THEMATIC BACKGROUND STUDY

GENETIC RESOURCES FOR FARMED FRESHWATER MACROPHYTES: A REVIEW

Disclaimer

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Acknowledgements

For the First Regional Review, thanks go to Le Thanh Hung, Truc Anh Minh, of Nong Lam University, Ho Chi Minh City, as well as Nguyen Thi Dieu Phuong, of the Research Institute of Aquaculture 1 (RIA 1) Hanoi, Viet Nam, for their help in data collection. Thanks also go to the many aquatic plant growers who have contributed their time and considerable experience to this review.

It should also be noted that any views expressed in this review are purely those of the author and not necessarily representative of the Food and Agriculture Organization of the United Nations (FAO).

All photos unless otherwise stated were taken by the author.

Acronyms and abbreviations

DBP	di-n-butyl phthalate
EC	European Commission
FAM	freshwater aquatic macrophyte
GRIN	Germplasm Resources Information Network
GUS	beta-glucuronidase gene
NGRL	National Germplasm Resources Laboratory
NPGS	National Plant Germplasm System
PAPUSSA	Production in Aquatic Peri-Urban Systems in Southeast Asia (EC FP Project)
PTE	potentially toxic element
SAR	Special Administrative Region

Background

At its Fifteenth Regular Session, the Commission on Genetic Resources for Food and Agriculture endorsed the preparation of a thematic study on the genetic resources of freshwater aquatic macrophytes (FAMs) of relevance for food and agriculture. This is an initiative in support of the preparation of the Report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (http://www.fao.org/3/CA0454EN/ca0454en.pdf). The purpose of this study is to enhance the understanding of the relevance of FAMs for food security and human well-being. The cultivation of FAMs for food production, as well as for non-food uses, has long been unrecognized and underreported in most national and international agriculture and aquaculture statistics, including statistics regularly reported to the Food and Agriculture Organization of the United Nations (FAO) by Member Countries. However, it is well known that cultivated FAMs play a pivotal role in food security in many countries, especially in the developing countries of South and Southeast Asia.

In order to fill the knowledge gap, FAO commissioned international experts to prepare two regional reviews, combined in the present document. The first regional review was prepared by Dr William Leschen, a consultant from the United Kingdom of Great Britain and Northern Ireland, and the second by Dr Meng Shunlong and Dr Jing Xiaojun from the Freshwater Fisheries Research Centre of the Chinese Academy of Fishery Sciences, Wuxi City, Jiangsu province, China. These regional reviews together provide an overview of key aspects relating to the use of genetic resources of cultivated FAMs, including:

- main farmed species, varieties and their principal destinations for food and non-food uses;
- drivers affecting the FAM farming sector;
- major stakeholders involved in FAM production, use, management and conservation;
- conservation status;
- extent of use of genetic technologies, scientific research and breeding programmes;
- food safety and occupational health.

Because of the relative paucity of literature on FAMs, primary source information, such as the interviews with farmers included in the first regional review, constitutes direct evidence of the impact of farmed FAMs on food security and as a potential source of income.

Although many FAMs are distributed globally, their use and production is currently very limited outside South and Southeast Asia. For this reason, the two commissioned reviews are focused on producer and consumer countries from this region. In particular, the first study provides an overview for South and

Southeast Asian countries, while the second is mainly focused on China, due to its leading role in the aquaculture production of FAMs.

Filamentous algae, which fall under the definition of FAMs, are excluded from this review, which deals specifically with large freshwater macrophytes. Also, rice (*Oryza sativa*), the most commercially important FAM at the global level, is only mentioned in passing, as this species is comprehensively covered in abundant scientific literature as a terrestrial plant, and is included in the *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (www.fao.org/docrep/013/i1500e/i1500e00.htm). For the same reason, other significant FAMs such as taro (*Colocasia* spp.) have been excluded from the present thematic study.

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1. FIRST REGIONAL REVIEW

Author: William Leschen

Organization: Casammak Aquaculture Consultancy

Above photo: Cultivation of water mimosa, Binh Chanh district peri-urban area of Ho Chi Minh City. Photo courtesy of William Leschen.

1.1 Introduction

The cultivation and consumption of edible freshwater macrophytes and their impact on food security has long been under-recognized and under-recorded in both scientific and grey literature. In a geographical context, they have largely been unrecognized outside South and Southeast Asia, where for centuries they have supported the livelihoods of millions of lower-income people, providing them with a low-cost, nutritious foodstuff for both themselves and their livestock, even including cultured fish (Korkut *et al*., 2016). Freshwater macrophytes are also often used to recycle waste nutrients. It could be said that freshwater aquatic macrophytes (FAMs) are the most forgotten form of freshwater aquatic food production, as they continually remain unrecorded in most government agriculture and/or aquaculture statistics and planning documents at the local, national and international levels despite their significant contribution to food production and nutrient recycling. In the global aquaculture development community, the range and scale of cultivated edible aquatic plant production is little known or practised outside South and Southeast Asia. It is rarely taught in curricula, addressed in the research agenda of the major academic aquaculture or agriculture organizations, or actively considered by international non-government research organizations.

Edwards (1980) estimated that there were more than 40 edible FAM species, of which around 25 percent are being cultivated for food at a scalable level, or have the potential for commercial production. There is little literature to suggest that genetic improvement such as selective breeding is taking place for these species. Selectable traits include growth performance, productivity, phytoremediation of wastewater and disease resistance. This is despite the significant translocation of germplasm between countries or regions over the past 600 years.

Owing to their scale and importance, particularly in Southeast Asia, FAMs can be considered a key (sub)tropical cultivatable crop, which can contribute to sustainable food production in developing countries. While this review includes a number of references related to the global historical context and impact of these aquatic macrophytes, its main content relates to South and Southeast Asia where their cultivation is culturally and economically significant.

This review focuses on the potential of FAMs for human food production in the tropics. They can also be used as key components in integrated multipurpose production systems. The incorporation of FAMs in aquaculture and other wastewater treatment and remediation in China continues to be developed (Zhang, 2014), and Korkut *et al.* (2016) analysed their potential as aquaculture feed ingredients. Zhou (2016) further discussed the relationship between aquatic plant production in aquaculture and agriculture/horticulture, including mention of the huge global market for ornamental aquatic plants. Therefore, there is a need for clear differentiation and clarity in the future collection and presentation of global production statistics for FAMs using discrete and well understood categories of production. The collection of these data is further complicated for species such as water spinach (*Ipomoea aquatica*), which is cultivated in different geographic locations for different purposes and delivering different beneficial outcomes.

This review first presents the available English language literature, which is still relatively sparse, despite FAMs having been researched for the past 50 years. This is the case due to the nature of FAM cultivation, with production being carried out at different scales and in diverse waterbodies, including canals and irrigation channels. FAMs are primarily farmed in South and Southeast Asian countries, such as Cambodia, China, India, Indonesia, Malaysia, Thailand and Viet Nam. In these countries, some of the key documents and publications, mostly from academia and the private sector and relating to the trade of FAMs, have been written in the local languages and thus have not been included in this review. This constrains knowledge sharing within the global field of academic research and development sectors. With many countries developing their aquaculture sectors, including China, key publications, especially from the twentieth and preceding centuries, have yet to be translated and therefore have limited global accessibility.

The review then addresses key themes, such as food safety and the occupational health for FAM farmers, who often work in wastewater environments. The scope of FAM genetic improvement is then discussed.

Further primary data collection and a series of four case studies is presented, including interviews with key stakeholders from the European Commission (EC) funded project called Production in Aquatic Peri-Urban Systems in Southeast Asia (PAPUSSA project 2003–2006), which identifies changes since 2006 in the region's peri-urban production and consumption of FAMs. The PAPUSSA project has been one of the few holistic, interdisciplinary research or development-based initiatives to document the current status and importance of peri-urban freshwater aquatic plant production across a geographic region, while also looking into the potential of FAM cultivation within the region and international translocation. The review then concludes by drawing together the overall findings and discusses the future role and potential of edible FAMs in global food production. It should be noted that rice, the most important single crop in the world, is an aquatic macrophyte, but due to its copious literature, research and commercial history is not included in this review; it is, however, included in *The State of the World's Plant Genetic Resources for Food and Agriculture*.[1]

1.2 Definition of freshwater aquatic macrophytes

Before charting the known history of freshwater aquatic plant consumption and cultivation, it is pertinent to define and understand what aquatic macrophytes actually are. Aquatic plants form an ecological rather than taxonomic group and cannot be defined with any degree of precision. Though there are no standard definitions for freshwater macrophytes in the literature, they are generally considered to be plants that either require a fairly continuous supply of freshwater or are present in soils which are covered by freshwater for a significant proportion of their growing cycle (Mitchell, 1974). They are distinguished as macrophytes by their size compared to phytoplankton, but can also include filamentous algae, which sometimes grow into larger floating mats that can then be harvested. FAMs can be broadly categorized into three groups by their methods of growth within the water column, although some species can move between categories at different stages in their life cycle (Edwards, 1980). These three categories are emergent species, submersed species and floating species.

1.2.1 Emergent species

Emergent species normally grow in waters shallower than 1 metre, with their vegetative growth above the surface and their lower stem below the waterline, and basally rooted into the soil substrate. Examples include *Phragmites* spp. (Figure 1) and *Typha caduciflora* L (Figure 2).

Typha caduciflora, the common cattail, originated in China where it has been cultivated for centuries as a food crop, and is now distributed globally (Li, 2007a). It belongs to the *Typha* genus of the Typhaceae family and has closely related species and varieties. Jianshui grass sprout, an edible rhizome plant, comes from the broad-leaf common cattail, while the edible pseudo-stem types, including the Huai'an common cattail and Minghu common cattail, belong to the water-candle species *T. angustifolia*, also known as the narrow-leaf common cattail (Kong, 2005). Common cattail is spread widely throughout China, and has been recorded in the annals of almost all counties.

The common reed *Phragmites* spp. is widely used as a material for roofing and house construction, which reinforces the fact that aquatic macrophytes are grown and used for purposes other than food production.

[1] www.fao.org/agriculture/crops/thematic-sitemap/theme/seeds-pgr/sow/en.

Figure 1: Common reed (*Phragmites australis*). Photo courtesy of Darkone under CC-BY-SA-2.0 (https://commons.wikimedia.org/wiki/File:Phragmites_australis_Schilfrohr.jpg).

Figure 2: Cattail (*Typha* sp.). Photo courtesy of Derek Jensen (Tysto) (https://commons.wikimedia.org/wiki/File:Typha-cattails-in-indiana.jpg).

1.2.2 Submersed species

Submersed species primarily have their vegetative growth tissues below the surface and are normally rooted into the soil substrate at a depth of no more than 1.25 m. Commercially important examples include water spinach, also known as water morning glory (*Ipomoea aquatica*), and water mimosa (*Neptunia oleracea*); see Figure 3 and Figure 4, respectively. Both of these species are commercially grown by thousands of producers and households and consumed by millions of people across Southeast Asia.

Figure 3: Water spinach (*Ipomoea aquatica*). Photo courtesy of Eric Guinther under CC-BY-SA-3.0-migrated (https://commons.wikimedia.org/w/index.php?curid=253457).

Figure 4: Water mimosa (*Neptunia oleracea*). Photo courtesy of Kurt Stüber under CC-BY-SA-3.0-migrated (https://commons.wikimedia.org/wiki/File:Neptunia_oleracea0.jpg).

1.2.3 Floating species

Floating species have no physical contact with the soil substrate, although they do have an extensive root network that is suspended in the water column to a depth of 0.25–0.75 m. Depending on the productivity and nutrient content of the waterbody in which they are growing, these plants can successfully colonize much deeper water columns, sometimes up to a depth of 15 m. Examples of these species include the invasive water hyacinth (*Eichornia crassipes*) (Figure 5), which is non-edible for humans. Although this FAM originated in South America, it has spread globally and has detrimentally impacted native habitats and their ecology, as well as human activities including navigation and other forms of aquaculture, such as commercial cage culture in Lake Victoria, Kenya and Uganda. Valuable floating FAMs include *Lemna* (Figure 6) and *Wolfia* spp., the former of which has been repeatedly proposed as a key aquaculture species, especially as a potential aquafeed ingredient or as a supplementary feed to some cultured species. Though useful at the hobby and extensive production levels, there have been mixed research findings on its usefulness on a commercial scale (Iqbal, 1999).

Figure 5: Water hyacinth (*Eichornia crassipes*). Photo courtesy of Wouter Hagens (https://commons.wikimedia.org/w/index.php?curid4500).

