0.30					0.35
LATIN AMERICA	1.70	0.04		0.43			2.17
AFRICA				0.02			0.02
WORLD	40.08	3.52	4.96	5.66	3.36	0.06	57.64

Sources: A variety of published and unpublished sources were used to construct the figures in Table 1. The starch industry in most developed countries is mature and has been relatively stable in size over time. Most of the growth in global starch production in the past decade has taken place in East and Southeast Asia.

AFRICA	Ostertag (1996). Industry is small and thought to be fairly stable.
EU & NAFTA	Starch production from LMC International (2002).
EX-USSR & EE	Ostertag (1996). Industry is thought to be fairly stable.
AUSTRALIA	Ostertag (1996). Industry is thought to be fairly stable.
LATIN AMERICA	ABAM (2004).
Japan	Starch production from Taniguchi (2003). Starch trade from FAOSTAT.
South Korea	Korea Agricultural Trade Information (2004) and industry sources.
Taiwan	Hwang *et al.* (2001).
Indonesia	Starch production from PT Capricorn (1998) and industry sources. Starch trade from FAOSTAT.
Vietnam	IFPRI (1998) and Howeler (2005).
China	Sweetpotato starch estimate from Huang *et al.* (2003). Potato starch estimate from FAS (2003). Starch trade from FAOSTAT.
Thailand	Thailand Tapioca Trade Association (2004).
Philippines	Starch production from Ostertag (1996).
India	Starch production from Ostertag (1996). Industry is thought to be fairly stable; restrictions on maize imports limit growth.
Malaysia	Starch production from Ostertag (1996) and industry sources. Starch trade from FAOSTAT.

Of all the figures on starch production shown in Table 1, perhaps the most uncertain estimate is the quantity of starch derived from root and tubers crops in China. The China Starch Industry Association (2004), which only includes production from large scale factories, reported that about 500,000 TONNES tons of starch were produced from cassava, sweetpotato and potato in 2001. But in China, most sweetpotato and potato starch is produced by small and medium-sized processors (Tang *et al*., 1990; Fuglie *et al*., 2005). Ostertag (1996) estimated that at least 4 million tonnes of starch were produced from sweetpotato alone in China in 1992, and Lin and Qiu (1995) reported a similar figure. However, Wheatley and Song (2002) estimated that in the mid 1990s only about 2 million t of sweetpotato starch were produced annually in China. From a survey of experts from major sweetpotato-producing provinces, Huang *et al*. (2003) estimated that by the late 1990s, the share of sweetpotato used by industry had risen to 33 percent of total crop production. Assuming 90 percent of industry use is for starch, this implies that about 4.82 million t of sweetpotato starch was produced by 2002. For potato, FAS (2003) reported that in the early 1990s, 20-22 percent of China's potato crop was used for processing and about 90 percent of this was for starch. Using potato crop production figures from 1994, this implies that about 0.99 million t of potato starch was produced. There does not appear to have been much growth in potato starch production over the past decade (unlike for sweetpotato), so we have continued to assume this level of starch production from potato in China in the figures in Table 1.

The most important factor explaining the global patterns of commodity utilization for starch shown in Table 1 is the relative prices of commodities in regional markets. In the NAFTA countries, maize is by far the cheapest source of starch and accounts for 98 percent of starch produced in this region. Especially important in the United States and Canada is the use of corn starch to produce high-fructose syrup (HFS) for soft drinks. In Europe, maize, wheat, and potato all contribute significant amounts of starch due to policies that equalize the raw material cost of using these commodities for producing starch by offering subsidies to processors (LMC International, 2002). In Southeast and South Asia, cassava is the cheapest source of starch and supplies over 90 percent of starch produced in this region (Fuglie, 2004). In Northeast Asia (China, Japan, and Korea), although starch from maize is generally cheaper than starch from root and tuber crops, there is a major demand for starch from root and tuber crops due to the special characteristics of the starches from these commodities.

