Studies on the Characteristics of Sago Starch in Relation to Growth Environment of Sago Palm (*Metroxylon sagu* Rottb.) and its Value Addition to Wheat Flour as a Food Starch Ingredient

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Hiroyuki KONUMA

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Abbreviations

AOAC	American Association of Cereal Chemists
ANOVA	Analysis of Variance
CLT	Central Location Test
CORIN	Coastal Resources Institute Foundation, Asia
EC	Electrical Conductivity
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographical Information System
IUCN	International Union for Conservation of Nature and Natural Resources
LDFDCs	Least Developed Food Deficit Countries
NGOs	Non-Governmental Organizations
RAPD	Random Amplified Polymorphic DNA
UN	United Nations
USA	United States of America
WAT	World Agriculture Towards 2030/2050 (FAO publication)
WHO	World Health Organization

Abstract

FAO projects that the global food production need to be increased by 60 percent by 2050 to meet increasing demands, out of which over 85 percent is expected to come from existing arable land through yield increase. The world food security is facing serious challenges and uncertainties resulted from the stagnation of productivity growth of major cereal crops, increasing land and water scarcity, advancing negative impacts of climate changes and competition with bio-energy development. The situation sparked interest in identifying alternative food resources. Sago palm (*Metroxylon sagu* Rottb.) is one of the typical underutilized indigenous food crops with very little attention and research in the past. It can be grown in underutilized wetlands and peat swamps where other food crops do not fit to grow economically. It produces high yield of starch (150-400 kg of dry starch per plant). The commercial value of sago starch is influenced by the quality and color of the starch (with higher value for whiter color).

Hence sago palm was selected for this research with an aim of the first study to promote sago starch's quality and commercial value through studying the correlation between the color of sago starch and characteristics of ecosystems from which the sago palm is harvested. The second study was aimed at to explore sago starch's contribution to food security through mixing it with wheat flour. The findings of the first study indicated that sago palm grown in the ecosystem with soils containing high sulphur and high acidity produced sago starch that contained high level of phenolic compounds and active soluble polyphenol oxidase enzymes which were highly prone to phenolic oxidation and led the starch pink to brown in color on extraction. The starch extracted from sago palms which were grown under neutral soil condition with comparably lower levels of sulphur was white in color. These results suggested that sulphur contained in soils served as a stress factor and promoted phenolic production which led to oxidization and browning of sago starch. The findings also highlighted that the quality characteristics of sago starch, and particularly the color, were greatly influenced by the growth conditions of sago palm. Further studies would be required in order to identify cost effective and user friendly methodology at village level to prevent browning and enhance starch quality and value. The findings of the second study revealed that wheat flour could be substituted by sago starch up to a level of 40 percent in producing cookies that find good consumer acceptance. The result highlighted the potential of sago starch to replace or substitute wheat flour in other types of local confectionery and food products, thereby increasing the availability of additional food resources which can be produced locally on underutilized land resources without or less competing with other food crops, and consequently contributes to food security,

Chapter 1 General Introduction

1.1 Global and regional food security situation and future outlook

1.1.1 Current status

According to FAO's estimates, at present, the world produces more or less sufficient food to meet the demand of everyone, and maintains adequate food stocks. The cereal supply as at July 2014 was over 1 percent above the estimated utilization (demands). Cereal production for 2014 (as of July 2014) is expected to reach 2.49 billion tones, about 1 percent below the level in 2013, but still higher than estimated demands (Figure 1.1.).

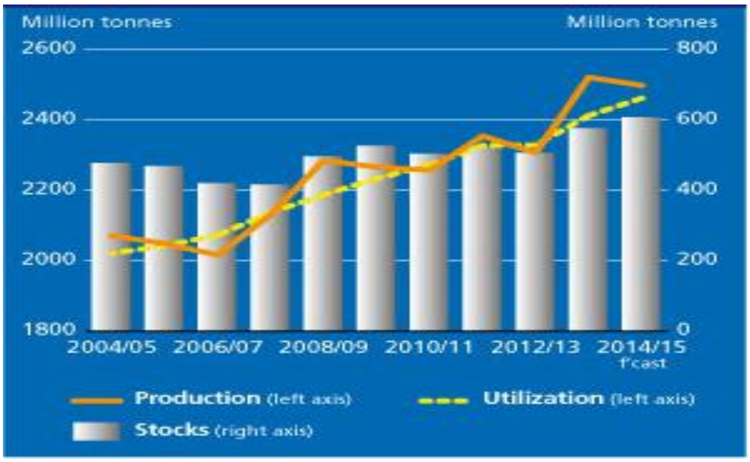

Figure 1.1 FAO cereal supply and demand brief , July 2014

http://www.fao.org/worldfoodsituation/csdb/en/ (data accessed on 15 July 2014)

Despite of the positive situation in supply side, FAO's estimation in 2013 indicated that, globally, 842 million people – 12 percent of the global population –were unable to meet their dietary energy requirements in 2011–13, down from 868 million reported for 2010–12. Thus, around one in eight people in the world were suffered from chronic hunger, not having enough food for an active and healthy life. The vast majority of these chronically hungry people – 827 million or 98 percent – live in developing world, where the prevalence of undernourishment was estimated at 14.3 percent (FAO State of Food Insecurity in the World 2013: SOFI 2013, http://www.fao.org/docrep/018/i3434e/i3434e.pdf).

Table 1.1 Changing distribution of hunger in the world, 1990-92 and 2011-13

(FAO SOFI 2013, http://www.fao.org/docrep/018/i3434e/i3434e00.htm data accessed on 15 July 2014)

	Number (millions)		Regional share (%)	
	1990–92	2011–13	1990–92	2011–13
A Developed regions	20	16	2	2
B Southern Asia	314	295	31	35
C Sub-Saharan Africa	173	223	17	26
D Eastern Asia	279	167	27	20
E South-Eastern Asia	140	65	14	8
F Latin America and the Caribbean	66	47	6	6
G Western Asia and Northern Africa	13	24	1	3
H Caucasus and Central Asia	10	6	1	1
I Oceania	1	1	0	0
Total	**1 015**	**842**	**100**	**100**

While at the global level, there has been an overall reduction in the number of undernourished people between 1990-92 and 2011-13 (Table 1.1), different rate of progress across the regions have led to change in the distribution of undernourished people in the world. Most of the world's undernourished people were still found in Southern Asia, closely followed by sub-Sahara Africa and Eastern Asia. Asia was a home of nearly two thirds (62%) of the total undernourished population (FAO SOFI 2013).

1.1.2 Future outlook towards 2050

The question is what is the food requirement to meet the needs of growing population and what is the future prospect of the production and challenges to ensure food security for our children and future generations. Current UN projections indicate that world population would increase by more than two billion people from today's levels, reaching 9.15 billion by 2050 (Figure 1.2). Incomes and per capita calorie intake will grow even faster. By 2050, some 52 percent of the world's population may live in countries where average calorie intake is more than 3 000 kcal/person/day, while the number of people living in countries with an average below 2 500 kcal may fall from 2.3 billion to 240 million. To meet increased demand, FAO projects that global agricultural production in 2050 will be 60 percent higher than in 2005/07 (FAO, World Agriculture Towards 2030/2050: The 2012 Revision: WAT 2030/50 2012, Summary, http://www.fao.org/fileadmin/user_upload/esag/docs/AT2050_revision_summary.pdf).

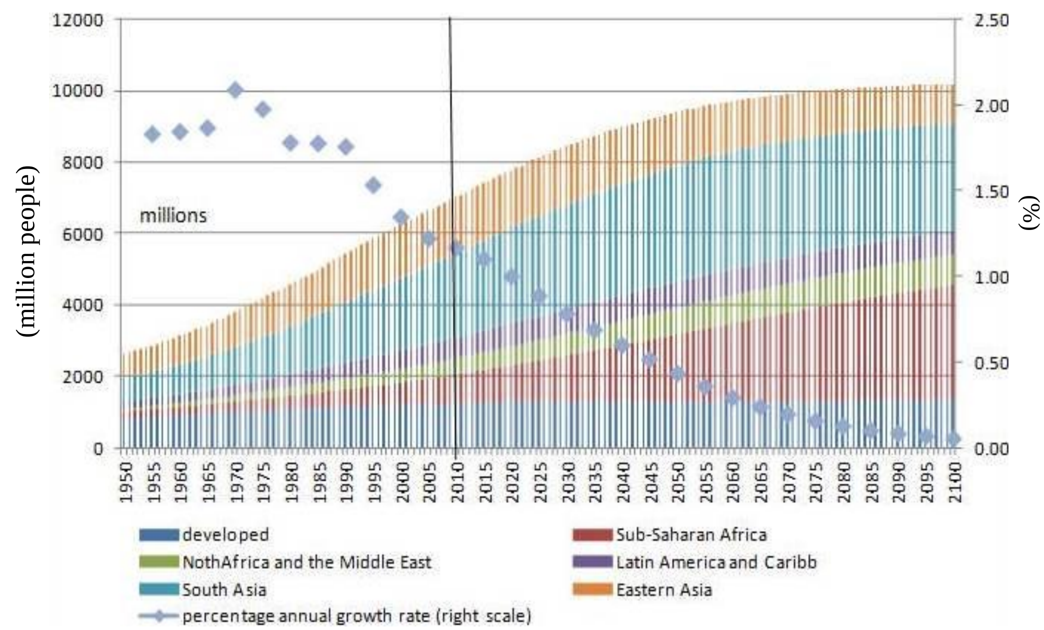

Figure 1.2 World population trends (UN, 2011, data accessed on 10 April 2014)

According to the FAO study, most of the increase in production (more than 85 percent) over the next 40 years (from 2005/07 to 2050) is expected to derive from improved yields (Figure 1.3). Some gains would also come from higher cropping intensity, predominantly in developed countries (FAO WAT 2030/50, 2012 Summary), and about 5 percent increase (70 million ha) from the expansion of arable land, mainly from developing countries in Africa and Latin America (FAO WAT 2030/50,2012).

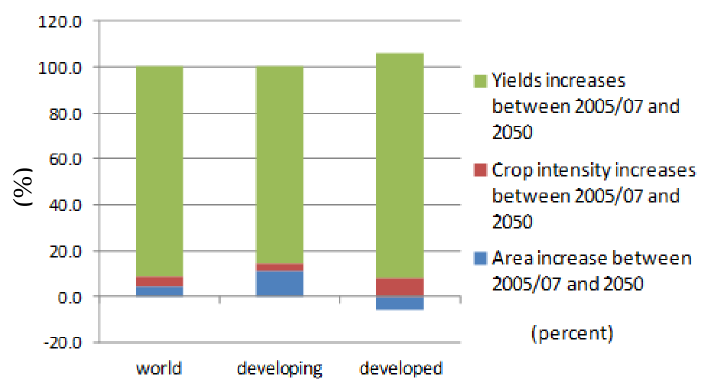

Figure 1.3 Sources of production growth from 2005/07 to 2050 (FAO WAT 2030/50, 2012, Summary). http://www.fao.org/fileadmin/user_upload/esag/docs/AT2050_revision_summary.pdf

(data accessed on 15 July 2014)

1.1.3 Arable land

This projection also reflects constraints on natural resource base, especially the future availability of land and water resources. Globally, expansion of arable land would be stagnated. Land under crops is projected to increase only by some 70 million ha (about 5 percent increase from the level in 2005/07) by 2050 (Figure 1.4). As much of the spare land is concentrated in a small number of countries, constraints may be very pronounced in other countries and regions. Where these constraints are coupled with fast population growth and inadequate income opportunities, land scarcity can lead to more poverty and migration. Thus, local resource scarcities are likely to remain a significant constraint in the quest for achieving food security for all (FAO WAT 2030/50, 2012).