Figure 6: Duckweed (*Lemna* sp.). Photo courtesy of Christian Fischer under CC-BY-SA-3.0-migrated (https://commons.wikimedia.org/wiki/File:LemnaGibba.jpg).

1.3 The cultural heritage of edible aquatic plants

As humans have developed from hunter-gatherers to become farmers, both plant and livestock production systems have evolved over the centuries to provide a regular, accessible and affordable food supply at the household, village, regional and latterly urban levels. Humans throughout their history have consumed over 6 000 species of plants, initially collected and subsequently selected for their suitability, and then cultivated on increasingly larger scales (Ruskin, 1975; FAO, 1997). Currently, this number has reduced so that the majority of the world's population is fed by a small number of species, with only nine of these plants accounting for over two-thirds of global crop production (FAO, 1997). The world's most important crop species is an aquatic macrophyte, Asian rice (*Oryza sativa*), which is providing a staple diet for over 50 percent of the world's population. China has historically produced and consumed a range of FAMs at a large scale. Because of climate and environmental water availability, they are mainly found and cultivated in the south, southeast and eastern regions of China, with Li (2007a) estimating there to be 12 main freshwater classes/families currently produced and consumed within these areas.

One of the earliest recorded users of FAMs documented in the English language were the ancient Egyptians, who made papyrus, a 2 500-year-old form of paper made from *Cyperus papyrus*, known as sedge, paper reed, Indian matting plant or Nile grass (Parkinson and Quirke, 1995). Although Egyptians ate the younger tender shoots of the plant, the plants were mainly dried and processed into a form, which could be used for papyrus scrolls, baskets and floor matting. In modern times, the plant has become a lot less common in Egypt and across the Nile Delta, but is widely found across the lower continent, especially in the rift valley, east African lakes and wetlands, as well as in Florida and Mississippi in the southern United States of

America, where it is considered an invasive species. The Romans and Persians were the first to use watercress (*Nasturtium* spp.) of the Cruciferae family, which originated in the eastern Mediterranean, with the plant then spreading into France and England by the fourteenth century. It later spread to Australia, South Africa and the United States of America, and was taken to Japan around 1780 (Li, 2007a). Before the colonization of the North American continent, the indigenous peoples would regularly gather and eat the grains of the native *Zizania aquatica*, commonly known as wild rice, found in swampy and waterlogged areas. This species has more recently been introduced into elevated land in the tropics. Another native South American emergent aquatic macrophyte, the yellow burrhead (*Limnocharis flava*) (Figure 7) was introduced into Southern Asia in the 1800s and is now widely spread, being grown in Malaysia in rice paddies and in west Java as part of an integrated polyculture system in conjunction with carp ponds (Cook *et al.*, 1974).

Figure 7: Yellow burrhead (*Limnocharis flava*). Photo courtesy of User:BotBln under CC-BY-SA-3.0-migrated (https://commons.wikimedia.org/wiki/File:Limnocharis_flava_HabitusFlower_BotGardBln0906.jpg).

Figure 8: Chinese water chestnut (*Eleocharis dulcis*). Photo courtesy of Xiaowei Zhou.

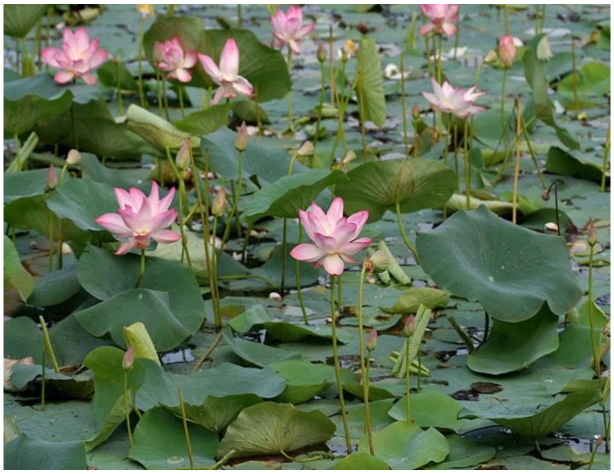

Figure 9: Lotus flower (*Nelumbo nucifera*). Photo courtesy of J. M. Garg under CC-BY-3.0 (https://commons.wikimedia.org/wiki/File:Nelumbo_nucifera_(Indian_Lotus)_in_Hyderabad_W_IMG_8736.jpg).

The perennial water chestnut (*Eleocharis dulcis*) (Figure 8), belonging to the family Cyperacea, has been cultivated for hundreds of years throughout the southern areas of China (Herklots, 1972), often in polyculture with paddy rice and seasonally rotated with other crops, such as lotus and arrowhead. Likewise, since the 1950s, it has been translocated for trials in Australia, Indonesia (Java) and the Philippines where it is considered to have potential as a high-value crop. It is cultivated for its tasty undersoil cormels, which can be used as a vegetable or a fruit, fresh or canned, or processed to extract the starch within. The earliest documented record of water chestnut is found in the book of Er Ya, around the second century BCE (Kong, 2005). Currently, it is distributed widely over the whole of China, except in the colder regions. The leading production areas are the Yangtze Valley and the southeast coastal regions. The popular varieties of water chestnut are regionally based, including Su water chestnut found and grown in Jiangsu, Hangzhou Big Red Coat in Zhejiang, Xiaogan water chestnut in Hubei, and Guilin Mati in Guangxi province.

The lotus flower (*Nelumbo nucifera*) (Figure 9), which has considerable religious significance throughout South Asia, has been recorded in China since the twelfth century and is mainly cultivated for its flowers, but also for food. The tubers and seeds are used in a range of cooked and fresh dishes. Its rhizome is nutritious, with 100 g of fresh underground stem containing 1 g protein, 19.8 g carbohydrates, 19 mg calcium, 51 mg phosphorus, 0.5 mg iron, and 25 mg vitamin C (Wang, 1991). These underground rhizomes can be harvested all year, allowing them to remain viable after being transported long distances (Zhao, 1999). Lotus is also used as a medicinal plant, for food packaging, and as feed for fish or castor silkworms.

Figure 10: *Trapa* spp. Photo courtesy of Xiaowei Zhou.

Figure 11: Water bamboo (*Zizania caduciflora).* Photo courtesy of Shizhao under CC-BY-3.0 (https://zh.wikipedia.org/wiki/File:Water_bamboo.jpg).

Water caltrop, *Trapa* spp. (Figure 10), is a floating aquatic herbal plant, which is found in the wild and can be cultivated in lakes and ponds, as well as shallow waters such as channels and rice fields. The edible fruit is rich in carbohydrates, proteins, various vitamins and minerals, and is eaten both cooked and processed alongside noodles and wine. It belongs to the Trapaceae family, and contains the compounds ergosterol and sitosterol, which have been recorded as stomach and uterine cancer treatments (Li, 2007a). Although now distributed across at least three continents, its main cultivation and consumption is in China, south of the Yangtze River.

Water bamboo (*Zizania caduciflora*) (Figure 11) is a persistent and wild growing perennial aquatic plant, which prefers shallow water, and now grows across Asia and the American continents. It belongs to the wild rice/grass family, and has an edible, fleshy stem and is a well-known cultivated specialty aquatic vegetable in China. It is believed to relieve coughs, and when boiled, children's diarrhoea (Kong, 2005). In

China, it is now commonly cultivated across the south, in Guangdong, Jiangsu, Taiwan Province of China, and Zhejiang.

Globally, perhaps the most cultivated and economically important FAM of all is water spinach (*Ipomoea aquatica*). Geographically, it is known by many different names, such as *rau muong* in Viet Nam, *pukbung* in Thailand, *keng xin cai* in China, *kalmi* in Bangladesh, *kangkong* in Sri Lanka, *kanzon* in Myanmar, and water spinach, water convolvulus and, confusingly, kale in English. Nutritional values of water spinach are superior compared with many other vegetables such as amaranth, celery, cucumber, spinach or gourds. It is an excellent source of vitamin A, and fairly rich in a range of other vitamins, as well as calcium, iron, potassium and phosphorus (Rahman, Yakupitiyage and Ranamukhaarachchi, 2006). Being a relatively short duration crop, it can be harvested regularly after 25–30 days, with the vines of the crop also used as fodder for cattle and swine, as well as supplementary aquaculture feeds.

In much of the literature, *I. aquatica* has been considered to originate from three main continents: Africa, Asia and Oceania (the southwestern Pacific islands). Austin (2007), in his ethnobotanical review of *I. aquatica*, endeavoured to ascertain the original distribution of the species, when it was collected as an edible and nutritious wild plant, and the date and location of its domestication. He found that in Southern Asia this plant had been gathered from the wild and used as a medicine and as an aquatic vegetable as far back as 300 CE, as recorded by Ji Han (304 CE) during the Chin Dynasty (290–307 CE), in the areas now known as Kwangsi (Guangxi) and Kwangtung (Guangdong) provinces of southern China and the central and northern parts of Viet Nam.

With the arrival of Europeans in these regions in the 1400s, the new colonists recognized the importance of this aquatic plant for its low production costs and ease of cultivation. They began transporting water spinach with them on major trade routes, first around Asia, and subsequently further afield to other tropical and subtropical locations, where it could then be dispersed and grown. The Dutch and Portuguese colonists in the 1400s and 1500s, in present day Indonesia and Malaysia, were certainly aware of the plant, and by the 1800s were cultivating water spinach at larger scales. Often grown on the outskirts of towns and cities, it became the second most popularly consumed green vegetable in the region behind pak choi (*Brassica rapa chinensis*). In Africa, there is less literature that can be used to determine if water spinach was indigenous or introduced. However, it is more likely that it was introduced into the northeastern side of the continent in the 1700s. The Chinese mariner Cheng Ho, and other explorers, carried on his ships, among other cargo, water spinach in huge earthenware pots containing soil to Egypt, Saudi Arabia, Somalia and Yemen (Lee, 2002).

Austin (2007) identifies the common names of the plant in different dialects going back as far as 300 BCE, which offers linguistic evidence of the historic use of the species. The original Sanskrit name, *kalamba*, is similar to that used in the present day in northern and central India. It was first recorded in China around 200 CE, but it is still unclear where water spinach was first significantly cultivated/farmed as opposed to being collected from the wild. However, the remaining known records and available literature related to cultivation, medicinal use and phylogenetic studies, as well as common names, suggest that *I. aquatica* was first cultivated on a significant scale in Southeast Asia. The plants may have been domesticated in China or India, first or simultaneously, but the remaining available literature does not make a definitive conclusion on where this FAM was first cultivated at scale.

There is more information in the literature from the twentieth century on FAMs being used in peri-urban contexts alongside growing and major urban populations. They were often cultivated in wastewater-fed ponds and wetlands on the outskirts of urban centres for water treatment, as well as for income generation from their cultivation as food or for other purposes. Strauss (1997) estimated that, at that time, there were over 130 sewage-fed aquaculture schemes across the Indian subcontinent, covering a total area of 12 000 ha. Perhaps the most famous of all are the wastewater aquaculture ponds on the outskirts of Kolkata, commonly known as the East Kolkata Wetlands, which are designated as a wetland of international importance under the Ramsar Convention. Over 20 000 low-income and economically marginalized families depend on the various biological products, including fish and vegetables, of these wetlands for their livelihoods (Ghosh, 2005). The wetlands, operational since around 1930, are the world's largest wastewater aquaculture scheme, comprising an area of approximately 4 000 ha. Despite their protected status, these wetlands are continually shrinking due to land pressures, especially from urban development. The series of ponds and linking waterways receive around 550 000 m^3 of untreated wastewater per day (Edwards and Pullin, 1990). In the early part of the twentieth century, 70 species of plants were recorded growing between the wetland embankments, including *Fimbristylis ferruginea, Suarda maritime, Acanthus ilicifolius, Excoecaria agallocha, Avicennia officinalis, Phragmites karka, Aegiceras majus* and *Typha elephantina*. In addition, 34 halophilic plant species were documented, including mangrove species confined to saline or brackish water habitats (Biswas, 1927). Later studies (Dasgupta, 1973) identified over 92 plant species, strongly indicating that salinity levels fluctuated between freshwater and brackish water over the past 50 years. In terms of more economically important plant species, the wetlands harbour a variety of FAMs. Local lower-income communities have cultivated *Ipomoea aquatica, Bacopa monnieri, Enhydra fluctuans* and *Marsilea minuta* (Ghosh, 2005) since the 1930s, often in the channels leading to the main fish ponds, or depending on the season, directly in the first of a series of ponds used to clean wastewater before entering lower fish ponds. Some are harvested and cooked as vegetables, and others are valued as medicinal plants. Fibrous emergent FAMs, such as *Cyperous rotundus, Phragmites karka* and *Typha angustifolia,* are used by local communities for thatching their roofs, making furniture, mats and basket ware, and as a pulp for waterproofing in house construction. In addition, apart from their continual function for water purification, these plants are used as fish and livestock feeds, and some are also used as green compost and manures depending on seasonal water volumes and wastewater quality (EKWMA, 2011). There is well-recorded indigenous knowledge throughout India of FAMs having specific medicinal properties (Mandal, 2008).