Due to the size of the industry, starch plays a major role in the market for root and tuber crop commodities in many countries of Asia (Table 2). In South and Southeast Asia, where cassava is the most important source of starch, more than 40 percent of total cassava production is used for starch extraction, including 64 percent of the cassava crop in Thailand and 29 percent in

Indonesia, the two largest cassava producing countries in Asia. In Vietnam, annual cassava production grew from around 2 to over 5 million t between 1999 and 2003, due largely to the expansion of the starch processing industry in that country (Howeler, 2005). In Northeast Asia, sweetpotato is second to maize in its overall contribution to starch production. We estimate that 30 percent of sweetpotato production in China, 63 percent in South Korea, and more than half of the sweetpotato crop in Japan are used for starch extraction. Sweetpotato is not widely used for starch in tropical Asia because of the availability of cheaper starch from cassava and different market preferences for starch quality.

Table 2. Share of commodity production utilized for starch extraction (%)

Country	Maize	Wheat	Sweet Potato	Cassava	Potato
China	6.9	0.1	29.7	44.5	11.0
Japan		5.6	58.3		73.2
Taiwan			52.4		
South Korea			63.2		
Thailand				64.0	
Indonesia	1.3			28.7	
Vietnam				39.8	
Philippines	2.7			4.4	
Malaysia				66.3	
India	3.0			20.8	
ASIA	9.6	0.1	28.8	40.6	10.0

Source: Starch production figures from Table 1. Commodity production figures from FAOSTAT.

Starch policy and trade

The global pattern of commodity prices and starch utilization has been significantly influenced by agricultural and trade policies. In the European Union, the Common Agricultural Policy (CAP) subsidizes the use of potatoes and wheat in starch production. Under the CAP scheme starch processors are compensated if raw material costs of potato or wheat exceed costs of using maize for starch. Export subsidies are also provided for starch and starch products (LMC International, 2002). This policy is designed to provide additional marketing opportunities for potato and wheat, commodities that are in surplus in Europe, and to reduce imports of maize. In the United States, subsidies are provided for fuel alcohol derived from maize starch. In South Korea and Japan, a tariff-rate-quota (TRQ) system is in place for imported starch. Under the TRQ system, a small share of starch is allowed to be imported under a relative low tariff, but tariffs on imports above the quota are prohibitively high. The starch import quota is allocated to factories in proportion to the quantity of locally-produced starch they purchase. Again, this scheme is designed to support local farmers by increasing the demand for their commodities from local food and non-food starch industries.

Trade barriers have kept starch markets largely regional. Most trade in starch takes place within regional trading blocks, such as within the European Union and among NAFTA countries. Recently, Thailand has emerged as a major exporter of cassava starch. More than 85 percent of Thailand's starch exports are to other countries in East and Southeast Asia, especially Japan, Taiwan, Indonesia, China and Malaysia. In 2003, Thailand exported about 1.6 million t of cassava starch, or about 60 percent of its domestic production (Thailand Tapioca Trade Association, 2004). About 80 percent of Thailand's starch exports were in the form of native (primary) starch, and about 20 percent as modified starches.

Gradually, barriers to trade in food and food products are being reduced. This is increasing the level of global integration in agricultural and food markets. Trade liberalization and agricultural policy reform would likely have a significant effect on global trade in starch. It would likely increase exports from countries with a strong comparative advantage in commodity production, such as the United States and Thailand. On the other hand, exports from the European Union would probably fall, and imports by Japan, South Korea and China would likely rise.

MARKET DEMAND FOR STARCH

The quantity of starch consumed per person in food and non-food products is closely associated with a country's level of economic development. As per capita incomes rise, consumers demand a more varied set of food and manufactured products, many of which use starch in their making. Thus, there is a close and positive relationship between income and quantity of starch demanded.