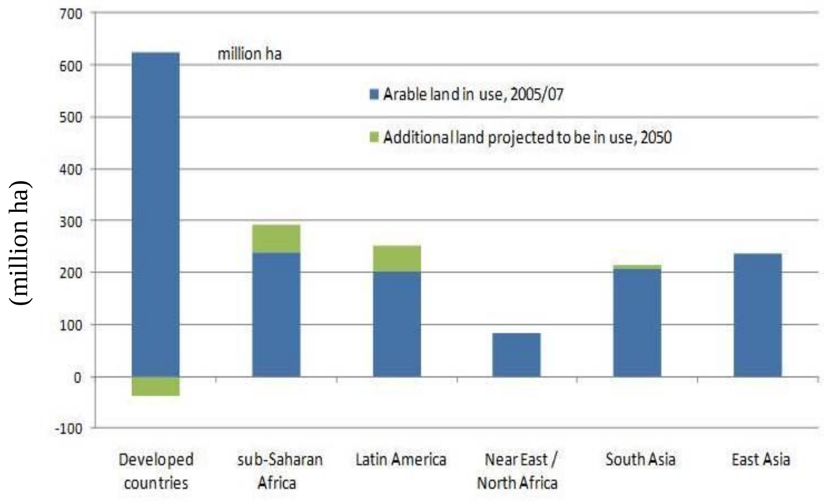

Figure 1.4 Limited scope for the expansion of arable lands (FAO WAT 2030/50, 2012, data accessed on 15 July 2014)

1.1.4 Water resources

Water is another critical resource, and irrigation has played a strong role in contributing to past yield and production growth. World area equipped for irrigation has doubled since the 1960s to 300 million ha, but the potential for further expansion is limited. While water resources are globally abundant, they are extremely scarce in the Near East and North Africa, and in northern China, where they are most needed. A net increase of 20 million ha of irrigated area (about 7 percent increase) is expected by 2050 (FAO WAT 2030/50, 2012, Summary).

1.1.5 Production and productivity growth of major cereals towards 2050

Annual productivitiy growth rate of main cereals,especially wheat and rice, declined sharply in recent decades to the level 0.8 peercent (wheat) and 0.6 percent (rice) if compared with that of 2.9 percent and 1.9 percent ,respectively, during the Green Revolution period (Table 1.2). At present, irrigated agriculture covers some 16 percent of the arable land in use, accounts for 44 percent of all crop production and some 42 percent of cereal production in the world. Similar estimates for developing countries are somewhat higher with 21 percent of arable land, accounting for 49 percent of all crop production and 60 percent of cereal production (FAO WAT 2030/50, 2012).

Table 1.2 Sources of growth for major cereals in developing countries (FAO WAT 2030/50, 2012 data accessed on 15 July 2014).

Name Cereals	Year	Annual growth (percent p.a.)			Contribution to growth (percent)	
		Production	Harvested land	Yield	Harvested land	Yield
Wheat	1961-2007	3.62	0.68	2.92	19	81
	2005/2007-2050	0.87	0.01	0.86	1	99
Rice, paddy	1961-2007	2.46	0.54	1.91	22	78
	2005/2007-2050	0.58	-0.05	0.63	-9	109
Maize	1961-2007	3.55	1.05	2.47	30	70
	2005/2007-2050	1.43	0.59	0.83	41	59

1.1.6 Future uncertainties: bio-fuels and climate change

While these projections represent the result of the best analysis and assumptions on factors affecting global agricultural supply and demand, there remain many risks to the projections. The projections assume sufficient investment and policy support in the agriculture sector, and even then areas of undernourishment will persist. Continued strengthening of the linkages between agriculture and energy present both an opportunity and a risk to food security. Significant changes in energy prices would potentially divert commodities and land to renewable energy production, which would result in higher competition on the use of land and water between food crops and bio-energy crops. Moreover, the projections are set in a future where the impact of climate change is not yet fully understood (FAO WAT 2030/50, 2012, Summary).

1.2 Value of underutilized food crops towards promotion of bio-diversity and food security

1.2.1 Biodiversity

Biodiversity for food and agriculture includes the components of biological diversity that are essential for feeding human populations and improving the quality of life. It includes the variety and variability of ecosystems, animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain human life as well as the key functions of eco systems(FAO Biodiversity: http://www.fao.org/biodiversity/group/en/).

Such diversity is the result of thousands of years of farmers' and breeders' activities, land and forest utilization, and fisheries and aquaculture activities combined with millions of years of natural selection. Most of the human population lives in areas where food production and nature co-exist together.

The large and increasing number of under- and mal-nourished in the world, the prospect of rising inequality, difficulty of access to food by the most vulnerable populations, the decreased availability of natural resources and the uncertainty of climate change are among the main challenges facing FAO and its work on biodiversity for food and agriculture.

It is foreseen that developing countries will, in some areas, show a decrease in agricultural productivity between 20-40% due to the effects of climate change. This may lead to pressure on natural resources.

The conservation and sustainable use of biodiversity for food and agriculture play a critical role in the fight against hunger, by ensuring environmental sustainability while increasing food and agriculture production. It is imperative to do so in a sustainable way: harvesting resources without compromising the natural capital, including biodiversity and ecosystem services, and capitalizing on biological processes.

To cope with all these challenges and uncertainties a large reservoir of genetic and species diversity will need to be maintained and sustainably used. This diversity will further help maintain and rehabilitate productive ecosystems to supply future generations with abundant food and agriculture (FAO Biodiversity: http://www.fao.org/biodiversity/group/en/).

1.2.2 Biodiversity and food security

The declining number of species upon which food security and economic growth depend has placed the future supply of food and rural incomes at risk. The shrinking portfolio of species and varieties used in agriculture reduces the ability of farmers to adapt to ecosystem changes, new environments, needs and opportunities.

About 7,000 species of plants have been cultivated for consumption in human history. The great diversity of varieties resulting from human and ecosystem interaction guaranteed food for the survival and development of human populations throughout the world in spite of pests, diseases, climate fluctuations, droughts and other unexpected environmental events. Presently, only about 30 crops provide 95% of human food energy needs, four of which (rice, wheat, maize and potato) are responsible for more than 60% of our energy intake. Due to the dependency on this relatively small number of crops for global food security, it will be crucial to maintain a high genetic diversity within these crops to deal with increasing environmental stress and to provide farmers and researchers with opportunities to breed for crops that can be cultivated under unfavourable conditions, such as drought, salinity, flooding, poor soils and extreme temperatures (FAO Bio-diversity: http://www.fao.org/biodiversity/components/plants/en/).

FAO advocates increased attention to tap underutilized food resources produced on poor lands (wet lands, swamps) by the poor. They directly contribute to local food availability and access by the poor. Many neglected and underutilized species are nutritionally rich and are adapted to low input agriculture. The use of these species – whether wild, managed or cultivated – can have immediate consequences on the food security and well-being of the poor (FAO Sustainable Diet and Bio-diversity,2012: http://www.fao.org/docrep/016/i3004e/i3004e.pdf)

Many neglected and underutilized species play a role in keeping cultural diversity alive. They occupy important niches, adapted to the risky and fragile conditions of rural communities (FAO Sustainable Diet and Bio-diversity 2012).

Against these backgrounds as outlined in the sections 1.1 and 1.2 above, and in view of the facts that it produces high yield of starch and growing underutilized wetlands and swamps, sago palm was identified as one of the most promising underutilized food resources with a high potential for its contribution to global food security.

1.3 Economic, social and environment benefit of sago palm and its products

1.3.1 Sago Palm (Metroxylon sagu **Rottb.)** *- General introduction*

Sago palm (*Metroxylon sagu* Rottb.) is a species of the genus Metroxylon belonging to the *Palmae* family, and is a socio-economically important crop in South-East Asia. It grows well in humid tropical lowlands, up to an altitude of 700 m, and a source of starch and offers considerable potential to contribute to food security where it is grown (Flach 1997 Sago Palm IPGRI).

Sago palm is grown between latitude 10° north and 10° south of Southeast Asia and Pacific Island countries (Figure 1.5).

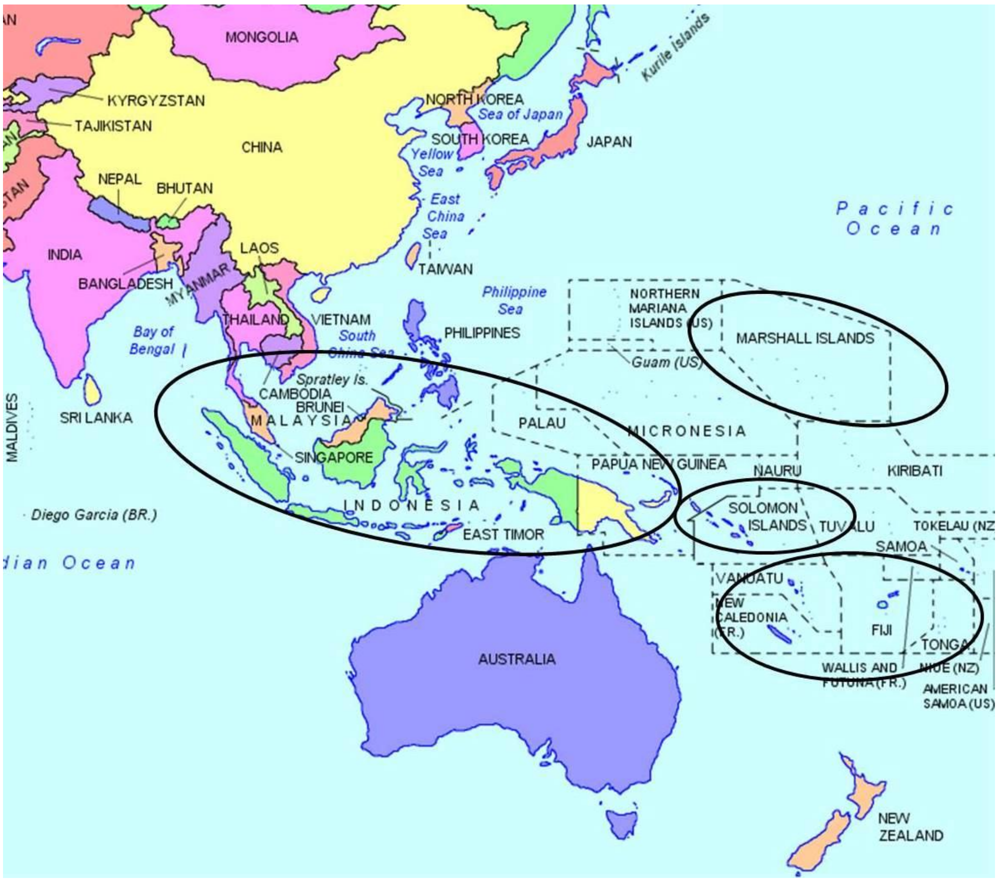

Figure 1.5 A map of sago palm growing countries (modified from google map)

Indonesia has the largest sago palm growing areas (both wild and semi cultivated stands) followed by Papua New Guinea, and limited semi cultivated stands in Malaysia, Thailand, Philippines and Pacific Island countries (Table 1.3).

Table 1.3 Country wise distribution of sago stands (IPGRI, 1997)

	Wild stands	(Semi-)cultivated stands
Papua New Guinea, total	1 000 000	20 000
Sepik province	500 000	5 000
Gulf province	400 000	5 000
Other provinces	100 000	10 000
Indonesia, total	1 250 000	148 000
Irian Jaya, total	1 200 000	14 000
Bintuni	300 000	2 000
Lake Plain	400 000	—
Southern Irian	350 000	2 000
Other Districts	150 000	10 000
Moluccas	50 000	10 000
Sulawesi	—†	30 000
Kalimantan	—	20 000
Sumatera	—	30 000
Riau islands	—	20 000
Mentawei islands	—	10 000
Malaysia, total	—	45 000
Sabah	—	10 000
Sarawak	—	30 000
West Malaysia	—	5 000
Thailand	—	3 000
Philippines	—	3 000
Other countries	—	5 000
Total	2 250 000	224 000
† No wild stands.		

Sago palm has the following specific characteristics ((Flach 1997:Sago Palm IPGRI, Promoting the conservation and use of underutilized and neglected crops. No.13.): ftp://ftp.cgiar.org/ipgri/Publications/pdf/238.PDF, data accessed on 15 July 2014).

- Grown in fresh water swamps and low/wet land
- Found in tropical areas with a warm temperature around 29-32°C (minimum 15°C)
- Found between latitude 10° north and 10° south, up to altitude of 700m above sea level
- Tolerance for mild saline water, but usually borders on nipa palm swamps, which can stand with higher salinity water
- Takes about 3½ years before stem (trunk) formation starts
- Flower initiation occur at about the trunk age of 4½ years old
- Takes 8-12 years to reach maturity stage (before flowering) suitable for harvesting
- Sago grows about 10-12 m in height with a diameter of trunk at 35-60 cm
- Fresh weight of trunk 1-2 tons, of which 10-25% of dried starch. (about 100 kg – 400 kg of dried starch from one matured sago palm tree can be obtained)

- Average leaf production is two/month. Leaves can be harvested when sago palm reaches about 4 years of age for making roofing materials.