The use of FAMs in the Taiwan Province of China is also well documented. Here, by the twentieth century, freshwater aquatic plants were important in the phytoaccumulation, regulation and removal of pollutants from wastewater, as well as cultivation for food and medicinal products. Liao and Chang (2004) described the 320 ha Erh-Chung wetlands, located south of Taipei City and adjacent to the Tang-sui River, which were originally formed in the 1960s. Overpumping of groundwater caused this peri-urban land to sink, and tides from the river inundated the existing farmland. By the early 1970s, the area became a wetland into which the seepage of adjacent domestic and factory effluents began to flow, causing significant pollution problems. Introduction of water hyacinth, either intentionally or accidentally, and its rapid growth to cover over 60–70 percent of the wetlands' area, reduced the levels of a range of heavy metals in the water table to levels well within the World Health Organization guidelines for safety to humans and wildlife within six months. The potential for phytoremediation of wastewater by different species of aquatic plants for heavy metals and other pollutants has been demonstrated in the Taiwan Province of China, and trialled elsewhere, has been shown to have beneficial outcomes by a number of researchers (Reddy, 1987; Lee *et al*., 1999; Lee *et al*., 1998).

Other South Asian countries, in which edible FAMs developed in their importance and created incomes and food throughout the twentieth century included Indonesia, particularly *Ipomoea aquatica* in the small rivers and canals of peri-urban areas such as Jakarta (Purnomohadi, 1999). In addition, *I. aquatica* cultivation in China, Hong Kong Special Administrative Region (Hong Kong SAR) and the outside provinces was developed in the late 1960s, where it supplied up to 15 percent of the local vegetable production, as a summer leaf vegetable. Two methods of cultivation were commonly used: in wetland flooded plots (up to 0.75 m depth) on former paddy fields; and on dry land utilizing raised irrigated beds, the latter which was more commonly used at the nursery stage. Annual production of *I. aquatica* in China and Hong Kong SAR has been estimated at 3-5 million kg (Edie and Ho, 1969), which at the time would have had an estimated value of USD 800 000 at production levels of up to 100 000 kg/ha. Under optimum conditions this species can grow up to 16 cm per day (Gilbert, 1984), and under upland cultivation, yields range from 7 to 30 tonnes/ha of fresh produce per crop. Annual production of water spinach in Thailand is reported to be 90 tonnes/ha. In Malaysia, water spinach is cultivated commercially on 600-1 100 ha with a total production of 60 000-220 000 tonnes/year. In 1992, in Malaysia, Singapore and Thailand, farmers' revenues from production of water spinach ranged between USD 0.05-0.40 per kg (Westphal, 1992).

One of the earlier, and perhaps still the most comprehensive, reviews of FAMs is Edwards' (1980) ICLARM publication, which systematically describes their classification, potential contribution for food production, for both humans and livestock, and also food safety. These are described within the context of the growing populations in Southeast Asia, and associated food production considerations. He concentrated on water morning glory, *I. aquatica,* and water mimosa, *N. oleracea,* due to their potential for large scale, financially viable production. Indeed, Edwards documented productivity of up to 100 tonnes per hectare per year owing to their rapid vegetative growth and regular monthly harvesting, when grown in sewage stabilisation ponds and former irrigated peri-urban shallow ponds or rice paddies (McGarry and Tongkasame, 1971). These two species became particularly prominent in the 1980s and 1990s for their commercial cultivation in four rapidly urbanising cities in Southeast Asia; Hanoi and Ho Chi Minh City, Viet Nam; Phnom Penh, Cambodia; and Bangkok, Thailand. The first three cities primarily cultivated aquatic plants using recycled peri-urban wastewater; Ho Chi Minh City, Phnom Penh and Bangkok have the added advantage of being able to produce water spinach and water mimosa throughout the year due to higher year-round temperatures. Conversely, aquatic plant growers in the more seasonally variable Hanoi rotated their production to grow water spinach and water mimosa in the warmer eight months. They then changed over to the slower growing watercress (*Rorippa nasturtium aquaticum*) (Figure 12) and water dropwort (*Oenanthe javanica*) (Figure 13) in the four cooler winter months in order to maintain their incomes.

Figure 12: Watercress (*Rorippa nasturtium aquaticum*). Photo courtesy of Masparasol under CC-BY-3.0 (https://commons.wikimedia.org/wiki/File:Watercress_(2).jpg).

Figure 13: Water dropwort (*Oenanthe javanica*) (semi-domesticated cultivar). Photo courtesy of Xiaowei Zhou.

Water dropwort is a perennial FAM belonging to the Umbelliferae family, which has a preference for growing in more temperate climates. One hundred grams of this aquatic plant contains 2.5 g of protein, 0.6 g of fat, 4 g of carbohydrates, 3.8 g of crude fibre, as well as vitamins, carotenoids, nicotinic acid and minerals (Wang, 1991). It is believed to originate from East Asia, including China. It can be found growing wild in rice fields, streams and wetlands bordering the Yangtze River and the areas south of it, including Sichuan and Yunnan provinces.

The role of FAMs in providing on-site livestock and fish feeds is documented by Northcott (1982) and Mandal *et al*. (2011). In terms of their composition and proximate analysis, FAMs have relatively high water content at 84.2–94.8 percent (Boyd, 1968), and documented crude protein values (dry weight) of 8.5–

22.8 percent for 12 submerged species; 9.3–23.7 percent for 19 emergent plants; and 16.7–31.3 percent for eight non-planktonic algae. These protein values are lower than those for duckweed, *Lemna* spp., at 42.6 percent. However, these figures should be taken as an example in comparison with pasture grass, for which it takes 2.5 times less live weight to obtain the same dried matter weight as FAMs (Little and Henson, 1967).

Duckweed is one of the more popular FAMs published in the scientific literature. Iqbal (1999) produced a comprehensive review in which he describes past and existing uses of duckweed in countries such as Bangladesh, China and India, primarily in systems recycling and treating both urban and rural wastewater. These systems were used to produce a dried feed supplement that has been used for raising fish, poultry and pigs. While duckweed has been promoted widely over the years as a low-cost environmentally sustainable means of protein production, recent evidence shows that it has rarely been taken up at any significant commercial scale in developing or other countries. One important constraint is the requirement for sufficient land and water to produce the quantities of duckweed needed for a commercially viable business; moreover, the operational labour of collecting, drying and processing the duckweed into meal has a significant cost.

Aquatic macrophytes are also planted in ponds and used as hides and supplementary feed within certain aquaculture production systems in Southeast Asia and the southern United States of America. First, in South Asia, FAMs are planted as feed for cultured mitten crabs (*Eriocheir sinensis*) (Zeng, 2012). During the nursery stage, farmers use rectangular ponds with 1-metre high mesh fence structures on their banks to prevent predators, including frogs and toads, from entering. They also dig deeper 60–90 cm channels in the nursery ponds, in which, before stocking, aquatic macrophytes including *Vallisneria spiralis*, *Hydrilla verticillata* and *Elodea* spp. are planted, serving as refuges and as supplementary food. Before the juveniles are ready to be stocked out into larger grow-out ponds, up to 1.5 ha in area, these ponds are disinfected with lime, and 10 days after disinfection, aquatic plants, such as *V. spiralis*, *H. verticillata*, *Ceratophyllum demersum*, *Potamogeton maackianus* and *Myriophyllum spicatum,* are introduced. These areas hide the crabs from predators, but also provide an abundant source of supplementary food, which provides variety and nutritional diversity to the animals' diets. In the southern United States of America, the extensive production systems developed in the 1960s for the red swamp crawfish (*Procambarus clarkia*) utilize FAMS. Prior to stocking the crawfish, the aquatic plants alligatorweed (*Alternathera philoxeroides*) and smartweed (*Polygonium*) spp. are introduced to provide cover as well as a low-cost supplementary source of food. If managed correctly and not overstocked with crawfish juveniles, these aquatic plants can continue to grow vegetatively, providing food continuously throughout the crawfish production cycle.

There is also a lucrative, largely unregulated, global trade in ornamental aquatic plants for the aquarium and pond hobbyist sector, which has increased its sales volume and diversity since the 1970s. This has led to significant concerns over the introduction of unwanted species, such as molluscs and other invertebrates often associated with the roots and stems of FAMs, and the release of imported ornamental plants into the wild, with their potential consequences for local aquatic ecosystems (Padilla and Williams, 2004). The aquarium trade and ship ballast water have long been implicated in the arrival and subsequent establishment of non-native, invasive aquatic plant species into North America. Cohen, Mirotchnick and Leung (2007) described the unwanted introduction into North America of Eurasian milfoil (*M. spicatum*), giant salvinia (*Salvinia molesta*) and Brazilian waterweed (*Egeria densa*). The detrimental introduction and the subsequent widespread establishment of *M. spicatum* and water caltrop (*Trapa natans*) in the Great Lakes is estimated to cost over USD 800 million per year to the local economy. While this is one example of an unwanted introduction of invasive aquatic plants into North America, there have been many others across Europe and globally.

1.4 Food safety and occupational health

One of the key factors that has potentially limited the scaling up and further spread of FAMs beyond Southeast Asia has been food safety concerns related to FAMs grown in wastewater and the associated occupational health issues for farmers.

The keystone publication on this topic is from Mara and Cairncross in 1989, which started this field of study, and related publications for safe use of wastewater and excreta in agriculture and aquaculture. Reilly and Kaferstein (1997) reviewed food safety hazards associated with both farmed fish and edible aquatic plants and proposed the application of the Hazard Analysis Critical Control Point (HACCP) systems as an overall strategy to control the food safety and health hazards identified.

The EC-funded PAPUSSA project (2003–2006) carried out an interdisciplinary, holistic overview of FAM value chains in four cities in Southeast Asia. This included an occupational health review of those working daily in these systems (van der Hoek *et al*., 2005), and an assessment of food safety of edible aquatic plants and fish raised in wastewater fed ponds (Dalsgaard *et al.*, 2006). While the latter found some concerns over two specific heavy metal concentrations of wastewater-grown water spinach in Hanoi and Phnom Penh, these were still well within the safe World Health Organization guidelines for human consumption. The authors recommended to initially wash the plants in clean water and to subsequently boil or cook them for two to three minutes in order to kill the bacteria or parasites that may be present. A further study (Marcussen, Dalsgaard and Holm, 2009) was carried out on Phnom Penh's Beung Cheung Ek Lake, which is located 6 km south of central Phnom Penh, Cambodia. Following a Japan International Cooperation Agency project in the early 2000s, the lake received over 80 percent of the city's domestic and industrial wastewater through a network of concrete channels, joining to flow into the lake at two main inlets. Households that had previously settled around the lake in the late 1980s quickly began to realize the potential of cultivating FAMs, particularly water spinach , which flourished in the nutrient-rich wastewater. The 2009 study determined the concentrations of 35 elements in the tissues of the cultivated water spinach and sediment that were collected along transects of the two wastewater inlets; samples were also taken from a nearby non-wastewater exposed fish pond which was used as a reference. Elevated concentrations of potentially toxic elements (PTEs), including cadmium, copper, nickel, lead, antimony and zinc, were found in the water spinach and sediment samples collected near the wastewater inlets. However, the intake of these elements from the water spinach consumption was significantly lower than the maximum tolerable intake level set by the FAO Codex Alimentarius for an adult person. The study therefore concluded that the consumption of water spinach from Beung Cheung Ek Lake constituted a low food safety risk with respect to PTEs.

In terms of potential human parasites, Marcussen's 2009 study of eight samples of water spinach taken from different points in Beung Cheung Ek Lake found that the protozoan parasites *Giardia* spp. and *Cyclospora* spp. were present at a range of 0–30 oocysts/g, and *Cryptosporidium* spp. oocysts and helminth eggs were not detected in any of the eight samples. There were no apparent differences in protozoan oocyst numbers between plants that were washed in wastewater and those with no wastewater exposure during harvesting. The study concluded that pathogenic parasites identified during the study would only be a problem for human health if the plants were not washed and cooked properly by boiling in water or heated in stews and soups before being consumed.