Engel function for starch demand in Asia

The statistical relationship between income and starch consumption can be formally estimated with the use of an Engel curve. We derived estimates of per capita consumption of starch for the Asian countries in Table 1 by taking total production plus net imports (imports minus exports) of native and modified starch and dividing by population. Per capita income is measured in international dollars (adjusted for purchasing power parity) and is from Heston, Summers and Aten (2002). The particular functional form used to represent the Engel curve is usually chosen on the basis of goodness-of-fit. We tested a variety of forms (linear, quadratic, log, log-linear) and found that the quadratic form provided an excellent fit ($R^2 = 0.93$) for an Engel curve fitted to starch demand in a cross-section of ten Asian countries. The estimated function is:

$$\text{Kg of starch/capita} = \underset{(-1.677)}{-3.979} + \underset{(5.328)}{2.864}\,(\text{GNP/capita}) - \underset{(-3.236)}{0.0685}\,(\text{GNP/capita})^2$$

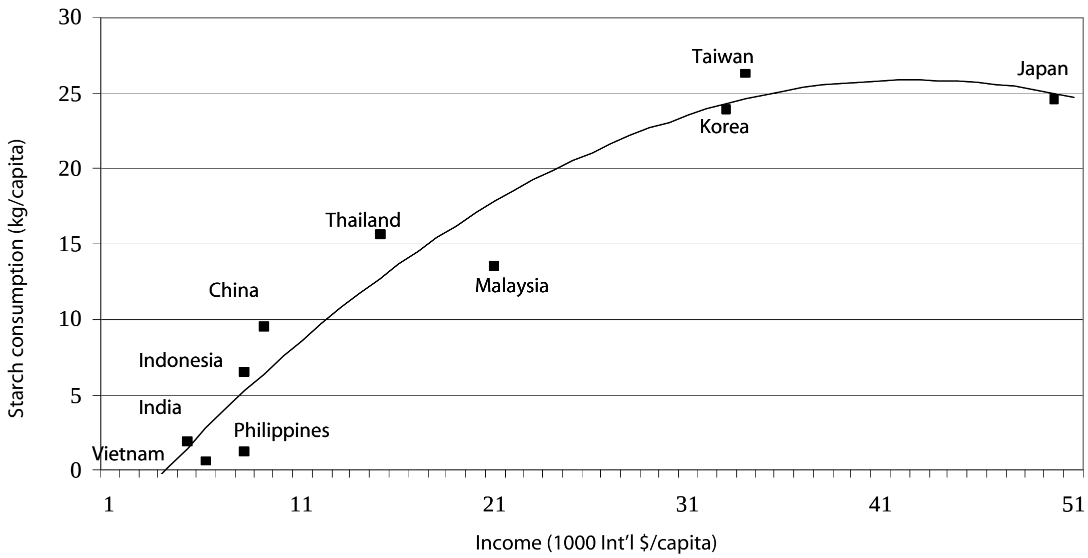
(t-statistics in parentheses)

The positive coefficient for (GNP/capita) confirms that starch/capita rises with income, and the negative sign on the quadratic term implies that the rate of growth in per capita starch consumption declines as income rises.

The estimated Engel curve for starch demand in Asia is plotted in Figure 1 together with the actual data points for the 10 Asian countries used to fit the curve. This relationship implies high income elasticities of demand for starch in developing countries. For low income developing countries with per capita GNP of less than $2,000 (e.g., India and Vietnam), the income elasticity of starch demand is as high as 2.0, meaning that a 1 percent increase in per capita income would result in a 2 percent increase in starch consumption. For lower-middle income countries with average per capita GNP of $3,000 to $4,000 (e.g., China and Indonesia), the income elasticity is between 1.6 and 1.8. For upper-middle income countries like Thailand and Malaysia with per capital income of $7,000 to $10,000, the income elasticity for starch ranges between 1.4 and 1.1. For industrialized nations with average per capita income over $10,000, the income elasticity of starch demand is less than 1.0 but still positive.

These income elasticities estimated for starch demand are substantially higher than income elasticities for most agricultural commodities. For cereal crops such as wheat and rice, income elasticities are typically below 1.0 even in poor countries, reflecting the general tendency of consumers to spend a declining proportion of their incomes on food as incomes increase. Elasticities for less desirable crop commodities, such as root crops and coarse grains, may even be negative, as consumers switch to more preferred foods as incomes rise. The high income elasticity for starch implies that starch is used in the manufacture of food products consumed mainly by persons in the middle and upper income strata. That the income elasticity remains high even in middle-income countries reflects the fact that starch is also used in the manufacture of many non-food products such as clothing, paper, and wood products; items with a relatively high income elasticity of demand.