1.3.2 Starch production for human consumption

The trunk of sago palm has been used to obtain starch as a staple food for human consumption. According to Flach (1997), at the semi-cultivated sago palm forests in Irian Jaya in Indonesia and Papua New Guinea, the local inhabitants harvest sago palm whenever the starch content per trunk is highest; just before the flowering starts. Their yields usually vary from 150 to 400 kg of dry starch per harvested trunk (Flach 1997).

Sago starch contains 27% amylose (the linear polymer) and 73% amylopectin, the branched polymer (Ito *el al* 1979). However, Kawabata *et al* (1984) found the amylose content of 21.7% in sago starch. Flach (1997) estimated that the difference of amylose content might occur according to the age, variety, or growing conditions of sago palm.

In some areas such as southern Thailand, simple starch extraction methods are used at farm household level, while a larger industrial scale extraction is generally found in Indonesia and Malaysia. There are different starch extraction methods in different countries. One of the common traditional methods of preparation of sago starch for human consumption is to pour hot water over the wet starch, and stir it with a stick or a spoon. The resulting glue-liked mass is eaten with some fish or other associated foods. It is also common to bake sago starch, occasionally mixed with other foods such as ground peanuts (Flach1997). In Thailand, sago starch is occasionally used as a raw material for making breads, noodles, pasta, etc. (Klanalong 1999).

1.3.3 Income generation

Sago starch is utilized in Thailand as a raw material to produce food for income generation at village level. The traditional sweets, cookies, and snacks produced from sago starch are the important extra income of farm families (Konuma 2008).

Sago leaves are widely used to make mats for roofing or partitioning (Flach 1997). The sago roofing mats are strong and last longer than those made from other palms and are the important source of income of sago growers. The shelf life of sago leaf roofing mats is about 6-10 years. In West Java, the palm is grown especially for leaf production and the average starch production then is only 55 kg/trunk compared with 175 kg/trunk from similar size of sago palm tree grown for starch only (Haska 1995).

The ground pith of sago palm is sometimes used as an animal feed, especially for pigs. When dried, it is also used for horses and chickens (Flach1997). The lower part of trunk is also used for sago worm farming in Southern Thailand which generates additional income for farmers (Klanalong 1999).

1.3.4 Processing and industrial use

The granular size of sago starch is about 30 µm in average, which is similar to that of potato and much larger than all other starches (Griffin 1977). Flach (1997) indicated that in the modern starch industry, starches can be modified to quite an extent. He also stated that sago starch would be competitive to all other starches, and for some purposes, it may even be preferred, provided there is a regular supply of cheap, clean and non-corroded starch.

In recent years, sago starch is given a special attention on as a potential source of ethanol production for bio-fuel due to global concern over the climatic changes and future energy crisis. It is estimated that whereas other food crops such as maize and cassava compete the use of land resources for staple food production with that for bio-fuel production thereby increasing the risk of food insecurity, sago palm can be grown on marginal land or on land where other food crops would unable to grow economically. Again, a regular supply of low cost quality starch in industrial quantity would a key for the success.

1.3.5 Community based traditional ecosystem and natural resource conservation

In Thailand, rapid expansion of oil palm industry and natural rubber plantations reflecting increased world demands and the price hike was another factor which affected the traditional farming systems. As a result, wet lands and peat swamps including sago palm forests have been rapidly disappearing and replaced by industrial crop plantations. The overall situation negatively affected on the environment and sustainable ecosystem as well as on the traditional values, culture, and livelihoods of people living in rural communities. The study results indicated that sago palm forest was an important local resource of the rural communities in southern Thailand (Konuma 2008). The villagers have harmonized their traditional life style and community spirit with the sago palm forest for their farming system, economy and culture. Through the review of various research reports, it was found that sago palm played an important role as a symbol for the protection of traditional ecosystem, biodiversity and cultural heritage.

1.4. Geographical distribution and characteristics sago palm in Thailand

Sago palms *(Metrxylon sagu* Rottb.*)* were usually grown in the wetland, canal banks and forest in Southern Thailand (Konuma 2008). It was found based on RAPD Analysis and Cluster Analysis that sago palm in Thailand was originated from the species which were commonly existed in Papua New Guinea (Hisajima 1995). It was also found that all sago palms observed in Chumporn, Phang-Nga, Krabi, Surat Thani, Trang and Nakhon Si Thammarat were non-spined *(Metroxylon sagu* Rottb.). Due to security problems, it was not possible to visit Narathiwat and other most Southern provinces of Thailand (Konuma 2008).

The Department of Land Development, based on the peat swamp forest area data, roughly estimated that nearly a half (50%) of sago palm forests in the country would be in Narathiwat Province in the most close to Malaysian border, followed by Nakhon Si Thammarat (approx. 25%), Songkhla (7.5%), Chumporn (5%), Phatthalung (4%), Pattani (2%) and rest is in Trat, Surat Thani, Trang, Phang-Nga, Krabi, Saturn, etc. (Jirasak *et al.* 1996). Photos of sago forests in Surat Thani and Phang-Nga provinces are shown below (Figure 1.6). Flach estimated the existence of 5,000 ha of good quality sago palm stands in Thailand in 1983 which was reduced to 3,000 ha in 1996 as per his revised estimate. In the absence of reliable inventory data, it was difficult to estimate the sago forest areas in Thailand while the Department of Land Development claimed in 1996 the existence of 64,000 ha of peat swamp forest areas in Thailand which were the potential home of sago palms (Klanarong 1999) .

Figure 1.6 Sago forest in Kandri, Ta Chana, Surat Thani Province (left) and Kapong, Phang-Nga Province (right) ,Thailand

The distribution of sago palm was studied during 2006-2007 (Konuma 2008). According to the field study, the northern edge of sago palm forest was found in Tambol Nasak, Sawi District in Chumporn Province at the latitude 11º north in the Gulf of Thailand coast, and in Kapong District in Phang-Nga Province (latitude 8.5º north) in the Andaman Sea coastal area. It was also reported with a photo evidence that sago palms grow at the Horticulture Research Centre in Chanta Buri (latitude 12º north) which is located near the border close to Cambodia. Two sago palm trees were brought to the Research Centre on an experiment basis from Surat Thani Province about 2 years ago. Chanta Buri Province is located beyond usual northern limit of latitude 10º north where sago palm can usually grow. Perhaps, the year round high humidity and warm weather in the area might facilitate the adoption of the plant in the area. However, it appeared that the growth speed of these palms is rather slow as they reached only about 1m in height in 2 years after the suckers were transplanted at the height of 50 cm. For people living in wetland and swampy areas, sago plays a significant role in their livelihood as the soil condition in such areas does not fit to support other crops economically. People in Southern Thailand have utilized sago palm as a source of food ingredient, an additional income source and a medicine. Yad Fon Association, a CSO based in Trang reported that sago palms play an important role in the village culture such as religious ceremonies and promoting community spirit. It also plays a significant role in maintaining the natural balance of wetlands as the palm absorb water, conserve soils and is the main plant in the ecological system.

The farmers in Surat Tani informed during the field study that at the time of the Second World War, when there was a shortage of rice and wheat, sago starch played an important role as an alternative staple food. In Thailand, sago starch is extracted by traditional means at household level and has never been regarded as a source of raw material for industrial purposes, despite if its potential benefits (Klanalong 1999).

Sago flour or sago starch is known in local language *"sa khu"* among the people in Southern Thailand. However, it has many meanings. True sago was initially introduced as sa khu pearl or sa khu bead before the beginning of the cassava industry in 1960th. At present, almost all sago pearl is made from cassava starch (Klanalong 1999).

1.5 Utilization of sago palm and its products in Thailand

Based on the information provided by Yad Fon Association in Trang, University of Prince of Songklan, and the interviews with people in Ban Nong Pab Nam, Tambol Cokesaba, Amphur

Nayong, Trang Province and Sago Forest Women's Group in Amphur Muang in Trang Province and villagers in Ban Num Kao, Tambol Fukeeri, Nakhon Sri Thammarat Province were conducted, and the utilization of a sago palm for different purposes were studies (Konuma 2008). The details are summarized as follows (Table 1.4):

Table 1.4 Utilization of Sago Palm in Tambol Cokesaba, Nayong ,Trang Province and Tambol Fukeeri, Nakhon Si Thammarat Province in 2007.

Sago palm parts		Utilization
Leave		- rooting material - partitioning material - wrapping material for foods
Rachis		- woven mats - shelves for holding fish, shrimp and vegetables for sun drying - stall for duck, chicken, etc
Sago latex		- paper adhesive - cosmetic for facial treatment
Trunk (stem)	Middle part	- starch extraction (sweets, cookies, snacks, noodle, bread etc.)
Trunk (steam)	Top/ bottom parts	- sago worm farming - animal feeds
Trunk bark		- fuel - plant containers/plots
Sago top		- food (soup, side dish, etc.)
Fruit		- food - herbal medicine
Sago pulp		- fertilizer
Roots		- herbal medicine

Leaves: The leaves are used to make roofing and partitioning materials which are more durable than those made from other palms. The material shelf life is about 6-10 years. When the materials are soaked in water before use, they can last longer. At the interview, villagers informed that sago roofing mats would last as long as 10 years. Mats are sold to a middle man who collects roofing mats periodically from farmers and sell them to markets or beach resorts in Phuket, Kurabi, etc. There are increased demands of sago roofing mats in recent past.

Roofing mats are made from old leaves (Figure 1.7). The leaves are cut from the leaf stalks and tied into a bundle using old areca palm or bamboo wood. The size is about 1.5-2 cm in diameter and 1.5 m in length. They are then soaked in water for 7-10 days to prevent weevils. The leaves are arranged in a mat tied with a rope. During binding, about 3-4 leaves are overlapped face-up; the two lower leaves will overlap only a half. Then, the leaves are folded and bound using areca palm ropes (0.5 cm in width). New leaves are then added to the mat by a similar method until the desired length is achieved. This is called one mat. The durability of the roofing mat can be improved by soaking in dirty water for 15-30 days, washed until no more dirt is left, and then sun-dried. The price of a roofing mat in 1984 was 3.50 Baht each or 350 Baht / 100 mats. A skilled person can produce about 40-50 mats per day. Today, the price of a roofing mat is about 9-10 Baht.

Figure 1.7 Roofing mats being made by a farmer (left) and a sago palm plantation (right) for leaves production in Tambol Fukeeri, Nakhon Si Thammarat Province.

At Ban Num Kao, Tambol Fukeeri in Nakhon Si Thammar Province, one of farmers planted sago palm in a small plot of 1.5 rai (approximately 0.25 ha) and is producing 700-800 sheets of sago roofing mats in every 6 months (Figure 1.7). One roofing mat is sold at 10 baht. This brings estimated income of 7,500 baht per 6 months (15,000 baht/year or about 1,250 baht month). If a farmer and his other his family members weave the roofing mat by themselves, more than 90% of the income (except minor external material costs such as stick, etc. which cost about 1 baht per mat) would be the net profit of the family, in addition to other associated incomes which may come from the sale of starch, sago worms, etc. Some villagers use sago leaves to wrap Thai dessert which is called 'Kanom Jak'. The dessert is prepared by mixing coconut, sugar, waxy rice flour and sago starch. The mixture is then wrapped by sago leaves and then grilled. Each packed Kanom Jak costs about 1-2 baht.

Sago rachis: Each sago rachis is about 3-4 m in length. It is spherical at the top and tapers at the end. When the end is cut, the rachis is about 1.5-2 m in length and then peels to collect the outer sheath which is called 'Na sago'. This is used to produce woven mats and shelves for holding shrimp, fish or vegetables during sun-drying. They are easier to produce with sago rachis than from bamboo. If the mat is used only for carrying light-weight products, it is as durable as the bamboo mats. This is more suitable to be used for house partitioning because of its light weight and weevil resistance. This can used to produce the collecting spawn for shrimp and baby fish. The rachis when dried is used to produce duck, chicken and vegetable stalls which usually last for 1-2 years.

Sago latex: When the rachis is freshly cut from the stem into small pieces (5-14 cm) and left for 20-30 minutes, the latex is produced from the cuts at two ends. The latex is clear and very sticky and can be used as paper adhesive. According to the information provided by the Yad Fon Association in Trang, in the past, women used this sago latex to mask their face for curing acne and improving face whiteness.