The bacterial loading of the lake was examined using *Escherichia coli* as an indicator organism. Mean numbers of *E. coli* in wastewater at the initial inlets and the final lake outlet, respectively, were recorded at 3.7 million *E. coli* per 100 ml and 35 500 *E. coli* per 100 ml. A nearby fish pond that did not use wastewater was used as a control, and *E. coli* was recorded as 43 300 cells per 100 ml. These results clearly illustrate the efficacy of wastewater treatment of the lake, considering the drastic reduction of bacterial load from inlet to outlet, with the final water quality similar to that of the control pond.

Van der Hoek's (2005) occupational health survey of 154 households around the periphery of Beung Cheung Ek Lake found contact dermatitis to be the main occupational health risk for those working in these systems, which was typically found on hands, lower arms and legs. Contact dermatitis normally is caused by dermal irritation or allergic reactions to specific waterborne chemicals or substances that can cause rashes, oedema and subcutaneous haemorrhaging. If not treated, these conditions can develop into dermal lesions, which can become infected by secondary bacterial pathogens such as *Staphylococcus* spp. While in the case of this study the specific irritants/allergens were not identified, contact dermatitis is often associated with exposure to waterborne metals such as nickel and zinc. Van der Hoek (2005) found that 62 percent of interviewees who worked in the lake in January and February, the peak months of the dry season, had skin problems. This declined to 42 percent for the months of July and August. Less than 1 percent of the control population of people not exposed to wastewater reported dermatitis. Of those who were diagnosed with contact dermatitis, 56 percent experienced symptoms on their hands, 36 percent on their feet, and 34 percent on their legs. The survey also found that only 2 percent of people working in the lake consult doctors, with 47 percent relying on home treatments because of locally prohibitive health-care costs. While these external dermal conditions were clearly indicated, the survey also found that most of those workers interviewed considered the conditions not to be serious. Workers often applied lime and orange juice to their arms and legs to treat themselves both prior to entering the water and at the end of the day following wastewater exposure, with some evidence to show this could be effective in reducing the incidence of bacterial infections developing within open cuts and lesions. Anh *et al.* (2007) carried out a similar occupational health study with the wastewater aquatic plant growers in peri-urban Hanoi, also finding contact dermatitis as the main acute health issue they had. However, both studies had limited time scales and were therefore unable to assess a range of other potential longer term or chronic medical conditions related to daily wastewater exposure, e.g. hepatitis, *Leptospirosis* infections or cholera, as well as other more immediate potential risks such as food poisoning from *Campylobacter* spp. and *E. coli*. This is an area where further research is needed to understand the dynamics and potential human pathogen loading under different environmental conditions of FAM production systems, an area of research that needs to be prioritized in future.

1.5 Genetic resources and development of freshwater aquatic macrophytes

While the cultivation and consumption of certain edible FAM species is well recognized in a number of countries in South and Southeast Asia, the development of their genetic resources, varietal development and selective breeding programmes, both actual and recorded in the literature, are far less apparent. Li *et al.* (2007b) states that in China there were an estimated 1 700 germplasm resources throughout the country. The historical translocation and spread over hundreds of years of 5–10 key species from their endemic range is well documented. Many FAMs have been transported to new locations in northern Africa, Australia and the Middle East, often under similar climatic and environmental conditions, which has opened up the potential for production and associated benefits. By their very nature of rapid vegetative growth in tropical climates of 27 °C and above, certain FAMs such as water mimosa (*Neptunia oleracea*) and water spinach (*Ipomoea aquatica*) are repeatedly grown, harvested and then replanted from asexual, clonal cuttings as nursery stock year after year without any obvious noticeable decline in their productivities. The growers involved in the PAPUSSA project reported that they were content with the available germplasm they repeatedly grow, harvest and then propagate from cuttings on land nursery plots (A. Salamanca, personal communication, 2006); however, some said that they would be interested in trialling more saline-tolerant varieties if they were actually available to them. While this review has carried out a comprehensive literature review on the genetic resources, selection and strain development of well-known FAMs, there is little evidence that genetic improvement has been undertaken or even deemed necessary for the development of the sector towards larger scale production and consumption across significant areas of Southern Asia.

Egbert (2010) described a lack of varieties as a possible constraint to further uptake and benefit the populations in other countries, including how FAMs fit into existing production systems. By 2010, the World Vegetable Center conducted activities, in collaboration with national partners in Indonesia, Taiwan Province of China and the Philippines, to promote the conservation and use of indigenous vegetables, some of which included FAMs. Their activities focused on the rescue, improved conservation and seed production of promising varieties, cultivar trials and participatory evaluation of selected accessions, as well as training personnel in germplasm management. Research has shown that key crops differ between countries. To introduce a FAM species to a country, it is first necessary to identify the species suitable for development, and subsequently to develop their culture and promote their benefits. Water spinach is one FAM promoted by the centre in the region.

Tiwari and Chandra (1985), in their review of water spinach, categorized and named three main varieties on the Indian subcontinent by the colour of their stems. The light-green variety has tender, smooth, even-surfaced shoots and oblong, narrow oval-shaped leaves tapering to a point at each end, spreading densely in shallow water. The most commonly grown cultivar, red green, has tender, glabrous shoots, thick, narrow triangular shaped leaves, and long trailing branches. The red-stem variety has soft, glabrous shoots and sagittate leaves, preferring to grow and spread on more firm but moist soils. They also described two further varieties commonly grown in China and Hong Kong SAR, also reported by Edie and Ho (1969). Ching Quat 1 is a green-stemmed and cold-resistant variety of *Ipomoea aquatica* than the aforementioned Indian varieties, but tends to give lower yields and quality and more textured plants that are more commonly used for livestock feeds. Pak Quat is a typically white-stemmed variety, which can be grown in both shallow water and in more moist soil-based systems, and is a large, good-quality plant, giving a high number of harvests each year.

The use of water spinach varieties for the phytoremediation and biodegradation of contaminated soils is referred to in the literature. Cai *et al.* (2008) examined comparative potentials for five different genotypic varieties of *I. aquatica* to clean soils contaminated with the industrial effluent di-n-butyl phthalate (DBP). The results clearly indicated differential variety tolerance to DBP uptake, with the local Chinese white-skin (variety V_5) and Taiwan Province of China filiform-leaf *I. aquatica* (variety V_1) presenting the highest phytoremediation potential in soils containing DBP. Li *et al.* (2007b) also carried out a study looking at the potential for nitrogen removal from eutrophic waterbodies using floating beds of three different varieties of water spinach. Varieties used in the experiments included Thailand angustifoliate, Jiangxi big leafage and Panteng native varieties. These were obtained from a Chinese/Thai commercial seed company. Despite the proactive use and future role of edible FAMs for phytoremediation of potentially hazardous substances in industrial effluents as reported above, the clear risk of human consumption of the associated plant tissues should be controlled. Within such systems, non-edible FAMs could be incorporated, with uses including construction and roofing.

In China, there are up to 600 reported varieties of the most popular, historically significant FAMs, including water lotus (Chen *et al*., 2008). However, there is some confusion over the classification of varieties, as different scholars have adopted different morphological traits and, based on these traits, they have then recorded different numbers of varieties. Wang and Zhang (2004) described 98 different varieties of water lotus. Despite the differences between publications, this suggests that, at least in China, there is a level of genetic diversity in key FAM species. Sheridan *et al.* (2001) measured the genetic diversity in two commercially produced watercress (*Roppia nasturtium aquaticum*) varieties, using a fingerprinting technique called RAPD-PCR (random amplification of polymorphic DNA-polymerase chain reaction). They found little genetic diversity between commercial watercress populations; however, watercress was clearly a unique cluster genetically distinct from other *Rorippa* species.

Ikakkar, Mohan and Ram (1986) demonstrated they could regenerate the commercially important FAM water mimosa through standard tissue cell culture procedures, utilizing the hypocotyl and cotyledon tissue from aseptically grown seedlings cultured on a specialized medium. Shoot elongation was then stimulated in specialized liquid media. Regenerated plants, once transferred to pond conditions, become established and develop nodules. Although not a practical, cost-effective method for commercial storage of different FAM varieties, it can provide plant researchers the opportunity for keeping a stock of a variety of different FAM varieties in low space storage facilities for further use in trials.

There are few documented examples of FAM genetic modification. Khamwan *et al.* (2005) developed a laboratory protocol for the stable transgenesis of *I. aquatica* by infecting cut cotyledons with an *Agrobacterium* harbouring a specific beta-glucuronidase gene (GUS), commonly used as a reporter gene to demonstrate successful gene transfer. The resulting transgenic plants grew normally to maturity and exhibited stable GUS activity. Yamamoto *et al.* (2001) similarly developed transgenesis protocols for two species of duckweed, *Lemna gibba* and *L. minor*, also using *Agrobacterium* mediated gene transfer. The authors hypothesized that these transformation protocols could facilitate genetic engineering of duckweed, with improved strains being tailor-made for bioremediation and larger-scale industrial production. Both studies indicated that genetic modification of commercially important FAMs could be readily achieved, improving their genotypic qualities, potentially for desired beneficial traits. By 2015, Van Hoeck *et al.* (2015) had produced the first draft genome and annotation of *L. minor* with the view that this could provide new insights into the biological understanding and biomass production applications of the species.

This review found no evidence indicating the widespread use of genetically modified FAMs in commercial or other food production systems. Globally, the contentious issues and potential of genetically modified crop species are well known. To the author’s knowledge, these techniques have not been applied to FAMs. This is probably due to the current acceptable productivity levels and commercial viabilities for the food production of existing varieties. However, their genetic modification and improvement for non-food usages such as water treatment, bioremediation and biofuel production are applications that will no doubt be put forward and discussed in the future.

1.6 Case studies of commercial producers of freshwater aquatic macrophytes

The following four individuals are commercial FAM farmers and were stakeholders in the original EC-funded PAPUSSA project (2003–2006). Each farmer was interviewed in 2004, and followed during the project to understand the involvement of their households in aquatic plant cultivation, as well as how this activity fitted into the aquatic plant value chain in each of the major cities on which the project focused. Twelve years later, in 2016, the four farmers were informally interviewed for the purposes of this review in order to find out whether they were still involved in aquatic plant production and their views on the future of the production of aquatic plants in peri-urban areas. Interviews were carried out using a semi-structured format. The format for each of the case studies below is divided into two. The first part presents the information, status and reflections of the individual plus the associated value chain back in 2004 during the PAPUSSA project. The second part focuses on the individual's status and associated information at the time of the interview in 2016.

1.6.1 Lu Hung Lanh – Bang B village, Thanh Tri district, Hanoi, Viet Nam

1.6.1.1 Lu Hung Lanh (2004)

Figure 14: Lu Hung Lanh beside his wastewater-fed water spinach and water mimosa plots, Bang B village, Hanoi, Viet Nam. Photo courtesy of William Leschen.

Mr Lu Hung Lanh was born and brought up in Bang B village, in the Thanh Tri district of Hanoi, located 7 km from the city centre on one of the city's five main wastewater rivers – the Tor Lich River (Figure 14). In 2004, he was a 44-year-old father of three. He joined the army in his late teens and, at the age of 25, left to get married. He then started to work with his brother-in-law in a small artisanal local steel and metal galvanizing workshop in Bang B village. At this time, the extensive local fields in Bang B were collectively used for growing rice for the commune and were irrigated with wastewater, a mixture of human sewage and other domestic effluents, pumped from the Tor Lich River using small portable Chinese petrol and diesel pumps. Lu Hung Lanh thought back to those years and the gradual improvement in living standards in the village, as electricity arrived and telephone lines, better roads and improved irrigation canals were constructed. He remembered some of the villagers growing aquatic plants in a rather ad hoc manner within the wastewater rivers themselves; however, he said that there was always friction over the ownership and the unnecessary blocking of the watercourse, causing waste accumulation as well as flooding during rainy seasons. According to Lu Hung Lanh, these issues were largely resolved as a result of local land tenure systems introduced by the government and the local commune committee in the 1980s and 1990s. By the mid-1990s, a transparent, transferable land ownership or leasing scheme was enacted at the commune level. As a result, aquatic plants were therefore no longer cultivated in the wastewater rivers. Each local commune also had an electric water pumping station installed next to the Tor Lich River (Figure 15), for which local households paid a small but regular sum if they were irrigating their plots with wastewater.

Figure 15: One of the electrically powered wastewater pumping stations for Bang B village from the Tor Lich River. Photo courtesy of William Leschen.