Figure 1. Income and starch consumption in Asia.



Although we are not able to estimate income elasticities for different kinds of starch, the relationship between starch and per capita income appears to hold for native starches generally. For root crops, transforming the raw commodity into starch effectively transforms its demand from an inferior good to a normal or superior good. A similar demand relationship probably holds for developing regions outside of Asia as well.

Elasticities of starch demand by type of product

Income elasticities can also be derived for starch according to different end uses. In Table 3, we show estimates of elasticities of starch demand for various food and nonfood starch-based products for Thailand. These elasticities were estimated using time series data from 1982 to 1993. For all starch, the income elasticity of demand was 1.01. But demand for starch from non-food industries grew by 1.51 percent for each 1 percent increase in income, compared with 0.85 percent for food uses. Within food products there was a wide range of elasticities, ranging from 0.21 for direct household use of starch to 1.9 for MSG and lysine. In 1993, non-food industries consumed 28 percent of starch consumed in Thailand, a share that is likely to grow over time.

Estimates of income elasticities of starch demand can be used to project future growth in starch demand. The annual growth rate in starch demand is given by:

*Demand growth = Population growth + (Income growth) * (Income elast. of demand)*

Thus, for a developing country with a population growth rate of 2 percent, per capita income growth of 2 percent, and where the income elasticity of starch demand is 1.50, the annual rate of growth in starch demand would be 5 percent. In the 1980s and early 1990s, many countries in East and Southeast Asia were growing by more than 6 percent per year and starch demand was growing by more than 10 percent per year. Growth in demand for starch was temporarily slowed by the 1997-1998 Asian economic crisis. But resumption of economic growth in the region since then has renewed the rapid expansion of the demand for starch. Overall, demand for starch in Asia continues to grow at around 5-10 percent per year.

Table 3. Starch demand in Thailand by type of product

Industry	Market demand for starch in 1993 ('000 tonnes)	Income elasticity of demand	R^2
All Uses	604.0	1.010	0.992
All Food Industries	432.5	0.853	0.993
Direct household use	138.8	0.209	0.993
Other food industries	37.9	0.820	0.998
Sago pearl	36.6	0.843	0.977
Sweeteners	91.9	1.216	0.983
MSG & lysine	127.2	1.909	0.987
All Non-Food Industries	171.4	1.509	0.986
Other non-food industries	95.1	1.455	0.987
Textiles	16.2	1.474	0.918
Paper	60.1	1.611	0.986

Estimates are from log-log regression using annual data from 1982-1993.
Source of data: Starch use by industry from Kajonwan Itharattana. Income is measured as real GDP in 1985 international dollars from Heston, Summers and Aten (2002).

RELATIONSHIPS AMONG STARCH PRICES IN SICHUAN, CHINA

One feature of the starch market in Asia is that several different kinds of starch substrates co-exist and are actively traded side by side. Native starches derived from maize, cassava, sweetpotato, potato, and other crops are in regular supply. While it is also true that in the European Union, maize, wheat and potato starch is widely used, this is largely driven by policy (see above). In developing countries of Asia, on the other hand, there is little or no direct government intervention in starch markets. While agricultural policies do influence the price of cereal grains (especially rice and maize), governments rarely intervene to influence prices of root and tuber crops.

Thus the Asian starch market provides an interesting opportunity to explore relative starch prices. Unfortunately, such price data are unavailable, except in the case of export and import prices from trade statistics. But trade in starch among Asian countries is heavily dominated by cassava starch. Most other kinds of starches are supplied and used domestically. Thus, trade statistics provide an incomplete picture of the market for different starch substrates.

To overcome these deficiencies we conducted a weekly survey of wholesale prices of native starches in Chengdu, Sichuan Province, China, over a two-year period (February 2002 to January 2004). Each week four wholesale traders were interviewed on prices received and quantities traded that week for maize, potato, sweetpotato, cassava and canna starch. Prices were obtained for 'high quality' and 'low quality' starches of each commodity (based primarily on its color and purity). The main buyers of these starches were noodle manufacturers located in and around Chengdu, the largest and capital city of Sichuan.