Sago trunk (for starch): The matured sago palm with age more than 7-9 years old (depending on the soil fertility) will enter the flowering stage. If the plant is used for starch production, the tree has to be cut at this period just before flowering stage, because it has a lot of starch. If the plant is left to pass flowering and fruiting stage, the quantity and quality of starch will be significantly reduced and hence becomes not economical. The plat will end its life after flowering and fruiting. Therefore, sago starch production begins by selecting plants just before flowering, cutting the trunk (Figure 1.8), removing the top and bottom parts which contain less starch but contain more fiber (these parts are usually used as animal feeds). The trunk is usually cut into small pieces (approximately 0.8-1.0 meter each) and then milled (Figure 1.8 and 1.9), mixed and washed by clean water, filtering the milled pulp using a cloth, collecting the starch cake and then drying. One sago palm plant yields dry starch of about 150-400 kg (15-20 % of the trunk weight).

Figure 1.8 Cutting sago palm trunk, Nayong in Trang Province

In Nakhon Si Thammarat Province, a live matured sago palm stand was sold at 300 baht at the sago growing site. After it was brought to milling site, the trunk is cut into approximately 10 pieces. Each of this piece (about 80 cm in length) costed 100 baht (Figure 1.8).

Figure 1.9 Milling a piece of sago trunk , Nayong , Trang Province.

Sago starch is used to produce many food dishes such as cookies and sweets (Figure 1.10). During the Second World War, when there was a rice shortage, the southern people ate sago starch as a replacement. Currently, sago starch is used to make many desserts such as cookies, sweet sticky dessert, sago pearl with pork stuffing and some snacks, to produce rice noodle and bread**.**

Figure 1.10 Making cookies and sweet from sago starch, Nayong, Trang Province.

Sago worms: sago worms contain a high protein content. The consumption of sago worms as a local delicacy and nutritional food depends on the local culture in each area. The villagers produce sago worms by 2 methods:

- Naturally: when the sago palm stem has a starch inside, some insects drill into the trunk and eat the flesh. Insects will then lay eggs which will grow to larvae and worms.
- Farming: sago worm farming is done by cutting sago palm trunks into small logs. This was observed in both Nayong in Trang Province and Fukeeri in Nakhon Si Tammarat Province. The logs are then kept wet (some areas will drop fish sauce to promote egg lying by insects) for about 40 – 60 days (Figure 1.11). Eggs grow to worms which are

3-4 cm in length and they have a light brown color. One sago palm tree can produce about 3-5 kg of sago worms. The price is about 200-300 baht per kg. At the time of field study, the worms were sold at 200 baht per 1 kg in Fukeeri, while the cost was higher in Nayong with the price at around 300 baht /kg.

Figure 1.11 Sago Warm Farming at Fukeeri, Nakhon Si Thammarat

Trunk bark: When the trunks are debarked before starch extraction, bark waste is generated. This bark waste is sun-dried and then used as a fuel source for burning. The matured trunks, after removing the flesh, have a hard bark around the stem which can be used as plant containers or pots. The bark in some cases, cut into a half and used to cover the floor to make a temporary walkway. There are research activities to explore the use of sago trunk bark cellulose for bio-ethanol production.

Trunk flesh: If the trunk is not processed for starch extraction, especially the top and bottom parts of the trunk where starch content is low, the trunk is used as an animal feed. The trunk is cut into small logs and further in half size; the logs are left for ducks and chickens to eat by themselves. Sometimes, cut log is debarked and then cut into small pieces for feeding fish or milled to fine pieces for mixing with other animal feed such as rice bran and vegetables. In Trang Province, this type of animal feed is typically used to feed pigs. In Nakhon Si Thammarat Province, milled trunk flesh is also used for feeding cattle which coasted 13 baht per 20 liter container (3-4 kg).

Sago fruits: Sago fruits can be eaten. Mature fruits have a sweet and astringent or acidulous taste. In order to eliminate astringent or acidulous taste, fruits are usually buried in mud or grilled before consumption. Fruits are also used as an herbal medicine to reduce a high blood pressure and heal the diabetes.

1.6 Justification for the selection of sago palm and its starch and the objective of the research

As outlined in the Chapter 1.1, the global food production is projected to increase by 60 percent by 2050 to meet increasing demands of rapidly growing population, out of which over 85 percent is expected to come from existing arable land through yield growth. On the other hand, the world food security is facing serious challenges and uncertainties such as increasing land and water scarcity, decline of annual productivity growth of major staple foods, advancing negative impacts of climate changes such as droughts and floods, and increasing competition on the use of arable lands between food crops and bio-energy crops. This has sparked interests in identifying alternative crops for food use.

FAO advocates increased attention to tap underutilized food resources produced on poor lands (wet lands, swamps, etc.) by the poor. They directly contribute to local food availability and access by the poor. Many neglected and underutilized species are adapted to low input agriculture. The use of these species – whether wild, managed or cultivated – can have immediate consequences on the food security and well-being of the poor. Graziano da Silva, the Director-General of FAO stressed at an international seminar held in Spain in December 2012 that neglected and underutilized species play crucial role in the fight against hunger and are a key resource for agriculture and rural development. He called for increasing research on underutilized crops for the benefit of smallholder farmers. In addition, many neglected and underutilized species play a role in keeping cultural diversity alive. They occupy important niches, conserving traditional landscape, adapted to the risky and fragile conditions of rural communities (FAO Sustainable Diet and Bio-diversity, 2012).

Sago palm (*Metroxylon sagu* Rottb.) is one of the typical underutilized indigenous food crops with very little attention and research in the past. It can be grown in underutilized wetlands and peat swamps where other food crops do not fit to grow economically, and produce high yield of starch (150-400 kg of dry starch per plant). Thus, sago palm has a high potential to contribute to food security as an additional source of staple foods without (or less) competition on the use of arable lands with other food crops, as well as for other industrial use including bio-plastic and bio-ethanol production. Sago palm is grown in Indonesia, Papua New Guinea, Malaysia, Thailand, Philippines, Pacific Island countries, etc. Despite of its important role being played as a source of traditional foods, and off-farm and non-farm income generation of poor rural communities, the palm population has drastically decreased in recent past due to the conversion of the lands for other purposes including for the expansion of industrial crops such as oil palm and rubber trees.

Despite its traditional uses, industrial and other potential benefits, relatively little efforts have been done to modernize the extraction of sago starch or to upgrade village level technologies used in adding value to sago starch, in order to maximise the use of sago palm and its starch. However, considerable potential exists to build on and improve traditionally produced value added products based on sago starch, and to market those products to a wider consumer base, thereby generating income and employment opportunities for poor villagers living in sago starch producing areas. This could also facilitate in increasing availability of starch resources to produce staple foods through substituting wheat flour by sago flour to meet increasing demands of staple foods in the future, and thereby contributing to future food security.

In addition, the quality and color of sago starch vary considerably depending on the growth environment of sago palm. It is well recognized that the commercial acceptance and value of sago starch hinges greatly on its quality characteristics, particularly its color. Browning contributes to the low marketability of sago starch (Yatsugi 1986, Ahmad 1991, Okamoto *et al*. 1988 and Onsa *et al*. 2000), and hence reduces the economic value of the starch. It was observed that the dry brown color sago starch sold at local market in Trang, Thailand was 60-70 Baht/kg, while white color sago starch sold at a market in Nakhon Si Thammarat, Thailand was 80-90 baht/kg at the same period (about 30 percent higher price with a higher demand).

Sago palm (*Metroxylon sagu* Rottb.) and its starch were selected for this research due to above reasons, with an overall objective to promote the effective utilization of sago starch and its products for their contribution to food security. The research was consisted from two components with specific aims to a) study on the potential of promoting sago starch's commercial acceptance and value, and income of farmers through identifying the correlation between the color of sago starch and characteristics of ecosystems from which the sago palm (*Metroxylon sagu* Rottb.) was harvested, and b) study on the sago starch's potential contribution to food security as a food ingredient through mixing it with wheat flour and consequently increase the overall volume of the starch and its products for human consumption.

The country of the study i.e. Thailand was selected as the country was the home ground of the research team and was convenient for frequent field visits. Nakhon Si Thamarat Province (see the map in Figure 1.12) was selected as the area represented one of the major sago palm growing areas in Thailand (it was estimated that nearly 25 percent of the total sago palms in Thailand grew in this province).

Figure 1.12 Sago growing areas in Thailand and the location of Nakhon Si Thamarat where the study was conducted (modified from Thailand Administrative Map).

Chapter 2 Characteristics of Sago Starch as they relate to the Growth Environment of the Sago Palm *(Metroxylon sagu* Rottb.*)*

2.1 Summary

The sstudies were undertaken in Nakhom Si Thamarat Province in Southern Thailand, in an effort to correlate the color of sago starch to the characteristics of ecosystems from which the sago palm (*Metroxylon sagu* Rottb.) was harvested and to the phenolic content. Sago palms grown in fresh water swamp under acidic conditions and high soil sulphur concentrations (samples obtained from Kreng), yielded starch of a high ash content that was highly prone to phenolic oxidation, and was pink to brown in color. This starch had a comparably high concentration of phenolic compounds (0.115 mg of catechin equiv/g dry weight**)** and underwent rapid browning during the extraction process, suggesting the presence of highly active polyphenol oxidases in the pith from which the starch was extracted.

Starch extracted from sago palms grown under neutral soil conditions with comparably lower levels of sulphur (1/6 the sulphur content of soil in Kreng) and ash as in the case of samples obtained from Lansakar, were white in color.

Starch samples extracted from sago palms grown under neutral brackish conditions, in the Ronpiboon ecosystem, underwent browning after an extended incubation period (four hours) at room temperature, and had a comparably lower phenolic content (0.089 mg of catechin equiv/g dry weight) suggesting the predominance of latent polyphenol oxidases in the pith from which the starch was extracted.

2.2 Introduction

New and potential growth opportunities for the use of sago starch as food warrants a greater focus on assuring the quality of sago starch. The commercial acceptance and value of sago starch hinges greatly on its quality characteristics, and particularly its color. Starches extracted from different ecosystems vary in color from gray to pink to various shades of white.

Browning contributes to the quality deterioration of sago starch and has been associated with low marketability of that product (Yatsugi 1986, Ahmad 1991, Okamoto *et al*. 1988 and Onsa *et al*. 2000). The occurrence of browning during extraction of starch from the sago pith, tremendously reduces the economic value of the starch.

Ahmad *et al.* (1999) noted that the quality of sago logs as well as their post-harvest handling operations greatly impact on sago starch quality. In a recent review, Karim *et al.* (2008) highlighted among a number of issues, the need to correlate growth conditions of the sago palm, to the quality and yield of starch.

Against these backgrounds, the studies were undertaken in an effort to correlate the color of sago starch to the characteristics of ecosystems from which the sago logs were harvested and the phenolic content of the sago starch extracted. This study combined the results of two researches i.e. “Color characteristics of sago starch as they relate to the growth environment of the sago palm (*Metroxylon sagu* Rottb)” which was published by the Journal of Agricultural Technology 2012 Vol.8 (1): pp273-287 (Konuma *et al.* 2012), and “Correlation of the browning of starch extracted from sago palm (*Metroxylon sagu* Rottb.) to the phenolic content and ecosystem conditions of growth” which was published by the Journal of Agricultural Technology 2013 Vol.9 (1): pp193-200 (Konuma *et al.* 2013).

2.3 Materials and methods

2.3.1 Materials

Samples of the sago trunks for starch extraction were obtained from 7-10 year old trees from three different ecosystems in Nakhom Si Thamarat Province in Southern Thailand - namely Ronpiboon (a costal site), Kreng (peat swamp) and Lansakar (a hill area) (Figure 2.1) .

(a) (b) (c)

Figure 2.1 Habitat from which sago palm samples were collected in Ronpiboon - a coastal site (a); Kreng – fresh water peat swamp (b) and Lansakar– a hill area (c)

Soil Sampling and Analysis - Soil samples were taken from each of the three ecological systems in two layers: an upper layer (15 cm) and lower layer (30 cm) using clean equipment and materials (hoe and spade, plastic bag, plastic can and plastic cloth, 1 x 1m) in accordance with the sampling plan illustrated in Figure 2. Samples from each respective ecosystem were combined, mixed and stored in Ziploc bags for analysis of pH and sulphur content.