Remembering his neighbour, Mrs Nhuan Ring, one of the first people to test growing aquatic plants, Lu Hung Lanh stated: “She dug the soil levels in her adjacent plots deeper and then constructed enclosed ponds into which wastewater was then pumped via the new commune pumping stations”. He remembers that Mrs Nhuan Ring was the first person in Bang B village to build a new house on the proceeds from her water spinach production. Subsequently, households and farmers learned from each other the techniques of growing aquatic plants in such a system by themselves, and the former rice plots were gradually converted to edible aquatic plant cultivation. Local households realized that they could earn between three to five times the income per hectare by growing aquatic plants rather than rice, and that the labour requirements in doing so were far less onerous and time consuming. Lu Hung Lanh became involved in the cultivation of aquatic plants in 1996, when he and his household were granted an 800 m^2 area of land adjacent to one of the concrete irrigation feeder channels. He divided the area into smaller individual plots of 200 m^2, which then allowed him to sequentially plant, crop and harvest throughout a normal eight-month cycle. During the summer months, March–October, he and his wife grew water spinach and water mimosa, harvesting the plants every 25–30 days during vegetative growth. In the colder winter months, they switched the plots to the slower growing watercress and water dropwort. For each of the four species, the young nursery plants were freely available and, once in production, Lu Hung Lanh learned to take cuttings at the end of each cycle to propagate new stocks in a small nursery plot nearby. In terms of other inputs, he used supplementary inorganic fertilizer, urea and lime, and fallowed the plots between cycles. After only a few years, he left his brother-in-law’s metal workshop to concentrate on the plants full time, since he realized that his wife’s full-time work and help from one child were not enough, especially in the water spinach season. Selling the plants was not a problem; at least once a fortnight, he and his wife harvested either water spinach or water mimosa, and washed and cut the plant into bundles (Figure 16).

Figure 16: Following harvesting, water spinach growers in Bang B village prepare and wash bundles in freshwater ready for transporting to market. The removed waste leaves are collected and used in the commune as pig and fish feed. Photo courtesy of William Leschen.

Lu Hung Lanh would transport up to 30 bundles, of approximately 45 kg wet weight, on his motorbike to the local wholesale market 3 km away, where it sold within 30 minutes. By 2003, from the proceeds, he was able to acquire a new motorbike and a further 600 m^2 plot in the village, which he also developed for aquatic plant cultivation, allowing he and his wife to achieve an annual income of VND 44.6 million (USD 2 900). He estimated that in Bang B village alone there were over 250 households, 50 percent of the total involved in the cultivation of aquatic plants with approximately 50 others, mainly women, who were solely involved in the marketing and selling of the plants. Lu Hung Lanh reported that, by the early 2000s, industrial development began to impinge on the wastewater aquatic plant cultivations since shoe, textile and leather factories set up, and new residential housing was constructed on former cultivated land. He added that, since these factories were established, he and his fellow aquatic plant growers noticed definite disease signs, including the yellowing and withering of leaves. This was particularly true for the water mimosa; therefore, some growers decided to switch their plots to water spinach production. He worried that this was due to the declining quality of the wastewater, but nothing was done to monitor or regulate it, despite interventions from delegations of growers at the local commune committee and the Ministry of Agriculture. Furthermore, Lu Hung Lanh reported that each year, during the dry season, there was a reduction of the water volume in the main rivers. He believed that the annual price fluctuations in local markets created uncertainty and that this was not good for producers like himself. He wished that the government in some way could regulate this. He also added that the ever-increasing urban construction, primarily for domestic residential housing, would likely reduce the land areas under cultivation in Bang B village within the next five years. As a result, he would be either starting to look for other available land further along the Tor Lich River to continue cultivating plants or to look for alternative employment.

1.6.1.2 Lu Hung Lanh (2016)

Lu Hung Lanh was contacted by telephone in June 2016. He and his wife still grew water spinach and some watercress and water dropwort in winter months, but on a much-reduced landholding of 400 m^2. In 2011, a development company compulsorily purchased their previous plot of land, as well as land belonging to their neighbours, for the construction of an office complex. With money from the sale of their land and other savings from growing aquatic plants, Lu Hung Lanh and his wife bought a small car. He recounted that by 2008–2009 it was increasingly difficult to cultivate water mimosa due to plant disease and die off. He believed this was due to the increasingly contaminated wastewater from surrounding factory effluents. Therefore, he and most other growers then concentrated on growing the hardier water spinach, even though the market prices per kilogram were lower by 10–25 percent. Despite joining a local commune action group in 2010, he was unable to prevent the purchase of his and his neighbours' land. They eventually received a remuneration payment from the local government. In 2012, Lu Hung Lanh began to work almost full-time in his brother-in-law's steel workshop. His wife still worked on the remaining water spinach plots for an average of three hours per day, with Lu Hung Lanh coming to assist her every three weeks when they harvested the plants. He said that, in 2016, perhaps over 60 percent of the original land in Bang B village under aquatic plant cultivation was now built on, and less than 50 remaining households were still growing aquatic plants. On the future of aquatic plant cultivation in cities like Hanoi, Lu Hung Lanh thought that further urbanization was inevitable and that the value of plots suitable for construction would continue to increase. He had heard that there were a number of new aquatic plant growers in Bac Giang and Son Tay provinces, further away from Hanoi, who were able to grow water mimosa and water spinach in much larger plots, up to 1 000 m^2. He had seen these crops being transported into Hanoi city markets in small Chinese trucks. He concluded by saying he now missed his days out in the fields working with the plants, but understood that when living on the periphery of a large city things are always likely to change.

1.6.2 Minh Thuy – Phong Phu commune, Binh Chanh district, Ho Chi Minh City, Viet Nam

1.6.2.1 Minh Thuy (2004)

Figure 17: Minh Thuy morning glory grower Binh Chanh district, Ho Chi Minh City. Photo courtesy of William Leschen.

In 2004, Ms Minh Thuy (Figure 17) was a 38-year-old mother of two. She was born in Dalat, Lam Dong province and moved to Ho Chi Minh City with her family in 1975. In the early 1990s, she and her husband settled in Binh Chanh district, where they were able to rent a 1 200 m^2 plot of land with a house in an area close to a wastewater canal network, where local households were already involved in the cultivation of water spinach on former rice fields. They were told that in the 1960s wastewater aquatic plant cultivation had been carried out intensively in Ho Chi Minh City District 6, which is closer to the city centre, but it had declined due to the land being bought up and built on for residential housing.

Minh Thuy and her husband quickly learned from others who were already growing water spinach. They divided their land into three plots of 400 m^2, where they set up a rotational system for cropping most weeks (Figure 18). The previous tenant had also grown water morning glory, so Minh Thuy had little initial work to do in preparing the plots other than purchasing a small petrol water pump and other chemical inputs, such as urea, triple superphosphate fertilizer and builders' lime. She also arranged for one of her neighbours, who traded aquatic plants, to collect and sell her regular harvests using his motorbike. Most of the aquatic plants grown in Binh Chanh were sent on a daily basis, early in the morning, to a collection point 2 km away, where they were sold and transported in small trucks to other wholesale and retail markets all over the city (Figure 19). Following the births of her two children, Minh went back to part time hairdressing in her home to supplement the household income while continuing to work on the aquatic plants. At this time, she also hired one of her nieces to work on the aquatic plants, mainly to help her with harvesting and preparing the water spinach in bundles, ready for transport and selling. Her income from the plants averaged at VND 600 000 (USD 50) per month, which equated to around 40 percent of her and her husband's total monthly income; he was often away working on the boats for one to two weeks at a time. In terms of productivity, her plots produced around 30 000 kg, fresh wet weight, of water spinach per hectare per year.

Figure 18: Water spinach cultivation in wastewater Phong Phu commune, Binh Chanh district, Ho Chi Minh City. Photo courtesy of William Leschen.

Figure 19: Small truck is the typical mode of transport for aquatic plants in Ho Chi Minh City. Photo courtesy of William Leschen.

In Minh Thuy's opinion, the major challenge with growing water spinach was that the increasing salinity of groundwater was affecting the growth and financial viability of her business. She thought that this was due to the continual pumping of groundwater by residential or industrial users throughout the city over the years. This was particularly evident during the dry season, when especially the young plants, replanted from the nursery, exhibited darkened, curled-up leaves and required two months to reach harvest size. This affected her cash flow; she found it more difficult to afford the necessary inputs, including fertilizer and urea. She and her neighbours sought advice and a potential solution from the local agriculture extension office of the government, but the initiative was unsuccessful. The office told them that there was probably a more saline resistant strain of water spinach grown in Thailand, but that they were unable to import it into Viet Nam due to strict disease and non-native plant importation regulations.

In early 2003, Minh Thuy was informed that a new feeder road was going to be built on her and her neighbours' aquatic plant plots; their rented houses, however, would be allowed to remain. Plot of lands would be compulsorily purchased with a reimbursement to each landowner. Those leasing the land, including Minh Thuy and her husband, had no legal rights of security to stay. By June 2006, when the PAPUSSA project finished, the road had still not been built, but a series of engineers and surveyors had visited in preparation for construction.

1.6.2.2 Minh Thuy, substituted by Anh Bay (2016)

When we tried to recontact Minh Thuy in 2016, we had difficulties in finding her and her family. The property where they lived and worked was now a dual carriageway, with adjoining offices, residential housing and small stores. The surrounding land appeared to be in various stages of new construction with the previous wastewater streams channelled into concrete culverts, under and alongside the new road. However, in between the buildings, there were still some water spinach and water mimosa plots, a new ornamental fish farm (Figure 20), and concrete tanks had started up on the former aquatic plant plots.

We spoke to one of the remaining water mimosa growers, Mr Anh Bay (Figure 21), who was 38 years old, born locally and married with two children. Anh Bay had been cultivating aquatic plants on the site for 20 years. He took us to his nearby shop and house where a team of eight women were processing water mimosa and water spinach for the market. Anh Bay and his wife had also been buying and selling mimosa from other growers for the past five years. He said that, after a first period as a tenant, he had been able to buy his own acre of land, where he grew aquatic plants. The property was then divided up into 10 plots, each one 1 000 m^2, with a relatively new water supply channel built directly from the Saigon River, 3 km away. This allowed him and the remaining growers to mix water from the river and wastewater to obtain the necessary quality for the growth of water mimosa. He added that the water quality was much better than ten years ago. Unlike ten years ago, he uses inorganic fertilizer in all ten ponds, and sprays to remove insect pests at least once in a 25–30 day production cycle. To process and pack the aquatic plants in his shop he had employed eight women, four days per week (Figure 22). On average, of his whole water mimosa production, 70 percent is destined to wholesale markets and 30 percent directly to restaurants and canteens every two days. A small truck is used to transport the processed food. Anh Bay's wife works nights, from midnight to 5 a.m., five days a week. After she sells the plants at one of the wholesale markets, she returns to sleep and then helps her husband in the afternoons with the work on the plots. He works full time on the plots, and he was not willing to tell us how much he is earning from the sales of his and others' aquatic plants. Anh Bay told us that he thought the market for edible aquatic plants in Ho Chi Minh City was buoyant and that in the future, if he ended up getting moved off his land, he would continue in this sector by using the compensation money to rent land outside the city. At the time of this interview, he was considering new contracts with two supermarket chains with whom he had been in contact for regular supply contracts.

Figure 22: Processing of water mimosa ready for sale at Anh Bay's shop. Photo courtesy of William Leschen.

Figure 21: Interviewing entrepreneurial Anh Bay, aquatic plant grower and trader, Binh Chanh district. Photo courtesy of William Leschen.

Figure 20: New ornamental fish farm set up on former aquatic plant cultivated land. Binh Chanh district, Ho Chi Minh City. Note the residential construction ongoing in the background. Photo courtesy of William Leschen.

Through Anh Bay we obtained the telephone number of Minh Thuy and were able to interview her. She was living with her family in a small, rented flat over her new hairdressing business in a retail area of Binh Chanh. Her two children were still living at home. Her husband continued to work in the docks, although in a more administrative post. In partnership with another woman, she had set up a small hairdressing business, a rented shop, which contributed 30 percent of their total household income.

Reflecting on the gradual demise of the aquatic plant culture in the area where Minh Thuy had previously lived, she noted that she had been able to draw a good income from growing water spinach. This income allowed her to send her children to school and her daughter to college; she also used part of the income to invest in the hairdressing shop, which had always been one of her dreams. Of the future of FAM production in cities, she said that the presence of green areas within cities is always good and that some areas should be set aside for the establishment of nature parks, where aquatic plant and fish cultivation are practised. Together with her neighbours, she had always struggled to receive help or technical advice about FAMs from any of the different government agriculture or advisory services, and suggested that it would be beneficial for the government to set up a new body specifically dedicated to urban food production.