Figure 2 charts the movements in high quality starch prices over the two years of the survey. There is a significant range in prices among starches, and prices were fairly stable over time. Potato and sweetpotato starch generally obtained the highest price, while cassava and maize starch received the lowest prices. Canna starch was priced in between. There was some tendency for potato and sweetpotato starch prices to decline around the time of the main harvest of these crops in Sichuan (September through November), although the price decline was not enough to alter the order of most-to-least expensive types of starch in the market. A similar structure of relative prices existed between low quality starches of the five substrates, although the range in prices between types of low-quality starch was less (not shown in the figure). Our survey found that an important change has taken place in the starch market since Wheatley and Song (2002) surveyed starch prices in the early 1990s. They found that during 1990-1995, sweetpotato starch was consistently cheaper than maize starch in Sichuan, although maize starch was cheaper that sweetpotato starch in coastal regions of China. They attributed the situation in Sichuan to poor transportation infrastructure and government policies that limited internal commodity trade in China. Since that time, China's commodity markets have gradually become more nationally integrated (Rozelle *et al.*,1997), which may account for an increase in supply of maize starch in Sichuan at lower prices than other starch substrates.

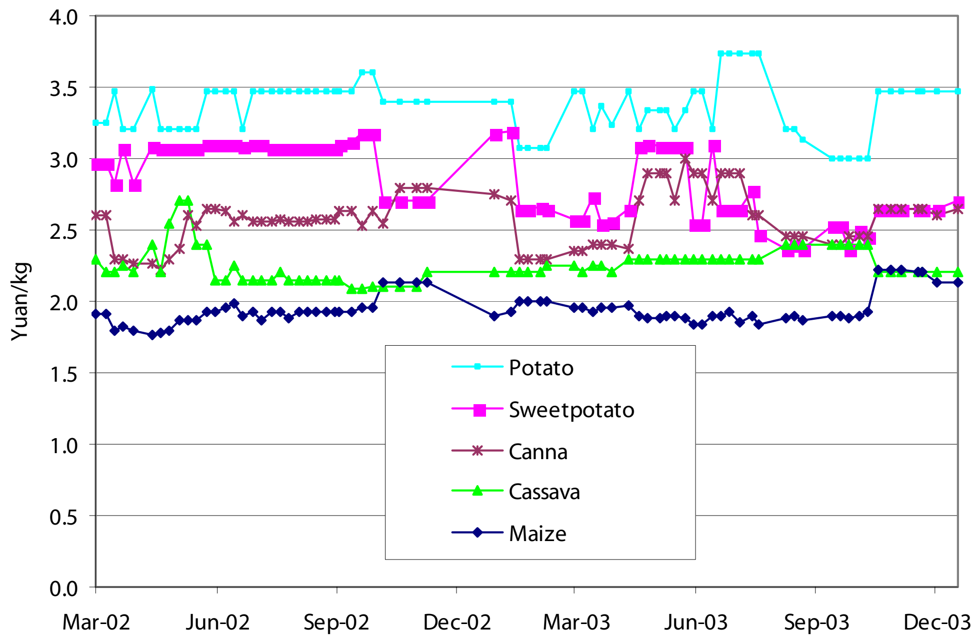


Figure 2. Seasonal movements in wholesale prices for native starch in Chengdu, Sichuan

Despite the relative seasonal stability of starch prices, there were sharp differences in quantities of starch traded. The most active season for starch trade of all types occurred during the first and fourth quarters of the year. This is the season when noodles are most widely consumed in China - the peak period of noodle consumption coincides with the Chinese Spring Festival held each February (Zhang, 1999). About two-thirds of the total starch traded annually in our survey occurred in the fourth quarter (October to December), with another 20 percent in the first quarter (January-April). Nevertheless, starch of each substrate was available throughout the year, with smaller quantities being traded in the second and third quarters of the year.