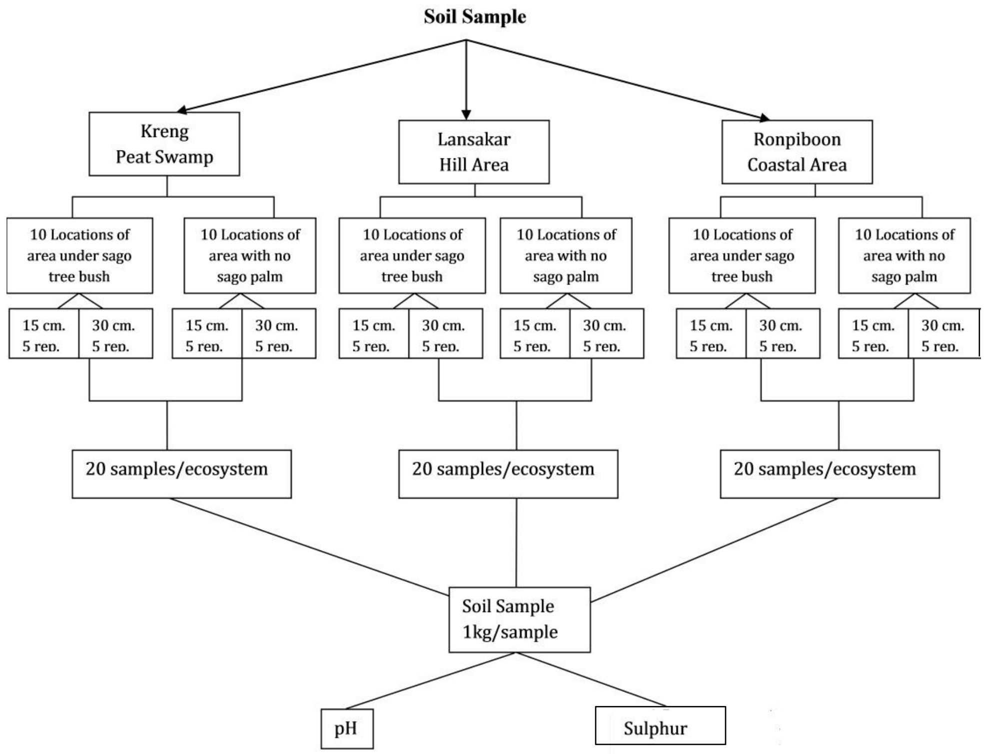

Figure 2.2 Sampling plan for the collection of soil specimens for analysis

Sampling of the sago-trunk – Sago trees were felled, following which the sago trunk was separated into lower, middle and upper portions according to the method of Srioroth *et al.* 1999 (Figure 2.3). A stainless steel axe was used to separate the bark from the sago pith for each portion of log (Figure 2.4)

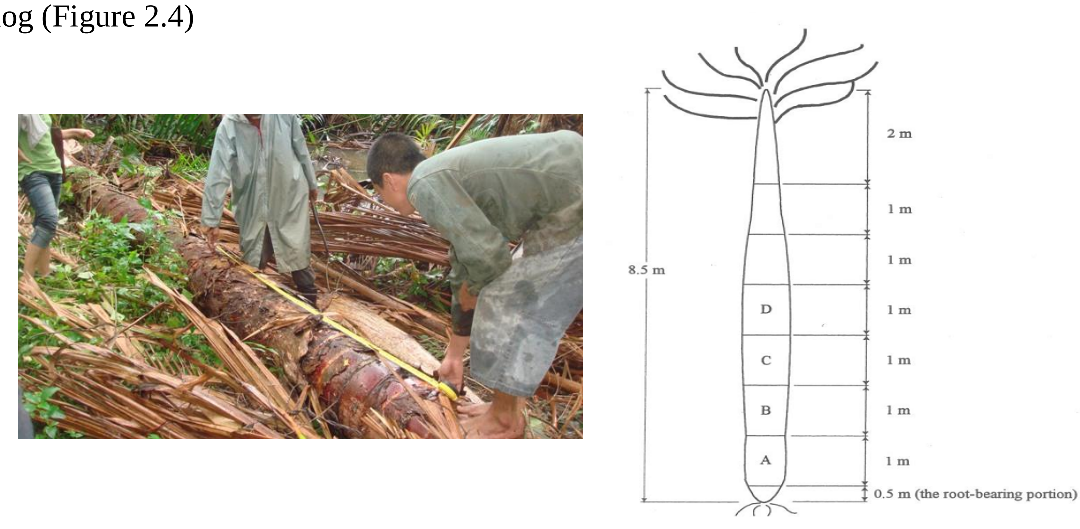

Figure 2.3 Measurement of the sago trunk into 1 meter portions for starch extraction (left); schematic identifying the categorization of samples of the sago trunk (right).

Figure 2.4 Method used for separating the bark from the sago pith

Extraction of sago starch – Sago starch was extracted from the pith according to the methodology of Cecil (1986), Flach (1981) and Fuji et al (1986). This involved grating the sago pith using a mechanized stainless coconut grater. Water adjusted to pH 4.5 with citric acid, was added to the grated starch. The starch slurry thus obtained was filtered through a clean cloth to separate any residual amounts of pith associated with the starch. The filtrate thus obtained was subsequently transferred to a plastic tank and allowed to precipitate over 1 day, under ambient conditions in the laboratory. The starch collected was subsequently sun dried and packaged in Ziploc bags for further study.

2.3.2 Physicochemical analysis of sago starch samples

The sulphur content of the soil samples was determined according to AOAC 2000. The ash content of extracted starch was also determined according to AOAC 2000.

Measurement of pH - One gram of the sample was ground and added to 25 ml distilled water at a temperature of 25^{o}C. The mixture was mechanical stirred for 5-10 minutes, following which the pH of the suspension thus obtained was measured using a pH meter (cyberscan 500 pH).

Measurement of particle size- *150-175 Mesh* - The particle size of sago starch granules suspended in distilled water was measured using a laser Coulter LS 230 counter.

Color ("L value") - *ColorFlex^{TM}* - The degree of whiteness of starch samples (L value) was measured using a chroma meter (CR-300, MIN LTA, Japan).

Statistical analysis - All data obtained was statistically analysed using an SPSS program

2.3.3 Assessment of starch browning and correlation to phenolic content

Qualitative assessment of sago starch browning - Samples of sago starch obtained from the Kreng and Ronpiboon ecosystems were transferred in triplicate to beakers containing methanol. The samples were periodically photographed at intervals over a 4 hour period.

Extraction of polyphenols from sago starch – Phenolic compounds was extracted from sago starch following the methodology of Aguilera, *et al*., 2011. Samples (2 g each) of the starch were incubated with 10 mL of a solution of methanol-HCl (1%): water solution (80:20 v/v) at 37°C for 2 hr. The samples were subsequently filtered using Whatman No.1 filter paper. A 10 ml aliquot of the methanol filtrate thus obtained was mixed with 10 mL of methanol for measurement of the total phenolic content.

Determination of total polyphenol content of extracted starch - Total phenolic content was measured using the modified Folin-Ciocalteu method (Singleton et al. 1999). An aliquot (0.1 ml) of the methanol extract of the starch was added to 2 ml of Folin-Ciocalteu Reagent (1:10 v/v with water). The mixture was allowed to equilibrate for 5 min, mixed with 1.5 ml of sodium carbonate solution (60 g/l) and incubated at room temperature for 90 min. The absorbance of the mixture was read at 725 nm with distilled water as a blank. Total phenolic content was reported as milligrams of catechin equivalents per gram dry weight of starch.

2.4 Results and discussion

2.4.1 Properties of soil samples

Sulphur content - The sulphur content of five replicates of soil samples taken from two layers (15 cm and 30 cm) of soil in each of the ecosystems where sago palms were growing as well as in areas where sago palms were not growing, was analyzed. The lower soil layer (30 cm) was found to have higher sulphur content when compared to the upper layer (15 cm) for soil samples obtained from Ronpiboon and Kreng (Table 2.1). Soil samples from Kreng (66.97 mg/kg) had by far, the highest sulphur content of the three ecosystems, followed by those obtained from Ronpiboon (11.61 mg/kg) and Lansakar (5.93 mg/kg). Kreng is therefore, a high sulphur peat swamp environment, while Ronpiboon and Lansakar could be categorized as being comparably low sulphur coastal and hill environments respectively.

Table 2.1 Sulphur content (mg/kg) of soil samples from the three ecosystems studied.

Ecosystems	Soil_level	Mean (mg/kg)	Std. Deviation	N
Ronpiboon	upper soil	5.74	.51	5
	lower soil	6.12	.97	5
	Average	5.93	.76	10
Kreng	upper soil	49.25	5.16	5
	lower soil	84.68	2.38	5
	Average	66.97	19.05	10
Lansakar	upper soil	12.93	3.80	5
	lower soil	10.29	.76	5
	Average	11.61	2.93	10

pH - The pH of the soil was found to range from acidic to almost neutral in the three ecosystems (Table 2.2). pH values for the three ecosystems varied significantly at $p<0.05$ (Table 2.3) . Soil samples obtained from Kreng were the most acidic (average pH 4.54) while by those obtained from Lansakar (average pH 6.23) and from Ronpiboon (average pH 6.36) were closer to neutral.

Table 2.2 Average pH values for soil samples obtained from each of the three eco-systems.

Ecosystem	soil_level	Mean	Std. Deviation	N
Ronpiboon	upper soil	6.20	.30	5
	lower soil	6.52	.42	5
	Average	6.36	.38	10
Kreng	upper soil	4.56	.05	5
	lower soil	4.53	.05	5
	Average	4.54	.05	10
Lansakar	upper soil	6.20	.23	5
	lower soil	6.27	.16	5
	Average	6.23	.19	10
Average	upper soil	5.65	.83	15
	lower soil	5.77	.95	15
	Overall Average	5.71	.88	30

Table 2.3 Homogeneous test (*Duncan*'s multiple range tests) for soil pH.

Ecosystems	N	Subset	
		1	2
Lansakar	10	4.54	
Ronpiboon	10		6.23
Kreng	10		6.36
Sig.		1.00	.25

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .058.

2.4.2 Physicochemical properties of sago starch

pH – pH values for starch samples from all three ecosystems, were similar (Table 2.4). These pH values are very much in line with the pH of aqueous extracts of industrial (4.0 minimum) and edible (4.0 minimum) grades of sago starch (Malaysian Standard Specifications 468 and 470 respectively, cited by Karim *et al.*,2008).***Ash*** - Sago starch samples obtained from Kreng had the highest ash content 5.76 %, followed by samples obtained from Lansakar which had an ash content of 3.81 % (Table 2.4). Samples obtained from Ronpiboon had the lowest ash content averaging at 2.55 %. Flores (2009) determined that the ash content of sago flour can go as high as 6 to 9 %. A recent draft regional FAO/WHO standard for sago flour N06-2007, however, recommends a maximum ash content of 2 % for optimum sensory properties of sago flour.

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Particle size of sago starch – According to McCrone *et al*. 1973 , sago starch grains average 30 to 50 µm in diameter. Starch samples obtained from Lansakar had the highest average particle size (34.49 µm) followed by those obtained from Kreng which had an average particle size of 33.59 μm (Table 2.5). Samples obtained from Ronpiboon had the lowest particle size; averaging at 31.54 μm. Average particle size showed a decreasing trend from the base to the higher end of the trunk, thus indicating that potential exists for enhancing the value added potential of starch by segmenting the sections of the trunk from which it is extracted. The upper part of the trunk had the smallest particle size average of 32.75μm (Table 2.5).

Table 2.4 Descriptive statistical analysis for pH, and ash content (%) of sago starch obtained from the three ecosystems

Parameters	Ecosystems	Trunk portion	Mean	Std. Deviation	N
pH (-)	Ronpiboon	Lower	4.54	0.72	25
		Middle	4.67	0.59	25
		Upper	4.41	0.53	24
		Average	4.54	0.62	74
	Kreng	Lower	4.66	0.43	25
		Middle	5.05	0.41	25
		Upper	4.56	0.43	25
		Average	4.75	0.47	75
	Lansakar	Lower	4.91	0.66	21
		Middle	4.69	0.65	25
		Upper	4.65	0.55	20
		Average	4.75	0.63	66
Ash (%)	Ronpiboon	Lower	1.7	2.22	25
		Middle	2.52	3.11	25
		Upper	3.48	2.79	24
		Average	2.55	2.79	74
	Kreng	Lower	6.6	2.35	25
		Middle	5.8	2.47	25
		Upper	4.88	2.56	25
		Average	5.76	2.53	75
	Lansakar	Lower	4.2	2.82	21
		Middle	3.28	2.52	25
		Upper	4.06	2.84	20
		Average	3.81	2.71	66

Table 2.5 Descriptive statistical analysis for particle size (μm) of sago starch from the three ecosystems

Ecosystems	Trunk portion	Mean (μ m)	Std. Deviation	N
Ronpiboon	Lower	31.87	2.65	25
	Middle	31.74	2.53	25
	Upper	30.99	2.98	24
	Average	31.54	2.71	74
Kreng	Lower	34.34	2.21	25
	Middle	33.38	1.67	25
	Upper	33.06	1.05	25
	Average	33.59	1.77	75
Lansakar	Lower	35.20	3.97	21
	Middle	33.92	3.38	25
	Upper	34.47	1.52	20
	Average	34.49	3.17	66

Nozaki et al. (2004) observed that starch derived from palms grown in acid sulphate (peat) soils, had larger granules than starch obtained from palms grown in mineral soil. Findings reported here are somewhat different given that starch samples obtained from acid sulphate peat soils conditions as occur in the Kreng ecosystems had a lower average particle size, than those obtained from Lansaker, where soils are of the mineral type.