1.6.3 Phan Kim – Tam Phu Commune, Thu Duc district, Ho Chi Minh City, Viet Nam

1.6.3.1 Phan Kim (2004)

Figure 23: Phan Kim with his water mimosa fields, Thu Duc district, Ho Chi Minh City. Note that another aquatic macrophyte, duckweed *Lemna* sp., was grown in conjunction with water mimosa. Photo courtesy of William Leschen.

In 2004, Phan Kim (Figure 23) was 42 years old and married with one daughter. He was born, and grew up, in Bac Giang province, in northern Viet Nam, where he started to work as a rice farmer and also farmed some fish and pigs. In 1987, he and his wife moved to Ho Chi Minh City to find work and increase their income. He had heard that, in the south, the government had opened up more opportunities for people to own or lease land. He also found out that Ho Chi Minh City municipal authorities had kept areas aside for agricultural farming in certain districts. After a few months, he rented a 1 000 m^2 plot in Tam Phu commune, a government-owned area that was beginning to switch from rice to aquatic plant cultivation. Little equipment was needed to start the venture, initially shovels and spades and a portable petrol water pump. He and his family modified the rice dykes to create two plots of 500 m^2, in which they began to cultivate water mimosa to sell in a nearby wholesale market. Although in the early years the work was hard, they learned from a number of mistakes, such as overfertilization with urea or excessive addition of wastewater into the plots during the dry season, both of which caused significant plant losses. By the early 1990s, he rented an adjacent field of 7 000 m^2. This was labour intensive. In 2004, the family's income was VND 50 million (USD 3 250) per year, mainly from the sale and production of water mimosa. From this income, Phan Kim was able to buy a residential plot and build a new house. He had no major problems growing water mimosa, and thought that the plant had provided him and his family with a steady income. He wished that there could be greater price stability in the wholesale market sector, as prices tended to fluctuate considerably, affecting their cash flow and margins at certain times of the year.

Figure 24: Water mimosa transported by motorbike at Thu Duc district wholesale market. Photo courtesy of William Leschen.

1.6.3.2 Phan Kim (2016)

In 2016, Phan Kim was still involved in aquatic plant production. He produced water mimosa and some water spinach from his original plots. Additionally, two years prior, he started to culture ornamental fish in ponds. Kim also employed an ex-army driver to transport both the harvested fresh plants and ornamental fish for selling on either a motorbike (Figure 24) or in a hired small truck. When asked about what had been the major changes in FAM production in the past 10–12 years, Kim said that in some of the neighbouring districts, the cultivation had declined due to land pressures. However, the price or demand in city markets had not been affected since new farmers had begun to produce at commercial scale, providing a regular supply of fresh products into the city, but undercutting the prices of the previously established growers. The intrusion of brackish groundwater was increasingly causing cultivation problems. He suggested that the government and scientists should be working on producing saline-tolerant water mimosa and water spinach plants, which he thought would greatly benefit aquatic plant growers and could potentially improve the taste of the plants for consumers. He also noted that the majority of growers, including himself, were now using more inorganic fertilizers and less wastewater in order to increase productivity per plot. Although this meant higher input costs, Kim said that he and others were now achieving faster growth, harvesting water mimosa on average every 25 days rather than every 30 days when he started back in the 1990s. In the future, he said that the introduction of some forms of mechanization production and processing would further lower their costs, and potentially the prices of the finished products. He also stated that competition and pressure on water availability for agriculture was going to increase in peri-urban areas; and that solar water pumping would allow a greater flow of water in the systems, resulting in higher productivities per unit area, possibly completing recirculation.

1.6.4 Boengchueng Congdoen – Sainoi district, Nonthaburi province, Bangkok, Thailand

1.6.4.1 Boengchueng Congdoen (2004)

Figure 25: Boengchueng Congdoen packing water spinach for Talat Thai wholesale market, Bangkok. In the background, a chemical-free water spinach trial for the PAPUSSA project. Photo courtesy of William Leschen.

In 2004, Mr Boengchueng Congdoen (Figure 25) was 51 years old. He was born in Pathumthani province, 45 km from Bangkok. After finishing high school, he attended a local agricultural college, where he gained an interest in and a passion for horticulture and growing vegetables. After leaving, he worked in northeast Thailand as a lorry driver, delivering fertilizers and other farm inputs. In 1978, he returned to the Bangkok area to work on a seasonal fruit and vegetable farm in Nonthaburi province. He started to work as a supervisor by the mid-1980s; he got married and bought his first house with a small adjoining plot where he grew vegetables. In 1987, he was able to obtain a 10-year lease on a further 3 hectares of rice paddy land close to his house, and began to grow vegetables such as tomatoes, chilies and okra on a converted area of 0.5 ha. He and his wife then grew the vegetables part time, employing one other person to help them. The vegetables were sold directly to local markets, and he was responsible for the marketing, transport and sales. With the income, after a few years he was able to buy a pick-up vehicle, which broadened his sales networks and access to other buyers. In 1990, he decided to leave his farm supervisor job to work full time on his own vegetable business, which was thriving. In the last year, he had seen the beginnings of FAM cultivation in neighbouring Pathumthani province, in particular water spinach in the irrigation canals, and water mimosa and water lotus in shallow plots converted from rice fields. Therefore, he decided to convert his remaining 2 ha of land to the cultivation of aquatic plants. By 1993, he was employing eight people on FAM cultivation, and his income was twice that of land vegetable production. His production system for aquatic plants was based on using water from one of Bangkok's irrigation canals. The water flowing through these canals, although not considered wastewater, contained nutrients from runoff from the surrounding agricultural land. From the early 1990s up to 2004, when he was interviewed for PAPUSSA project, he steadily intensified production through increasing levels of inputs, including fertilizer and sprays to control pests. His annual production of water spinach increased from about 20 tonnes/ha (wet weight) to over 70 tonnes/ha by 2004. At this time, he was transporting and selling up to 2 tonnes (wet weight) of water spinach and water mimosa per week in Talat Thai market (Figures 26 and 27). Boengchueng Congdoen estimated that this market received and sold between 80 and 100 tonnes of FAMs every day, mainly water spinach, water mimosa and lotus, at an approximate value of USD 35 000/year. When asked about the future of FAM cultivation in and around Bangkok, he expressed the view that growing market demand would ensure people like him could continue to profitably produce. However, he was concerned about the continuing expansion of the city, and the inevitable disappearance of agricultural land. He thought that the increasing influence of supermarkets, some of which he had contracts with to sell vegetables and aquatic plants, would address consumer pressure to see more chemical-free, healthier, organic vegetables. In the last few years, he had started to trial chemical-free land vegetable production, which, although having lower yields, could command premium prices in the larger Bangkok supermarkets.

Figure 26: Harvesting water spinach, Nongpraongai village, Nonthaburi province. Photo courtesy of William Leschen.

Figure 27: Collection point and transport of water spinach to wholesale markets, Sainoi district, Nonthaburi province, peri-urban Bangkok. Photo courtesy of William Leschen.

1.6.4.2 Boengchueng Congdoen (2016)

In 2016, when we contacted Boengchueng Congdoen by telephone, he had semi-retired due to ill health, handing over his farming business to one of his daughters. The original 3 hectares of land had been reduced to 1 hectare. Indeed, he sold 2 hectares in 2014 after receiving a good offer, and that land had now become a residential housing estate. He said that the cultivation of aquatic plants around Bangkok had intensified, and had become more specialized than when he had started in the 1990s. He had heard of much larger farms of 10–15 ha, further out of the city, that were using tractors and mechanical sprayers to produce water spinach at a lower cost. Furthermore, he had also heard that a number of different varieties of water spinach were commercially available. These varieties had higher yields and allowed growers to test them under different growing conditions. When he was asked about his health, Boengchueng Congdoen said that he increasingly suffered from respiratory problems, which he felt might have been caused by the prolonged use of sprays and the different chemicals during the years he spent working in the horticulture sector. He added that his daughter was now cultivating chemical-free land vegetables and organic water spinach. However, these were still niche products, probably representing less than 10 percent of his daughter's total sales.

1.7 Discussion and conclusions

This review primarily focuses on the few FAM species which have been cultivated across South and Southeast Asia over the centuries and used as aquatic vegetables, as well as for bioremediation, water treatment and construction materials. Despite a significant population directly or indirectly involved in FAM production, there is little scientific or grey literature that focuses on its scale and importance. There are few specialized government departments or research institutes involved in this cultivation. The successes and impacts of FAM production are often underreported, potentially due to their simple, fast vegetative growth and low start-up cost production cycles, which are relatively risk averse. FAMs can be produced close to large urban centres, and are known to be able to treat and recycle nutrients from urban wastewater. Other than land, water and nutrient inputs, FAMs require few expensive inputs or complicated technical management. There is a large, growing market for relatively cheap and nutritious fresh green-leaf products across the region.

With the possible exception of water spinach, there have been few developments in genetic improvement. It is known, however, that translocation of FAMs, including internationally, is relatively common. The varieties that farmers have been using over the past 50-100 years, for species including water mimosa, have sufficient growth rates and productivity for farmers to make a living from their cultivation. However, in recent years, FAM production has intensified and continues to intensify, and there are increasing environmental challenges facing the peri-urban environments in which they are grown. These challenges include the industrial contamination of wastewater, pests and the salinization of water tables. These factors are drivers for research into faster growing varieties, as well as for pollution, salinity and pest resistance. Likewise, comparative research trials using different varieties of a FAM species have clearly shown a differential in their capabilities for bioremediation and water treatment.

Considering the lack of technical support for aquatic plant growers across the region, especially from governments and academia, any effort for varietal improvement will need to be built in access pathways for farmers. Currently, the private sectors of China and Thailand, as well as international vegetable research institutes, invest in funds to develop better varieties of water spinach. It is hoped that, in future, the importance of good seed stock will be recognized, allowing the continuation of profitable FAM production, and to increase food production for urban populations in new and existing locations under changing environmental and socio-economic conditions.

Over the past 30 years, key findings from the above case studies demonstrate the transitory nature of FAM production, as some peri-urban production sites have disappeared as a result of urban development. Viet Nam has set some legislation to support FAM production. Government urban planners have designated green belts or areas in which agriculture and environmental developments can continue while being protected from further urban construction. These areas include Thu Duc and District 11 in Ho Chi Minh City. FAM production, especially of water mimosa and water water spinach, still flourishes there in 2016, despite the tendency of production areas to radiate to the peripheries of cities. Land is more affordable on the outskirts of cities, and good transport links allow plants to be harvested and sold fresh in urban markets within a few hours, or to be processed and packed for sale to the increasing number of supermarkets.

This review demonstrates the importance of nutrient sources in sustainable FAM production. In urban contexts, nutrients are often provided by wastewater. As wastewater-based systems have evolved alongside urbanization, productivity has reduced because of higher concentrations of industrial contaminants in the wastewater. Younger, better-informed urban populations have had increasing health concerns as a result. This evidence clearly shows that FAM production, while having to move further out of cities, has been intensifying and is becoming less reliant on wastewater, and inorganic fertilizer inputs are increasing.

Certain FAM species lend themselves to mass production, providing livelihoods for thousands and a nutritious and cheap food source for millions living in urban areas. However, it is uncertain how production systems will change in the future.

FAM production has been recorded for the past 2 000 years, yet their commercial production in South and Southeast Asia has only taken place somewhere between 30 and 40 years. Some FAMs represent a relatively young food production system, but their value chain is likely to develop in future. It is hoped that the research, development and the private sector will see the potential for FAM production, and will look to identify further species that could be candidates for commercial production.

In conclusion, there is considerable potential for FAM production systems in tropical and temperate developing countries where wastewater is freely available, and this production can be both financially and environmentally sustainable. Key stakeholders, including urban planners, occupational health and food safety researchers, aquaculturalists, agriculturalists, farmers and market chains, need to cooperate to develop sustainable integrated workable models and associated budgeted plans, which can potentially be taken up by new cities and peri-urban areas. It seems likely that, as FAM production expands and intensifies, there will be growing incentives for the development of varieties specifically adapted to culture systems and environments.

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2. SECOND REGIONAL REVIEW

Authors: Dr Meng Shunlong, Dr Jing Xiaojun

Institution: Freshwater Fisheries Research Center of the Chinese Academy of Fishery Sciences

2.1 Introduction

Freshwater aquatic macrophytes (FAMs) are freshwater plants that can produce seeds, roots, leaves and flowers, and valued as food, medicines, fibrous material, and for aesthetic and cultural reasons. Examples of their cultivation and significance can be found globally.