Table 4 provides some additional statistics on relative prices of starch in Sichuan. Over the period of our survey, average prices of high quality starch ranged from 3.36 yuan/kg for potato starch to 1.94 yuan/kg for maize starch. For low quality starch, the range among average prices was narrower (2.54 yuan/kg to 1.73 yuan/kg). The average premium over the maize starch was 73 percent for high quality potato starch but only 16 percent for cassava starch. Price premiums for sweetpotato starch were 47 percent and for canna starch 32 percent. For low quality starches the premiums paid over maize starch were substantially lower but still significant (47 percent in the case of potato starch). There was some tendency for prices of high quality starch to show more seasonal variation, especially for sweetpotato and canna.

Table 4. Wholesale prices of native starch in 2002-2003, Chengdu, Sichuan

Native starch substrate	High quality starch		Low quality starch		Price premium over maize	
	Average (yuan/kg)	Coef. of variation	Average (yuan/kg)	Coef. of variation	High quality	Low quality
Potato	3.36	5.6%	2.54	4.1%	1.73	1.47
Sweetpotato	2.85	9.1%	2.12	6.6%	1.47	1.23
Canna	2.57	7.3%	2.08	4.8%	1.32	1.21
Cassava	2.26	5.4%	1.96	4.4%	1.16	1.13
Maize	1.94	5.5%	1.73	6.1%	1.00	1.00

Source: authors' weekly survey of trades between February 2002 and January 2004.

The findings from our survey of starch prices in Sichuan, China show that starch users are willing to pay substantially more for the particular properties of potato and sweetpotato starch. These starches are especially suitable for making starch (vermicelli) noodles (Wheatley and Song 2002). Prices appear remarkably stable over the course of the year even though supply is highly seasonal. This probably reflects the fact that demand for a starch noodle, the principal use of these starches, is also highly seasonal.

INDUSTRIAL ORGANIZATION OF STARCH PROCESSING IN ASIA

Since root and tuber crops play such a significant role in supplying starch in Asia, the scale and structure of the starch processing industry differs in some important ways from its counterpart in industrialized nations. Due to their perishability and high transportation cost relative to crop value, processing of roots and tubers tends to be done near centers of crop production. Therefore, linkages to the rural economy are strong. Both large- and small-scale processors may co-exist and provide complementary services, at least while wages are relatively low. In this section of the paper, we review the cost structure of starch processing, economies of scale, and linkages between small and large processors in the industrial organization of starch from root and tuber crops in Asia.

Cost structure of starch processing

For both large-scale and small-scale processors, the cost of raw material is by far the most significant cost item in starch processing. Table 5 shows the cost of producing native starch for three large-sized starch mills and from a sample of small-scale mills in Asia. Raw material costs account for 70-80 percent of total production costs in each case after subtracting the value of by-products. The Thai cassava starch mill is the least-cost producer of the all of the mills shown in

Table 5. It has lower costs than the Indonesian cassava starch mill because of more efficient use of capital and labor, and than the Chinese sweetpotato starch mills due to lower cost of raw materials.

Table 5. Cost of starch production in large-scale factories in Asia

	Thailand cassava starch mill (large)		Indonesia cassava starch mill (large)		China sweetpotato starch mill (large)		China sweetpotato starch mill (small)	
Capacity:	5000/year		8000/year		5000 /year		4.5 /year	
	US$	%	US $	%	US$	%	US$	%
Raw material price	35.0		40.0		35.0		34.0	
Raw material cost	175.0		200.0		233.0		239.0	
Value of by-products	(9.2)		(8.7)		(9.0)		(9.0)	
Raw material net cost	165.8	76%	191.3	70%	224.0	80%	230.0	80%
Capital and labor cost	52.0	24%	82.0	30%	56.0	20%	57.0	20%
Cost of production	217.8	100%	273.3	100%	280.0	100%	287.0	100%

Raw material price is US$/ of commodity. Other figures are in terms of US$/ starch produced.
Figures converted to 1998 US dollars.
Extraction rates

Cassava: 1 native starch from 5 fresh roots (20% starch extraction rate)

Sweetpotato: 1 native starch from 6.67 fresh roots (15% starch extraction rate)

Sources: Thailand: Titapiwatanakun (1994); Indonesia: Nelson (1984); China: authors' survey of large mill in Shandong Province in 1998, and average from survey of 74 small mills in Sichuan Province in 2003 (see Fuglie *et al.* 2005).