Color - The L value gives an indication of the level of whiteness of the starch. An L value that is close to 100 indicates a more reflecting diffuser indicating a whiter color. Starch samples obtained from Lansakar showed the highest L value reading (L = 89.45), indicating that starch samples obtained from that ecosystem were comparably whiter than samples obtained from Ronpiboon (L = 88.81) and Kreng (L = 86.10) (Table 2.6).

Table 2.6 Descriptive statistical analysis for the L Value of sago starch extracted from the three ecosystems

Ecosystems	Trunk portion	Mean	Std. Deviation	N
Ronpiboon	Lower	88.37	2.36	25
	Middle	88.84	1.04	25
	Upper	89.24	1.82	24
	Average	88.81	1.83	74
Kreng	Lower	84.63	1.93	25
	Middle	86.56	2.35	25
	Upper	87.12	1.04	25
	Average	86.10	2.12	75
Lansakar	Lower	89.47	1.69	21
	Middle	90.36	1.22	25
	Upper	88.29	4.89	20
	Average	89.45	3.03	66

Samples obtained from Ronpiboon were visually pale pink in color, when compared to those obtained from Lansakar (Figure 2.5) which were whiter in color. The low L value obtained for the sample from Kreng, showed good correlation to the brown color of the wash water after extraction of sago starch from the pith (Figure 2.6).

Figure 2.5 Starch cake samples extracted from Ronpiboon (left) and Lansakar (right)

Figure 2.6 Wash water obtained during extraction of sago starch from the pith of samples obtained from Kreng (left) and Ronpiboon (right).

The color difference between starch from Kreng and that obtained from Lansakar was also very easily visually discernible (Figure 2.7).

Figure 2.7 Dried starch samples obtained from Kreng (left) and Lansakar (right)

Starch samples obtained from different trees in the Ronpiboon, ecosystem, showed differences in color (Figure 2.8) suggesting some differences among the varieties of sago palm grown in that ecosystem.

Figure 2.8 Starch samples obtained from two different trees in Ronpiboon

The debarked pith of sago palms from different trees obtained from that ecosystem also showed different rates of discoloration (Figure 2.9).

Figure 2.9 Discoloration of 7-10 year old debarked sago palms harvested from the Ronpiboon ecosystem

Statistical analyses were conducted to ascertain the correlation between the L value of extracted starch and available suphur in the soil. Results of these analyses (Tables 2.7 - 2.9) showed that an increase in the independent variable (available S) was associated with a decrease in the dependent variable (L value). The reverse was found to be true where a decrease in S value was associated to an increase in L value. Since a higher L value indicates a whiter color of starch, the results indicate that the higher the level of sulphur in the soil, the lower the L value and the darker color of the starch as was observed in Kreng.

Table 2.7 Regression analysis of the effects of available soil sulphur on the L value of sago starch samples from the three ecosystems

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	222.66	1	222.67	191.87	.00[a]
	Residual	30.17	26	1.16		
	Total	252.84	27			

a. Predictors: (Constant), available S

Table 2.8 Correlation of the available soil sulphur and L values (independent variable S) for sago starch samples from the three ecosystems

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.94[a]	.88	.88	1.08

a. Predictors: (Constant), available S

Table 2.9 Correlation of available sulphur and L value (dependent variable L) for sago starch samples from the three ecosystems.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	91.33	.28		323.51	.00
	Available S	-.09	.01	-.94	-13.85	.00

Browning of sago starch **-** In an effort to further study the correlation between sago starch browning and the ecosystems in which the palms were grown, the total phenolic content of sago starch extracted from the pith of sago palms obtained from Ronpiboon and Kreng ecosystems, was measured using the modified Folin-Ciocalteu method (Singleton *et al*. 1999). The rate of browning of sago starch slurries in methanol was also qualitatively evaluated by photographing samples of the slurries maintained at room temperature, over four hours for comparison.

Starch extracted from the pith of palms grown in Ronpiboon, was white in color immediately following extraction, but progressively underwent browning over time (Figure 2.10 right), during incubation at room temperature (Figure 2.10 left) over four hours. The formation of brown polymers was particularly noticeable on the surface of the slurries after four hours of incubation, owing largely to direct exposure of the surface of the slurry to oxygen in the environment.

0 h 4 h

Figure 2.10 Samples of methanol starch slurry extracted from the Ronpiboon ecosystem, incubated at room temperature under ambient conditions over a four hour periods. Samples at 0 h (left); Samples at 4 h (right).

The phenolic content of starch samples extracted from this ecosystem ranged from 0.063 to 0.119 mg of catechin equivalents /gram of dry weight with an average phenolic concentration of 0.089 catechin equivalents /gram of dry weight (Table 2.10). Okamoto et al. 1985, identified DL-epicatechin, D-catechin and procyanidin in sago palm pith and noted that DL-epicatechin and D-catechin produced colored substances by oxidation with enzymes prepared from the sago palm. Shirlene, 2002, also reported the identification (+)-catechin and (-)-epicatechin in sago pith.

Table 2.10 Total phenolic content of starch extracted in triplicate from the pith of five trees, from each of the two ecosystems studied

Ecosystems	Replications	Mean TPC (mg of catechin equiv./g dry weight)
Ronpiboon	Tree1	0.06
	Tree2	0.08
	Tree3	0.12
	Tree4	0.11
	Tree5	0.08
	Average	0.09
Kreng	Tree1	0.18
	Tree2	0.13
	Tree3	0.06
	Tree4	0.12
	Tree5	0.08
	Average	0.12

TPC = Total phenolic content

Binn Sari (2004) studied the effect of holding time, pH and temperature of sago pith slurry on browning and determined that the holding time of sago pith slurry was an important factor in determining the amount of soluble phenolic compounds that were oxidized. Onsa *et al.* 2007, reported the occurrence of latent and soluble polyphenoloxidases in the sago palm. The slow onset of browning observed in starch samples extracted from the Ronpiboon ecosystem seems to suggest the presence of a latent polyphenoloxidase in the sago palms extracted from that ecosystem.

Starch samples extracted from palms grown in Kreng were uniformly pink in color after extraction (Figure 2.11 left), suggesting the presence of high polyphenoloxidase activity during the extraction of these starch samples from the pith. This high polyphenoloxidase activity also correlated very well the intensity of the wash water, during starch extraction (Figure 2.6).

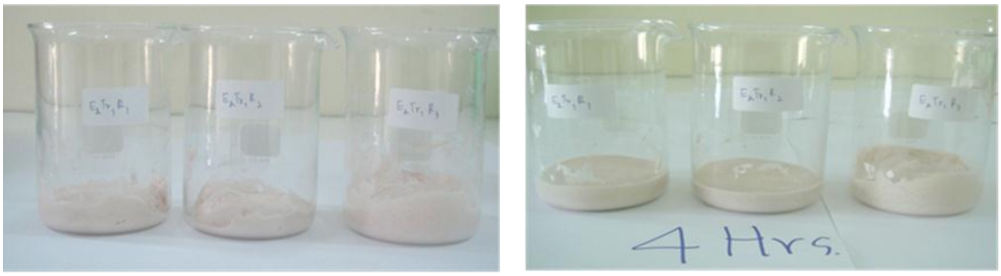

Figure 2.11 Samples of methanolic starch slurry extracted from the Kreng ecosystem, incubated at room temperature under ambient conditions over a four hour periods. Samples at 0 h (left); Samples at 4 h (right)

The phenolic content of starch samples extracted from samples obtained in Kreng, was also comparably higher than that of starch extracted from the Ronpiboon ecosystem and ranged from 0.06 mg of catechin equivalents/gram of dry weight to 0.18 mg of catechin equivalents /gram of dry weight, with average of 0.115 mg of catechin equivalents /gram of dry weight for that ecosystem (Table 2.10).

These starch samples underwent a uniform color change from pale pink (Figure 2.11 left) to pale brown (figure 2.11 right) when incubated at room temperature over four hours. This color change appears to have been largely due to the polymerization of pink quinone present in the starch to melanin during room temperature incubation. In contrast to the samples extracted from Ronpiboon, there was no evidence of a dependency on the requirement for oxygen as a substrate in this reaction, suggesting that the color change which took place on incubation was not catalyzed by polyphenol oxidases despite the comparably high phenolic content of the starch. It is quite possible that the melanin produced in the starch, had an inhibitory effect on polyphenol oxidase enzymes present, thereby precluding further changes in the color of the starch. Shirlene (2007) studied the effect of holding time on the browning of sago pith slurry and determined that colour development was significantly more intense with increased holding time but was not significant (P<0.05) after six hours.

An ANOVA analysis comparing the total phenolic content of the starch samples extracted from the two habitats indicated a significant difference in total phenolic content between starch extracted from the two ecosystems and among starch samples extracted from different trees ($p < 0.05$) within the same ecosystem.

Table 2.11 Analysis of Variance *(*ANOVA) of triplicate measurements of the total phenolic content of starch extracted from five trees obtained from each of the two ecosystems studied

Source	Type III Sum of Squares	df	Mean square	F	Sig.
Corrected Model	.038[a]	9	.004	17.58	.000
Intercept	.310	1	.310	1.30	.000
Ecosystems	.005	1	.005	21.86	.000
Trees	.007	4	.002	7.00	.001
Ecosystems Trees	.026	4	.006	27.11	.000
Error	.005	20	.000		
Total	.353	30			
Corrected Total	.043	29			

a. R Squared = .888 (Adjusted R Squared = .837)

2.4.3 Observations on economic value of sago starch affected by its color and a practical suggestion

As stated earlier, it was well recognized that the commercial acceptance and value of sago starch hinges greatly on its quality characteristics, particularly its color. Browning contributes to the quality deterioration of sago starch and has been associated with low marketability of that product (Yatsugi, 1986; Ahmad, 1991; Okamoto *et al*. 1988 and Onsa *et al*. 2000), and hence reduces the economic value of the starch.

It was observed that the dry brown color sago starch sold at local market in Trang, Thailand was 60-70 Baht/kg, while white color sago starch sold at local market in Nakhon Si Thammarat, Thailand was 80-90 baht/kg at the same period (about 30 percent difference in market prince).

One of the practical, cost-effective and feasible approaches to inhibiting the brown discoloration of the sago pith in field level operation would be the inclusion of a bleaching agent such as sodium metabisulphite in the wash water of the debarked pith. Apart from its bleaching effect, sodium metabisulphite is also effective in retarding microbial activity in the wash water. Karim et al., reported the efficacy of a 700 ppm sodium metabisulfite in the processing water in helping to retard microbial activity during the extraction of sago pith. The breaching agent needs to be handled carefully to avoid a respiratory problem such as asthma. Water used in processing operations must be free from heavy metals such as iron and copper, both of which are promoters of the rate of browning.

2.5 Conclusion

The result of the sago starch analysis showed that sago palms grown in fresh water swamp under acidic conditions and high soil sulphur concentrations (Kreng), yielded starch of a high ash content that contains comparably high levels of phenolic compounds and active soluble polyphenol oxidase enzymes was highly prone to phenolic oxidation, was pink to brown in color on extraction. On the other hand, palms grown under neutral soil conditions with a comparably lower levels of sulphur (1/6 the sulphur content of soil in Kreng) and ash as in the case of Lansakar, were white in color. Sago Starch Samples taken from Ronpiboon area where sago palms grown under neutral brackish conditions, and had comparably low levels of phenolic compounds if compare with that of from Kreng area, underwent oxidation after a large period of about four hours at room temperature. This suggested the existence of latent polyphenol oxidases in the pith extracted from that ecosystem.