Aquatic vegetables, a group of freshwater macrophytes used as food, are primarily cultivated in southern China. They are highly nutritious, rich in dietary fibre and phytochemicals, and have unique flavours. In China, more than 10 FAM species are commercially produced for consumption; this is an economically important industry.

Lotus (*Nelumbo nucifera*) roots and seeds and water bamboo (*Zizania latifolia*) stems are examples of the edible parts of FAMs. Many of these parts can be used as functional medicines, such as lotus root (*N. nucifera*), water bamboo (*Z. latifolia*), arrowhead (*Sagittaria sagittifolia*), water dropwort (*Oenanthe stolonifera*), water caltrop (*Trapa spinose*), water chestnut (*Eleocharis tuberose*), cordon euryale (*Euryale ferox*), common cattail (*Typha latifolia*), water shield (*Brasenia schreberi*), and watercress (*Nasturium officinale*).

Freshwater macrophytes are an important part of wetland ecosystems and contribute greatly to the environment and economies of many countries. FAMs utilize the nutrients and minerals found in water, helping to prevent eutrophication and the salinization of soil, and can improve the water quality in intensive fish farming ponds. In this way, they may improve the efficiency of land resource utilization and management. In addition, FAMs have aesthetic, cultural or religious significance and contribute to the attractiveness of aquatic landscapes.

In many countries, such as China and India, freshwater macrophytes have proved to be important commercial products, which can support poverty alleviation and social welfare when produced locally as vegetables. Several varieties have been developed for different species. In India, it was reported that 1–3 percent of people, usually those living below the poverty line, rely on the aquatic plants for food. In 2016, in China, the area used for aquatic vegetable production was more than 8 million ha (Table 1), with a production value of USD 8.68 billion.

This paper reviews issues around the culture of FAM genetic resources with emphasis on China, which has a long history of FAM culture and produces large volumes of FAMs.

Table 1: Area and production of major freshwater aquatic macrophytes in China, 2016

Species	Estimated culture area (ha)	Major producer region	Production (kg/ha)	Price (USD/kg)	Value (USD/ha)
Lotus root *(Nelumbo nucifera)*	400 000	Hubei, Henan, Shandong, Shanxi, Sichuan	167–233	3–6	977
Lotus seed *(Nelumbo nucifera)*	135 000	Hubei, Jiangxi, Hunan, Fujian, Zhejiang	3–7	1	8
Water bamboo *(Zizania latifolia)*	73 300	Zhejiang, Jiangsu, Anhui, Jiangxi, Hubei	300	0.40–0.47	132
Taro *(Colocasia esculenta)*	53 300	Shandong, Guangxi, Yunnan, Hubei, Hunan, Jiangxi	100–167	0.14–0.2	31
Chinese water chestnut *(Eleocharis dulcis)*	50 000	Guangxi, Hubei, Anhui, Zhejiang	73	0.6–0.9	54
Pennywort *(Oenanthe javanica)*	26 700	Jiangsu, Jiangxi, Zhejiang, Guangdong	233	0.23	55
Gorgon nut *(Euryale ferox)*	10 000	Jiangsu, Fujian, Shandong	13	4–4.4	56
Arrowhead *(Sagittaria subulata)*	6 700	Jiangsu, Guangdong	200	0.4–0.7	98
Other species	2753				
Total production area (ha)	800 000		Total production value (USD)		USD 8 billion

Source: Data gathered by the authors in 2017.

In China, FAMs have recently been established in rivers, lakes and wetlands in part to enhance their aesthetic value. The commercial production of economically viable species in wetlands has also increased and these "aquatic vegetables" have been grown to improve people's livelihoods. FAMs have also been planted for environmental rehabilitation, including water purification and the protection of soil, and for improving biodiversity. They have also been promoted as useful tools in agriculture structure modification, helping to improve rural economic development in some areas of China.

FAM genetic resources should be conserved while their culture models and processing technologies are improved. Urbanization has reduced the area available for FAM cultivation. Water pollution has caused degradation of growing areas. Overexploitation of economic aquatic plants has led to the extinction of some species. The unregulated distribution of aquatic plants across regions and areas and poor management has caused, in some cases, inbreeding and crossbreeding. This has diluted genetic variability and led to disease outbreaks. Few varieties have been developed for improved yields.

China has established a national network of more than 30 research institutes for the study and collection of genetic resources important for agriculture. The programme for varietal improvement has made some significant progress towards increasing production volumes, streamlining harvesting and improving the quality of the product. Local technical extension offices, farmers' cooperatives and the private sector have disseminated technology. Research and technology transfer has contributed to the success of Chinese commercial FAM production.

In China, before the 1980s, there were no improved varieties for FAM species used as aquatic vegetables. Wild varieties dominated cultivation. From the 1980s, demand for lotus and water bamboo increased, so genetic improvement programmes were launched to increase yields. Many new varieties were created to satisfy farmer and consumer demand. In 2017, there were at least 160 registered varieties of the ten selectively bred, commercially important species. These have greatly contributed to the development of the aquatic vegetable production sector. Table 2 shows a selection of these registered varieties from Jiangsu province, along with the institute responsible for their development. Generally, the improved varieties have high productivity, are suitable for large-scale industrial cultivation, have high-quality seeds, and exhibit uniform growth, making standard harvesting and processing more efficient.

Aquatic vegetable production data from the years up to and including 2017 have shown that yield has increased, as well as the area used for their production. Additional drivers include the ecological and economic benefits of alternating wet and dry crop production. Many processed aquatic vegetable products are exported globally, especially to regions with significant Chinese populations. Barriers to further aquatic vegetable production include a limited number of available species and varieties, as well as a need for the development of further cultivation and processing techniques. Further development is also held back by poor market information and a lack of consumer acceptance outside of China.

Table 2: List of new varieties of freshwater aquatic macrophytes registered in Jiangsu province

Freshwater aquatic macrophyte	Name	Year of registration	Institute
Lotus *(Nelumbo nucifera)*	Chuixiu	2012	Yangzhou University
	Chuijia	2012	Yangzhou University
Pennywort *(Oenanthe javanica)*	Fuqin No. 1	2010	Yangzhou University
	Qiuqin No. 1	2010	Yangzhou University
	Chunhui	2012	Yangzhou University
	Suqinza No. 5	2012	Suzhou Institute for Vegetables
Arrowhead *(Sagittaria subulata)*	Zijinxing	2012	Yangzhou University
	Ciyu	2012	Yangzhou University
Gorgon nut *(Euryale ferox)*	Gusuqian No. 1	2012	Suzhou Institute for Vegetables
	Gusuqian No. 2	2012	Suzhou Institute for Vegetables
Chinese water chestnut *(Eleocharis dulcis)*	Hongbaoshi	2012	Yangzhou University
	Hongbaoyu	2012	Yangzhou University

Source: Zhang Yuming and Li Liangjun (2016).

2.2 General description of freshwater aquatic macrophytes

Aquatic macrophytes can be physically attached to the bottom and emerge from the water, float on the surface, or be completely submerged for at least part of their reproductive cycle (Chen, 2012). Aquatic plants can be both small and large, ranging from phytoplankton to lotus, arrowheads and reeds. These plants grow in both freshwater and saline water. Large aquatic plants are higher plant groups that can be either partially or fully submerged or float above the water. This mode of growth may vary throughout the year. They include flowering plants (angiosperms), ferns and bryophytes, as well as macroalgae. Aquatic plants that grow in freshwater environments, such as ponds, lakes and ditches, are generally referred to as FAMs (Hu, 1984), the focus of this thematic study.

2.2.1 Morphological characteristics of large aquatic plants

Large aquatic plants are adapted to their environment, exhibiting different morphological characteristics, growth habits and physiological functions to terrestrial plants. They are a convergent adaptive phenotype formed by long-term adaptation of different taxa to the aquatic environment. Some of these adaptations include roots, which are generally underdeveloped or completely disappeared; underdeveloped vascular bundles and mechanical tissues; ventilated tissues and drainage organs with strong gas exchange functionality; vegetative reproduction; and pollination specificity.

Aquatic plants have particularly well developed intercellular spaces, and often contain special aeration tissues to ensure sufficient gas exchange in submerged parts. The ventilation of aquatic plants falls into two categories, open and closed. Ventilation of plants including lotus is open-ended. Air enters the stomata of the leaves, passes through stem tissues, and enters air chambers in the underground stem and roots. All of the plant tissues can directly exchange gases with the outside air through stoma. Plants that have closed ventilation, including algae, have underwater tissues that cannot directly exchange gases with the air. Instead, gas exchange must be done within the aquatic environment, and gases, including oxygen from photosynthesis and carbon dioxide from respiration, are stored.

Aquatic plants generally have a greater leaf area than similarly sized terrestrial plants, with a weak or absent epidermis. When the epidermis is present, there are no stomata on the submerged side and a high number of stomata on the dry side of floating leaves. Foliar assimilation in submerged water does not show any differentiation between palisade and sponge tissues. These characteristics of aquatic plant leaves are adaptions to the reduced light and lower oxygen content of the aquatic environment. The leaves of submerged aquatic plants are often split into bands or filaments to increase the absorption of light, carbon dioxide and inorganic salts, as well as to resist damage from currents or waves. Water bamboo has two types of leaves. Its leaves on the water surface perform photosynthesis; its submerged leaves, which are strong and split, can absorb inorganic salts.

One adaptation to aquatic environments is that the mechanical tissues within the stems of plants living in still water, or in slow-moving bodies of water, almost completely disappear. The root system is very weak, in some cases absent, mainly because submerged leaves absorb nutrients instead of roots. FAMs, including water hyacinth (*Eichornia crassipes*), exhibit strong vegetative reproduction and can be prolific. Other plants rely on water for pollination, even if they can reproduce vegetativly, such as *Vallisneria spiralis.*

2.2.2 Classification of large aquatic plants

Globally, about 33 families, 124 genera and 1 022 species of large aquatic vascular plants are reported (Hu, 1984). They are usually classified as emergent, floating or submerged plants (Chen, 2012).

Emergent macrophytes are plants that have roots or underground stems that grow the sediment, with their upper parts above the waterline. These plants are relatively tall and tend to have large roots in order to support the upper plant body, and have hollow stems, or petioles, to facilitate gas exchange in the roots and rhizomes. Parts exposed to the air have similar characteristics to terrestrial plants, while submerged parts have hydrophyte characteristics. They are often distributed in shallow water, not exceeding a depth of 1.5 m, and are generally found in rivers, lakes, reservoirs and ponds, or growing in beach wetlands and swamps. Common species include reeds, water chestnuts, lotus, cress and cattails.

Floating macrophytes, also known as fully floating plants, do not grow in the sediment. The entire plants float on the surface. These plants usually have underdeveloped roots, well-developed ventilation organization, or have an enlarged petiole, or balloon, to facilitate gas exchange with the air. The plant body floats above the water, and drifts with the wind and waves. Most are foliage-oriented, providing the waterbody with decoration and shade. Floating leaves shield the sun's rays from the water, inhibiting phytoplankton growth. Floating plants grow very fast, quickly providing surface cover. Some species grow and reproduce rapidly and have no valuable use. Some are ecological nuisances and may need to be regularly removed. Common types include *Azolla* spp. and the water hyacinth (*Eichhornia crassipes*).

Floating-leaved macrophytes, known as raw floating plants, have roots that are attached to the sediment, with leaves floating on the surface. These plants have pliable, elongated petioles or stems in order to adapt to the wind and waves. The stomata are usually found on the upper surface of the leaves, with no or very few stomata on the lower surface. They usually have waxy leaves and have high transpiration rates. Most have open ventilation systems; submerged tissues benefit from the porosity of floating organs, reducing the potential for hypoxia. Common floating plants include *Nelumbo nucifera*, *Nymphaea tetragona*, *Hydrocharis asiatica* and *Nymphoides peitatum*.

Submersed, or submerged, macrophytes are plants that grow completely immersed in water and are rooted in the sediment. The attenuation of sunlight in water, and reduced potential for gas exchange, limit their growth. Thus, these plants have highly developed ventilation mechanisms, with a large air cavity which is conducive to gas exchange, and more finely split leaves for a larger photosynthetic surface area, but also to resist the damage that may result from water flow. Plants are green or brown, depending on the need to absorb the weaker light available underwater. Common submerged macrophytes include foxtail algae and plants belonging to the genera *Hydrilla* and *Elodea*.