What the data in Table 5 indicate is that raw material cost is a key to the competitiveness of a starch producer and industry. A ten percent reduction in raw material costs will have 4 to 5 times the impact on competitiveness as a ten percent reduction in capital and labor costs. Lowering raw material costs requires improvements in farm productivity, such as by developing higher starch-yielding crop varieties. One reason why sweetpotato starch processing developed into a profitable industry in China and not Indonesia (the two largest producers of sweetpotato in Asia) is that sweetpotato productivity is much higher in China compared with Indonesia (Fuglie, 2005). The diffusion of modern, high-yielding varieties of cassava provided a major impetus to the growth of the starch industry in both Thailand and, more recently, Vietnam (Howeler, 2005).

Industrial structure

Industrial structure of the starch industry refers to the size, scale and organization among firms producing and using starch. In industrialized countries, nearly all starch production occurs in large-scale factories and is dominated by a few firms. In many developing countries, however, a significant share of starch production still takes place in small and medium-size mills. Scale of production is partly driven by differences in the relative costs of labor and capital, with labor-intensively methods more economical in low-wage countries. Optimal location and scale are also determined by the commodities used for starch processing. Starch extraction from cereal crops such as maize is more amenable to economies of scale. The commodity can be stored for long periods of time and is relatively easy to transport. Further, technical factors favor large-scale, modern milling – maize starch is relatively difficult to separate from proteins. Even in developing countries, maize starch production is dominated by large-scale mills. Root and tuber crops, on the other hand, consist mostly of water, are more perishable, and their starch is relatively easy to separate. Starch extraction tends to take place close to centers of crop production shortly after harvest. The advantages of mills located close to farms have led to forms of industrial organization that favor involvement of small and medium-sized starch mills in the industry. These firms often providing intermediate processing for large mills.

The complementary between large and small starch mills can be illustrated by the system of sweetpotato starch production in Shandong Province, China. Shandong produces about 18 million tonnes of fresh sweetpotato annually, about 40 percent of which is used for starch (Huang *et al.*, 2003). The entire crop is harvested during September-November. In Sushi County, the Lu Xu Group runs a large starch mill with an annual capacity of 30,000 tonnes of starch, making it one of the largest starch mills in Asia. Immediately following the sweetpotato harvest, the factory purchases fresh roots from within a radius of about 100 km from the factory for processing into starch and starch products. Within one or two months of harvest, the mill discontinues buying fresh roots and instead purchases wet starch (consisting of 30-40 percent water) from small mills. The small mills may be located several hundred km from the Lu Xu factory, too far to profitably transport fresh roots directly. In nearby Pinying County, the number of small and medium starch mills grew significantly in the 1990s to supply the growing demand for wet starch from the Lu Xu mill. The large mill purifies and dries the wet starch and then either sells it directly or uses it to make starch-based products such as noodles. According to managers at the large mill, wet starch is easier than fresh roots or dried chips to store in ambient conditions without deterioration in starch quality.

Another advantage of using small starch mills to undertake intermediate processing is that it reduces the transactions costs faced by large mills in securing raw materials directly from farms. In Shandong Province, for example, a typical farm produces only 1-2 tonnes of sweetpotato per year (Huang *et al.*, 2003). Small mills purchase sweetpotato from nearby farms for intermediate processing into wet starch. The large mills then only need to deal with the small mills rather than thousands of individual farmers. Similar farm structures in other developing countries of Asia favor the existence of small mills to reduce transactions costs of commodity procurement.