Starch granules from the low sulphur environment (Lansakar) had a comparably larger average particle size (34.49 µm) than those obtained from the high sulphur acidic peat swamp environment (33.59 µm).

These findings highlighted the fact that the quality characteristics of sago starch, and particularly the color were greatly influenced by the conditions under which the palm was grown. Further studies would be required in order to better correlate sago starch quality to the growth conditions of sago palm, and identify cost effective and user friendly methodology at village level to prevent browning and enhance starch quality and value.

Chapter 3 Adding Value to Sago: Adding Wheat Flour with Sago Starch in Cookie Formulations

3.1 Summary

Sago starch has been consumed as a food in wetland areas for centuries. Relatively little has, however, been done to upgrade village level technology for the extraction of sago starch and to maximise its value added potential as a major food starch ingredient. The substitution of wheat flour with sago starch in a standard cookie formulation was studied. Findings revealed that wheat flour could be substituted by sago starch up to a level of 40 percent in producing cookies that found a good consumer acceptance in Southern Thailand. Consumer acceptance of cookies, declined dramatically when the proportion of sago starch in the cookie formulation increased beyond 40 percent, owing to poor appearance and a crumbly texture. These findings highlighted the potential of sago starch to replace wheat flour in other types of local confectionery and food products and the untapped value added potential of underutilized crops such as sago palm.

3.2 Introduction

Sago palm (*Metroxylon sagu* Rottb.) has been described as one of humankind's oldest food plants (Ave, 1977). Starch present in the trunk of the palm has for centuries, been consumed as a staple food in South-East Asian countries where the crop is grown. Sago starch is commonly prepared by pouring hot water over slightly sour wet starch and stirring with a stick or a spoon into a paste (Karim *et al.*, 2008) for consumption. A range of other traditional sago-based food products such as cookies, puddings and pancakes are produced and consumed by poor households in sago-producing countries.

Apart from these traditional food uses, sago starch is widely used together with rice, corn and potatoes in the manufacture of noodles in Malaysia (Karim *et al.*, 2008). Sago starch is commonly used as a functional ingredient – thickener, stabilizer and gelling agent – in the food industry (Mohamed *et al*. 2008).

Structurally, sago starch consists of 24 to 31 percent of the linear polymer amylose (Fasihuddin et al. 1999), and 73 % of the branched polymer, amylopectin (Ito and and Hisajima, 1979). It is, however, of a low protein content 0.19 – 0.25 percent crude protein (Fasihuddin et al., 1999) and lacks gluten, which negatively impacts on its functional properties in bakery applications.

Despite its traditional uses, and industrial potential, relatively little has been done in Thailand to modernize the extraction of sago starch or to upgrade village level technologies used in adding value to sago starch, in order to maximise the use of sago palm and its starch. However, considerable potential exists to build on and improve traditionally produced value added products based on sago starch, and to market those products to a wider consumer base, thereby generating income and employment opportunities for poor villagers living in sago starch producing areas. This could also facilitate in increasing availability of starch resources to produce staple foods through substituting wheat flour by sago flour to meet increasing demands of staple foods in the future, and thereby contributing to future food security. Taking into consideration of these much wider contexts in mind, this study focused on the partial substitution of wheat flour by sago flour in the production of cookies which would result in a good consumer acceptance in Southern Thailand. The study was published by an international scientific journal i.e. the Journal of Agricultural Technology 2012 Vol. 8(3) 1067-1077 with a title "Adding value to underutilized food resources: substituting wheat flour with sago starch in cookie formulations".

3.3 Materials and methods

3.3.1 Materials

Sago flour used in the study was produced in Nakhon Si Thammarat, Thailand, following the methodology described in Konuma *et al.*, 2012. Bakery ingredients including butter, powdered sugar, baking powder, egg and vanilla were purchased from the local market. All reagents and chemicals used in studies were of analytical grade.

3.3.2 Proximate analysis of the composition of wheat and sago flours

Standard AOAC (American Association of Cereal Chemists, 2000) methods were used for the determination of the moisture, fat, ash, and nitrogen content of sago starch. The protein content of sago starch was determined on the basis of estimates of total nitrogen, using a conversion factor of 6.25.

3.3.3 Selection of cookie formulations for testing

Three cookie formulations (Table 3.1, 3.2 and 3.3) that incorporate wheat flour as a key starch ingredient were tested. Cookies were prepared in accordance with these formulations and their overall acceptability was evaluated as described below in the section on sensory evaluation. The cookie formulation with the highest overall acceptability scores arbitrarily identified as HA, was adopted as the basic formulation for the conduct of further studies.

3.3.4 Proportioning of wheat flour and sago flour for incorporating into cookie formulations

Sago flour was mixed with wheat flour in different ratios and proportions of (wheat:sago): 100:0 (control), 80:20, 60:40, 40:60, 20:80 and 0:100 on a weight to weight basis, and was incorporated into cookie the formulation HA as a substitute for wheat flour. Sensory evaluations were conducted on cookies produced.

3.3.5 Preparation of cookie dough

Cookie dough was prepared using a Hobart type mixer (Continental Kitchen Aid, USA). Margarine was weighed and transferred into the bowl of the mixture, and mixed to a thin and shiny consistency. Powdered sugar was then added, followed by thorough mixing. The flours were weighed, combined and sieved, following which the sieved flour was added to the cookie dough and mixed. This followed by the addition of eggs, vanilla and milk butter flavour. The cookie dough thus obtained was flattened with a rolling pin and was subsequently cut into appropriate shapes. The cookies were transferred to an oven pre-heated to 160 C and baked for 15 – 20 minutes.

3.3.6 Sensory evaluation of cookies

The quality, sensory attributes - appearance, color, flavor, texture - and overall acceptability of the cookies was evaluated according to Ranganna1994, using a 5 point hedonic scale. Evaluations were performed by a semi-trained panel consisting of 30 judges. The scores for individual attributes were recorded and an analysis was carried out to determine the significance of variation of average scores, and the contribution of individual parameters.

3.3.7 Just-About-Right Scale Test for Cookies

Thirty respondents were requested to rate the acceptability of cookies prepared using a mixture of 60 % wheat flour and 40 % sago starch into formulation HA. Acceptance was rated on the basis of appearance, color, smell, flavor, hardness and cohesiveness using the 5 point hedonic scale (Table 3.4) and the just about right scale, a 1–7 point scale, ranging from the extreme like (1) to dislike extremely (7) as described by Larmond (1977).

3.3.8 Evaluation of consumer acceptance of cookies

Consumer preferences were determined using the Central Location Test (CLT), wherein a total of 150 respondents of three age groups: 1-5 years old, 6-15 years old, and 17-25 years old, (50 individuals per age group) were randomly requested to indicate their preferences for specific attributes of the cookies produced using 60 percent wheat flour and 40 percent sago starch in the HA formulation. The level of satisfaction of the surveyed tasters was recorded and analysed.

3.3.9 Texture Analyses

Cookie dough was blended using a Hobart type mixer (Continental, Kitchen Aid, USA) operating at a medium speed for 3 minutes. The dough was allowed to rest for 30 min prior to testing. The dough was sheeted using a cocky cylinder over a rectangular frame of 6 mm height in order to obtain uniform thickness. The cookies were subsequently baked according to the previously described conditions.

Textural characteristics of the baked cookies were evaluated using a Texture Analyzer equipped with a three-point bending probe HDP/BSK with the following settings:

Pre-Test Speed: 5.0 mm/s

Test Speed: 5.0 mm/s

Post Test Speed: 10.0 mm/s

Distance: 10 mm.

Each texture parameter was calculated based on the average of 10 replications

3.4 Results and discussions

3.4.1 Proximate composition of wheat flour and sago flour

The proximate composition of wheat flour and sago flour used in cookie formulations is summarised in Table 3.5. Wheat flour was found to be of a lower (12.8 percent) moisture content than sago flour (13.1 percent). Fasihuddin *et al*., 1999 studied the physiochemical characteristics of sago starch and determined that the moisture content varied between 10.6 and 20 percent, which is typical for commercial starches. The moisture and ash contents of the sago starch samples (13.1 percent and 0.19 percent respectively) used in the current study were in line with the Codex Regional Standard for Edible Sago Flour (*CODEX STAN 301R-20*). The protein content of the sago flour was found to be somewhat lower than that reported by Fasihuddin *et al*. (1999).

3.4.2 Sensory attributes of the three cookie formulations tested

Results of the sensory evaluation of cookies prepared using formulation No. 1, 2 and 3 (Tables 3.1, 3.2 and 3.3) are presented in Table 3.6. Cookie formulation No. 3, had the highest overall acceptability in terms of appearance, odour, flavour and texture (Table 3.6) and was therefore used as the base formulation (HA) for all subsequent consumer testing.

3.4.3 Evaluation of sago cookies prepared using sago and wheat flour combinations

Sensory scores for cookies produced using different proportions of wheat flour and sago flour in product formulation HA, revealed a preference for cookies produced using wheat flour and sago flour proportioned in ratios of 60:40 and the 80:20 (Table 3.7). Cookie formulations containing a high proportion of sago flour showed a very low level of cohesiveness, thereby crumbling very easily. This low level of cohesiveness and was largely due to the low gluten content, of sago starch.

Dramatic changes were observed in consumer acceptance of the cookies, based on their appearance when sago starch was included in the product formulations at levels exceeding 40 percent (Figure 3.1). Poor consumer acceptance of the latter formulations was largely due to the comparably flat appearance of cookies containing large quantities of sago starch. Consumer acceptance of colour, taste and texture also declined, for cookies having a sago starch content exceeding 40 percent, but somewhat less dramatically (Figure 3.1).

Cookie formulations containing the 60:40 proportioning of wheat to sago flour were of a softer texture when compared to those containing 100 percent wheat flour. The inclusion of sago flour in the mixture decreased the crispiness and hardness of the cookie (Table 3.8).

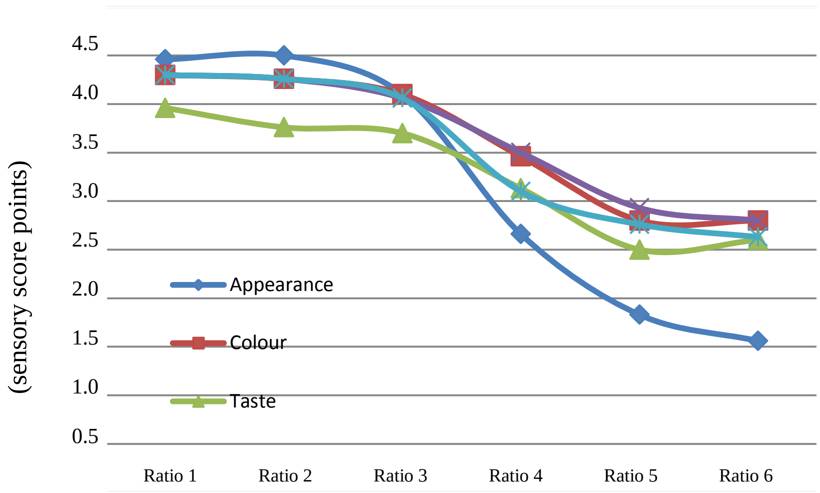

Figure. 3.1 Average sensory scores obtained for cookie formulation containing different proportions of sago flour and wheat flour

Ratios of wheat to sago starch: Ratio 1 (100:0); Ratio 2 (80:20); Ratio 3 (60:40); Ratio 4 (40:60); Ratio 5 (20:80) and Ratio 6 (0:100)

3.4.4 Just-about-right scale test for cookies

Cookies formulated using a 60:40 ratio of wheat flour to sago flour were found acceptable by a panel of judges, on the basis of their appearance, colour, smell, flavour, hardness and cohesiveness using the 5 point Hedonic Scale, and the Just About Right Scale, with an overall acceptance value of 90 percent (Table 3.9).

3.4.5 Assessment of consumer satisfaction with sago-based cookies

A Central Location Test (CLT) was conducted in order to assess consumer acceptance of sago-based cookies. Seventy two percent 72 percent of children aged 1-5 were satisfied with the cookies formulated with a 60:40 proportioning of wheat flour to sago flour (Table 3.10).

Consumers in the 6-15 age group were likely satisfied with the physical appearance and color of the cookie formulation containing a 60:40 proportioning of wheat flour to sago flour. A majority of these consumers were “mostly likely” satisfied with the smell, flavor and eating characteristics of the cookies (Table 3.11), with overall “most likely” satisfaction of 70 percent.