The advantages of small and medium-size mills for intermediate processing would seem to be greater in regions where crop production is seasonal. In regions where year-round crop production is possible, large factories can secure a regular supply of fresh roots and extend the processing season, although high transactions costs of dealing directly with many small farmers remain. However, as labor costs rise with economic development, small mills are likely to become increasingly unprofitable due to their reliance on labor-intensive starch extraction methods. In Japan, the number of sweetpotato starch factories numbered over 1000 until the late 1960s. But by 1980, the number of starch producers fell to less than 50 as large mills took over the industry (Komaki, 1998). The rapid reduction in the number of mills reflected a point in the development process in which wages rose sufficiently high to offset the advantages of intermediate processing by small firms. Large, capital-intensive methods of transporting, storing, and processing fresh roots into starch became more profitable.

The point at which the sweetpotato starch milling industry in Japan began to undergo significant structural change was when real GDP per capita reached $4000-$5000 (measured in 1985 international dollars). A similar change occurred in the cassava starch processing industry in Thailand in the 1980s. Titapiwatanakun (1994) reports that the number of cassava starch mills in Thailand increased steadily until the 1980s but began to fall toward the end of the decade as large mills took over the industry and small mills exited (Titapiwatanakun 1994). This was also a period when annual GDP per capita reached $4000.

If we extrapolate these trends to the rest of Asia we can draw some conclusions about the future of small and medium-size starch mills. Using the $4000-$5000 GDP/capita range as a threshold, we can predict that given current economic growth rates, coastal areas of China will reach this range before the end of this decade. At this point the small mills in Shandong Province may no longer be competitive. However, interior provinces of China such as Sichuan are probably one or two decades from this level of economic development. In Southeast Asia, Thailand and Malaysia are already at or beyond this stage, but other countries such as Indonesia and Vietnam are probably at least 10-20 years away from reaching this wage threshold. South Asia is probably several decades away. Thus it appears that small- and medium-scale starch processors of root and tuber crops may continue to participate in the industry for some time to come.

SUMMARY AND CONCLUSIONS

The processing of starch has emerged as an important agro-industry for many developing countries in Asia, and provides a significant new market outlet for its farm commodities. While information on starch industry is sparse and incomplete, the estimates we provide in this paper indicate that Asia probably accounts for more than one-third of global starch production. Further, the Asian starch industry differs from its counterpart in Europe and North America in that (i) it relies mostly on root and tuber crops (cassava, sweetpotato and potato) for supplying starch rather than cereal grains, (ii) it involves a large number of small-scale firms in centers of crop production to provide starch processing services, and (iii) it is relatively free from government intervention (except for some trade restrictions by developed Asian nations). Because starch processing of root and tuber crops tends to be done close to the centers of crop production, and because these commodities tend to be produced in marginal agricultural environments, the growth of the starch industry provides an important opportunity for rural economic development in some as Asia's poorer regions.

In Asian there is a strong positive correlation between per capita income and per capita consumption of starch. We estimate the income elasticity of demand for starch ranges between 1.0 to 2.0 in low and middle income countries, and gradual falls to zero for upper income countries. This implies that the demand for starch by food and non-food industries in developing countries of Asia is likely to grow by 5-10 percent per year. Starch demand by non-food industries will tend to grow faster than demand by food industries because many of the non-food products have higher income elasticities of demand.

For some products, starch quality is not important and industries choose the starch substrate based on whichever is offered at the cheapest price. In Southeast Asia, cassava generally provides the lowest-cost source of starch while in Northeast Asia the lowest-cost starch substrate has been maize. For other products, such as noodles, starch quality is a desirable factor and starch from some crops (such as sweetpotato and potato) is preferred over starch from other crops (such as corn and cassava). In China, sweetpotato starch utilization by the noodle industry has grown sharply over the past decade. From our survey of wholesale prices for starch in Sichuan, users of starch (primarily noodle manufacturers) were willing to pay substantial premiums for potato and sweetpotato starch in order to have the special attributes of these starches for their products.

Due to the bulkiness and perishability of root and tuber crops, initial starch extraction usually takes place near the farm gate in most Asian countries. Crude or wet starch may be processed by small enterprises from fresh roots and then sold to large mills for final processing. Thus, starch processing from cassava and sweetpotato has created new economic and employment activities for farm and rural households and adds value to these commodities. As wages rise in the region, we can expect more capital intensive methods of processing to be adopted in these countries.

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