The 16-25 age group showed a similar trend to the 6-15 age group, wherein more than half of these individuals were “likely” satisfied with the physical appearance (Table 3.12). Approximately 86 percent were “likely” (40 percent) and most likely (46 percent) satisfied with the color of the cookies. More than half were “most likely” satisfied with the flavour and eating characteristics. Overall, seventy-eight percent of these respondents were “most likely” satisfied with the cookie product.

Table 3.1 Cookie formulation No.1 (Puengkam, 1999)

Ingredients	**Quantity**	**Unit**
Wheat flour	250	gram
Butter	220	gram
Icing sugar	110	gram
Milk	60	gram
Powdered Milk	50	gram
Baking powder	1	teaspoon
Vanilla	1/2	teaspoon

Table 3.2 Cookie formulation No. 2 (Chitsanantavittaya, 2011)

Ingredients	Quantity	Unit
Wheat flour	3	Cup
Butter	1	gram
Cheese	1/2	gram
Sugar	1 1/4	gram
Yolk	2	gram
Baking powder	2	teaspoon
Vanilla	2	teaspoon

Table 3.3 Cookie formulation No. 3 (Ngamprapawat, 2011)

Ingredients	Quantity	Unit
Wheat flour	500	gram
Baking powder	1	Tablespoon
Salt	1	Teaspoon
Butter	200	Gram
Margarine	100	Gram
Icing sugar	250	Teaspoon
Yolk	2	Pieces
Vanilla	1	Teaspoon
Milk butter flavour	1/2	Teaspoon

Table 3.4 Some terms and definitions for sensory texture attributes of cookies

Sensory Attributes	Definition	Evaluation	Scale (5-point)
Color	i) The actual hue of the color, light to dark brown ii) Homogeneity of the color	Observe the intensity of the color along with homogeneity	5-light brown (smooth) to 1-dark brown with patches
Hardness (Firmer bite)	Something that is not too hard but does not immediately disintegrate in the mouth	Compress or bite through sample with molars	5-needs firm bite 1-easily crumbles
Chewiness	Number of chews necessary to prepare sample for swallowing	Chew sample 3 or 8 times and evaluate	5- completely swallow 1-gummy and leathery
Texture	Amount of smoothness perceived in the chewed sample	Chew sample with molars 8 times and evaluate	5-with smooth texture 1-with rough mass
Over all flavor	Degree to which mouth contains small particles after samples have been swallowed		5-like the most 1-with-out feelings

Table 3.5 Proximate composition of sago flour and wheat flour

Samples	Sago flour	Wheat flour	Codex Standard*
Parameter			
Moisture (%)	13.1	12.8	13
Fat (%)	0.01	0.90	
Ash (%)	0.19	0.65	0.5
Protein (%)	0.04	10.9	

*Codex Stan 301R-2011

Table 3.6 Sensory evaluation scores for three cookie formulations produced using 100 percent wheat flour

Sensory Parameter	Formula 1	Formula 2	Formula 3
Appearance	4.05 ± 0.43	2.72 ± 0.51	4.10 ± 0.84
Color	3.93 ± 0.57	3.15 ± 0.76	3.86 ± 0.72
Odor	3.91 ± 0.53	3.31 ± 0.68	4.02 ± 0.71
Flavor	4.03 ±0.66	3.14 ± 0.67	4.14 ± 0.75
Texture	4.13 ± 0.52	3.08 ± 0.59	4.22 ± 0.83
Overall Acceptability	4.07 ± 0.37	3.18 ± 0.51	4.21 ± 0.77

Table 3.7 Sensory scores of cookies formulated using different proportions of wheat and sago starch

Parameter	Average Value	Just About Right Scale						
		1	2	3	4	5	6	7
		Very Low			Moderate		Very High	
Appearane	4.30	-	-	-	70.00	30.00	-	-
Color	4.23	-	-	3.33	80.00	16.67	-	-
Odor	4.53	-	-	3.33	86.67	6.67	3.33	-
Flavor	4.20	-	-	10.00	76.67	13.33	-	-
Mouth sensibility	4.56	-	-	3.33	86.67	10.00	-	-
Cohesivess	4.26	-	-	-	96.67	3.33	-	-
Overall Acceptance	4.43	-	-	-	90.00	10.00	-	-

Table 3.8 Texture values of cookie formulations with and without the addition of sago flour

Product	Hardness (kg)	Crisp Linear Distance (mm)
Cookie (control)	1.92 + 0.39	24.57 + 0.77
Cookie with 40 % sago flour	1.69 + 0.31	23.54 + 0.26

Table 3.9 Sensory scores obtained for sago cookies containing a 60:40 ratio of wheat flour to sago flour

Wheat: Sago	Sensory Score			
	Appearance	Hardness	Flavor	Overall acceptability
0:100	1.56	2.80	2.50	2.63
20: 80	1.83	2.93	2.60	2.76
40: 60	2.66	3.50	3.13	3.10
60: 40	4.10	4.06	3.70	4.06
80: 20	4.50	4.26	3.76	4.26
100:0	4.50	4.30	3.96	4.30

Table 3.10 Consumer satisfaction of 1-5 year old children, with sago cookies formulated using a 60:40 proportioning of wheat flour to sago

Preference scale	Number of respondents	Percentage
Most satisfied	36	72
Satisfied	12	24
Neutral	1	2
Less satisfied	-	-
Not satisfied	1	2

Table 3.11 Consumer satisfaction of 6-15 year olds, with sago cookies formulated using a 60:40 proportioning of wheat flour to sago

Parameter	Consumer Satisfaction									
	Most likely		**Likely**		**Neutral**		**Less likely**		**Not at all**	
	No.	%	No.	%	No.	%	No.	%	No.	%
Physical Appearance	18	36	28	56	3	6	1	2	-	-
Color	21	42	26	52	2	4	1	2	-	-
Smell	31	62	15	30	4	8	-	-	-	-
Flavor	35	70	15	30	-	-	-	-	-	-
Eating characteristics	34	68	13	26	3	6	-	-	-	-
Overall satisfaction	35	70	13	26	2	4	-	-	-	-

Table 3.12 Consumer satisfaction of 16-25 year olds, with sago cookies formulated using a 60:40 proportioning of wheat flour to sago

Parameter	Consumer Satisfaction									
	Most likely		**Likely**		**Neutral**		**Less likely**		**Not at all**	
	No.	%	No.	%	No.	%	No.	%	No.	%
Physical Appearance	15	30	26	52	9	18	-	-	-	-
Color	23	46	20	40	6	12	1	2	-	-
Smell	28	56	17	34	5	10	-	-	-	-
Flavor	34	68	15	30	1	2	-	-	-	-
Eating Characteristics	30	60	18	36	2	4	-	-	-	-
Overall satisfaction	39	78	10	20	1	2	-	-	-	-

3.5 Conclusions

These findings highlighted that sago flour can substitute up to 40 percent of wheat flour in cookie formulations with a good consumer acceptance. Appropriate proportioning of the wheat and sago flour in such formulations was, however, found to be critical in assuring consumer acceptance of appearance and texture of the final product. The results indicated a considerable potential of sago starch in substituting for wheat flour in cookies and in other bakery and food products, and highlighted the untapped potential of sago starch in contributing to the food security globally, and to the local communities in wetland areas in particular where sago palms are grown.

Realizing the true potential of sago starch in food security and livelihoods development would hinge greatly on upgrading the technology for starch extraction in order improve yields, and provide opportunity for diversified food and non-food uses of sago starch.

This would also necessitate research and training in product development designed to improve consumer acceptance of foods prepared with the incorporation of sago flour. These findings also highlighted a need for greater attention and emphasis to be accorded for the promotion of underutilized food security crops such as the sago palm.

Chapter 4 General Conclusions

The world population is expected to grow further and would exceed 9 billion by the year 2050 with increasing per capita calorie consumption. FAO estimates that the global food production has to be increased by 60 percent during the period 2005/07 and 2050 to meet the increasing demands, out of which over 85 percent is expected to come from existing arable land through yield increase as there is a very little potential to expand arable land in the future. This goal has to be achieved under various constraints and uncertainties such as decline of annual productivity growth rate of major staple foods, increasing water scarcity, advancing negative impacts of climate changes and natural disasters, and rapidly increasing competition between food crops and bio-energy crops on the use of land and water resources. Consequently, there has been growing global concern on serious food security challenges and uncertainties in coming decades, which may further impact world peace and stability, if sufficient foods will not be produced to satisfy future global needs, especially for the poor in food deficit countries. There is an urgent need to advance agricultural research and maximize the effective use of land resources for food production. On the other hand, globalization has created homogeneity of food resources, accompanied by a loss of different culinary traditions and agricultural biodiversity, and created negative consequences for ecosystems, food diversity and health. Accordingly, FAO stressed the importance of neglected and underutilized species which would play a crucial role in the fighting against hunger, and called for increased research on underutilized food resources especially those produced on poor and underutilized lands (wet lands, swamps, saline soil, etc.) by the poor.

In Asia and the Pacific Region, sago palm (*Metroxylon sagu* Rottb.) is one of the typical underutilized indigenous food crops which meet above mentioned criteria, with very little attention and research efforts in the past. It can be grown in underutilized wetlands and peat swamps, produce high yield of starch (100kg-400kg of dry starch per plant), and contribute to food security, and conservation of traditional ecosystems and environment. It was well recognized that the commercial acceptance and value of sago starch hinges greatly on its quality characteristics, particularly its color. Browning contributed to the quality deterioration of sago starch and has been associated with low marketability of that product and hence reduces the economic value of the starch. The quality, color and commercial value of sago starch (with higher value for whiter color) were influenced by the growth environment of sago palm.

Against these backgrounds, sago palm (*Metroxylon sagu* Rottb.) was selected for this research with an aim to promote the effective utilization of sago starch and its products for their contribution to food security. More specifically, the research focused a) study on the potential of promoting sago starch's commercial acceptance and value, and income of farmers through identifying the correlation between the color of sago starch and characteristics of ecosystems from which the sago palm (*Metroxylon sagu* Rottb.) was harvested, and b) study on the sago starch's potential contribution to food security as a food ingredient through mixing it with wheat flour and consequently increase the overall volume of the starch and its products for human consumption.

The studies were undertaken in three villages in different ecosystems in Nakhom Si Thamarat Province in Southern Thailand. The findings of the Chapter 2 suggested that sago palms grown under peat swamp conditions, high sulphur and acidic soils (Kreng area), yielded starch of a high phenolic content and that was dark in color. It is quite possible that the sulphur served as a stress factor and promoted phenolic production and led to oxidization and browning. Starches extracted from sago palms grown under almost neutral soil conditions with comparably lower levels of sulphur (Lansakar area) were white in color. Starch samples extracted from sago palms grown under neutral brackish conditions (Ronpiboon area) underwent browning after an extended incubation period (four hours) at room temperature, and had a comparably lower phenolic content suggested the predominance of latent polyphenol oxidases in the pith from which the starch was extracted. Further studies would be required in order to better correlate sago starch quality to the conditions under which the sago palm is grown, and identify cost effective and user friendly methodology at village level to prevent browning and enhance starch quality and the value.

The study on the substitution of wheat flour with sago starch in a standard cookie formulation (Chapter 3) revealed that wheat flour can be substituted by sago starch up to a level of 40 percent in producing cookies that find good consumer acceptance in Southern Thailand. Consumer acceptance of cookies, however, declined dramatically when the level of sago starch in the cookie formulation increased beyond 40 percent, owing to poor appearance and a crumbly texture. These findings highlight the potential of sago starch to replace wheat flour in other types of local confectionery and food products, and untapped value added potential of sago palm to contribute to household and global food security.

FAO advocates increased attention to tap underutilized food resources such as sago palm which are produced on poor lands (wet lands, swamps) by the poor. They directly contribute to local food availability and access by the poor. They play a role in keeping cultural diversity alive. They occupy important niches, adapted to the risky and fragile conditions of rural communities as well as changing climate conditions over the history. In fact, adding sago starch in wheat flour in food making, for example, would increase the volume and availability of starch products for human consumption. The use of these species – whether wild, managed or cultivated – can have immediate consequences on the national and household food security and well-being of the poor.

These findings necessitate further advancement of research on sago palm production and its products development, as well as advocating sago products to the public with an aim to promote the value of sago palm, and consumer acceptance of foods with the incorporation of sago flour, and consequently promote its contribution to food security, biodiversity and ecosystem conservation, and rural livelihood development.

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