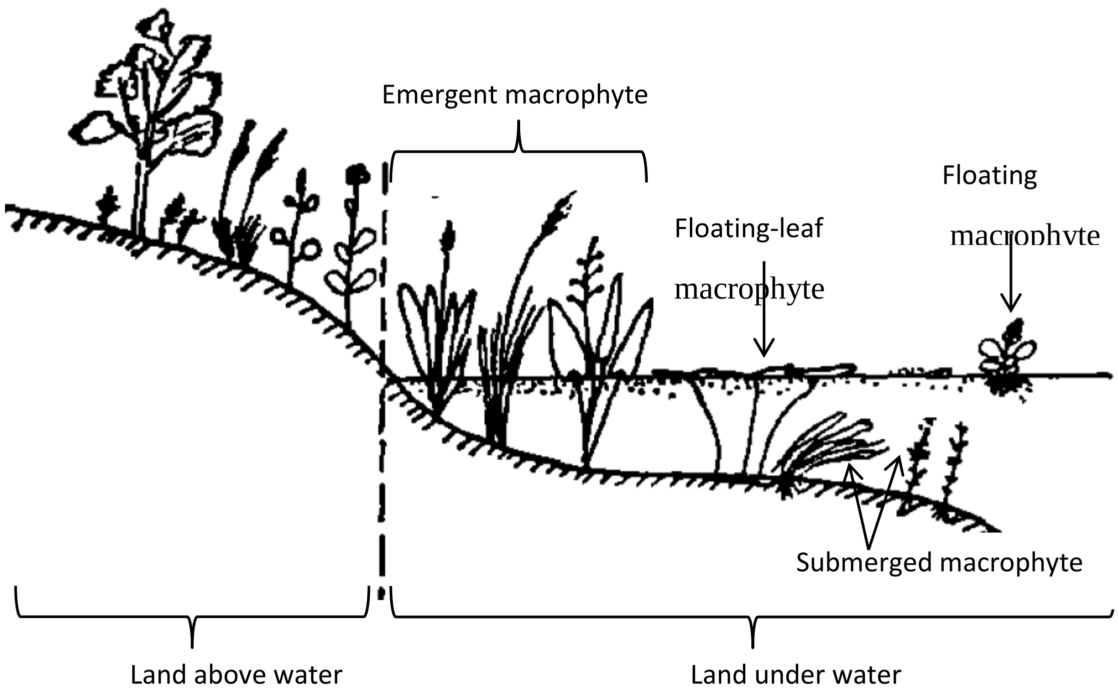

Figure 1: Common groupings of aquatic macrophytes based on where they grow in the water

2.3 Main farmed species and varieties: uses, farming systems, producer countries, trends in production and future prospects

Many FAMs are economically valuable and can be used for food, fibrous material or to provide ecosystem services. Though many species are collected from the wild, farmed aquatic plants are artificially cultivated. Among them, aquatic vegetables have a high demand and a long cultivation history. China has the largest aquatic vegetable planting area and yield, accounting for more than 80 percent of the world's total production.

2.3.1 Lotus (Nelumbo nucifera)

Lotus (*Nelumbo nucifera*) is a perennial aquatic plant, which has usable roots, flowers and seeds. The seeds and underground stem, either fresh or dried, can and are widely used in China for their reported medicinal functions (Pan, 2007).

Lotus has the largest cultivated area among Chinese aquatic vegetables, approximately 400 000 ha. Lotus production in Hubei province accounts for roughly 80 000 ha. In recent years, lotus culture has rapidly developed in provinces, including Sichuan, Shanxi, Shandong, and elsewhere along the Yellow River basin and Western China, with more than 13 300 ha used.

Lotus lives in relatively calm, stagnant water. Their cultivation environment, varieties and growth period vary with scale of culture and water quality and quantity. Lotus grows well in ponds, lakes and rivers with a depth of 1.0–1.2 m. When water depth exceeds 1.5 m, the plant has a greater risk of mortality and is highly dependent on its floating leaves. When water depth exceeds 1.8 m, most lotus species cannot survive.

Early life stages should be cultivated in shallow water. Once leaves stand out of water, the water level can be increased accordingly. Lotus is a sun-loving plant; it grows and develops rapidly under full exposure, blooming earlier compared with those grown in the shade. The optimal temperature suitable for lotus growth is 22–32 ℃. Lotus is readily adaptable to changing growth conditions, but grows best in slightly acidic, highly organic soil.

Lotus originated in India, and is now distributed across five continents. It is mainly cultivated in China, India, Japan, Republic of Korea, the Russian Federation, Viet Nam, the United States of America, and Europe. Lotus is the most commonly produced Chinese aquatic vegetable. It is mainly produced in Jiangsu, Zhejiang, Hubei, Shandong, Henan, Hebei and Guangdong provinces and elsewhere along the Yangtze River and Pearl River basin. Traditional pond cultivation produces average annual yields of 30 000–37 500 kg/ha.

There are many famous Chinese lotus varieties, selected for both quality and taste. Varieties include Baoying lotus root; Jinhu lotus root of Jiangsu province; Linyi lotus root of Shandong province; Cizhou white lotus root of Hebei province; and Jian lotus of Fujian province. Roots, seeds and flowers are typically harvested from lotus plants, and the characteristics of these parts drive selection. Ornamental varieties are grown for their flower and produce almost no seed. During cold winter months, harvesting lotus root is difficult and labour intensive, and this led to a demand for easy-harvest varieties.

In recent years, there has been an increasing demand for lotus root and its products, and the cultivation area has therefore expanded to meet the Chinese agriculture structure modification policy. In some counties, lotus production has become one of the pillars of their agriculture. For example, Jianning County of Fujian province farms Jian lotus over an area of 3 000 ha. The annual production of lotus seed is above 4 000 tonnes, worth more than USD 88 million, USD 20 million of which was produced for export. Most of the lotus cultivated for export is produced in Jianning County.

At present, the farmer's organization for the development of the Chinese lotus industry is requesting further innovations in farming technology. In response to these demands, local governments have set policies to standardize production technology, ensure the high quality of products, and improve brand development. This provides economic and environmental benefits to rural communities. Key stakeholders in the lotus industry include private enterprises, farmers' professional cooperatives, colleges and universities, research institutes and consumers. The development of new varieties and technologies were prioritized. In the lotus blossom season, tourism is well integrated, combining leisure, sightseeing and catering for rural communities.

2.3.2 Water bamboo (Zizania latifolia)

Water bamboo (*Zizania latifolia*), also known as wild rice, is a perennial native to China. The plant height is 1.6–2 m and has five to eight leaves, comprising of blades and sheathes. The leaf blade is attached to the leaf sheath and has a triangular pulvinus. The leaf sheath extends to the ground and forms a false stem. Water bamboo is parasitized by the black smut fungus (*Ustilago esculenta*), whose mycelium grows within the plant stem. In response, the stem becomes bigger and tender. It is a traditional, delicious and highly nutritious aquatic vegetable popular in China.

There are two varieties of water bamboo, selected for either autumn or autumn/summer harvest. Water bamboo growth can be divided into four stages:

- The budding stage: the plant begins to sprout once the diurnal low temperature is above °5 C, with optimal growth at this stage occurring at 10–20 °C.
- The tillering stage: from late April until the end of August, every plant undergoes tillering and can be extended to more than 10–20 plants. The optimum temperature at this stage is 20–30 °C.
- Stem swelling stage: stem swells from early June to late June, and again in late August to late September, while the one harvest season variety only swell in late August and early September; the optimum temperature is 15–25 °C. The stem will not swell when the temperature is below 10 °C or above 30 °C.

- Growth stagnation and dormancy stage: after swelling, when the temperature is below 15 °C, the tillers and the parts below ground stop growing, and when the temperature is below 5 °C, the parts above ground will die, while underground parts over-winter in the soil (Li, 1998).

Water bamboo can be found across Asia, Europe and the Russian Federation. It has been used as a vegetable for centuries.

In China, water bamboo is cultivated across 73 300 hectares, 50 percent of which are in Zhejiang province. Huangyan, Jinyun, Yuyao and Tongxiang make up the main producing areas in China. Panan County in Zhejiang is the "county for water bamboo cultivated on high mountains", where the planting area is about 1 400 ha, with a total annual output exceeding 40 000 tonnes and a production value of about USD 18 million, providing a major source of income for nearly 11 000 people. It is reported that production efficiency and output of water bamboo is much higher than that of rice. Therefore, increasing numbers of farmers grow water bamboo instead of the traditional rice in the paddy fields.

Developmental trends in the water bamboo industry include product quality improvement, the gradual establishment of supervisory systems, and improvement in capacity for preservation and processing; these can increase the added value of products as well as production efficiency. Further value may be added by developing models of integrated cultivation, by combining water bamboo and vegetable production, paddy-land rotation and bamboo-fish cultivation systems. In addition, the water bamboo industry may be integrated with leisure sightseeing and enhance the ecological-tourism business model.

2.3.3 Arrowhead (Sagittaria trifolia)

Arrowhead (*Sagittaria trifolia*) is a perennial herb and famous in China. The plants are tall and leafy with many roots at the base. Slender stolons are borne near the roots, and branches become bulbs at the end of autumn, with a diameter of 3 cm. The leaf blade is wide and arrow-shaped, 20–30 cm long, with longer left and right lobes on either side of the leaf base than the central slice. The petiole is stout and 50–80 cm long. The inflorescence is cone-shaped (Pan, 2007). It has high economic value. Its underground bulb is used as a vegetable and has medicinal properties. Arrowhead products contain a variety of secondary alkaloids, which are used to cure respiratory and cardiovascular system diseases. The products are sold internationally, sold fresh, or processed for exportation. Processed forms include fried pottage film in typical flavours, or snacks, which are popular in Japan and other countries.

Arrowhead is highly adaptable. It grows well in shallow waterbodies, but requires sufficient sunshine, a mild climate, leeward exposure and fertile soil. It should be planted in well-irrigated fields with deep, rich soil. There are many reports on their intensive production in rice paddies. The growth period of arrowhead is generally divided into the following three stages:

- Germination period: the germination temperature of sprouted green shoots is 14 °C, bulb crown scales open, and one or two leaves are produced. During this period, the bulbs store nutrients to maintain growth. The water should be 3 cm deep; shallow water has a higher water temperature and promotes faster growth.

- Plant growth period: the plant develops the typical arrow-leaf shape and the bulbs expand. New leaves will develop every 7–10 days, or even faster when the average temperature is 25–28 °C. When the plant has seven large leaves, the underground stem becomes a stolon. During this period, plants grow rapidly given that the nutrient and water supply is adequate. The water level, 10–15 cm, should be appropriately increased, as to avoid overly rapid vegetative growth which may delay the formation of the bulb.

- Bulb forming period: the bulb begins to expand and takes about 30 days to reach harvest size. During this period, the photosynthetic products are transferred and accumulated at the stolon and form the bulb's most nutrient-rich parts.

Arrowhead is mainly cultivated in Jiangsu, Zhejiang, Guangdong and Guangxi, with a total cultivation area of 66 700 ha, primarily situated in Baoying of Jiangsu province and Liuzhou of Guangxi province. The average annual yield is around 100 kg/ha.

The arrowhead is native to China, and is distributed throughout Asia, Europe and the temperate and tropical regions of Africa. In Europe, it is mostly used as an ornamental plant, and in China, India, Japan and the Republic of Korea it is used as a vegetable. The cultivation area of arrowhead in China predominantly occurs within the Yangtze River basin and its southern provinces, the Lake Taihu shore area and the Pearl River delta region. There is a limited area for cultivation in northern China. The common cultured varieties of arrowhead are Chinese, Japanese and American types.

In recent years, there has been continual development of arrowhead processing technology and products to meet increased demand from Japan. The planting area has rapidly expanded in China. Baoying County of Jiangsu province is known as the "county of arrowhead in China", with a planting area of about 6 700 ha, total annual production of about 100 000 tonnes, and a total production value of about USD 37 million.

There has been little scientific and technological support for the development of industrial arrowhead production, with few standardized production methods and limited marketing. Breeding technology for selected varieties, the introduction of new varieties, a unified seedling supply network, and a standardized production model should be enhanced to provide support for sustainable development. Recognizing this need, the government has put supportive policies in place to guide and support entrepreneurship and business development for arrowhead, as well as the integration of ecological model development in communities.

2.3.4 Water chestnut (Eleocharis dulcis)

In China, the term water chestnut refers to the Chinese water chestnut (*Eleocharis dulcis*), eaten for its crisp corm, but is also sometimes used for the water caltrop (*Trapa natans*), eaten for its starchy seed. Water chestnut (*E. dulcis*) is an annual aquatic grass. When tender, the nut can be eaten raw. The ripe nut can be cooked or processed into various forms. When dried, it can be stored for extended periods. The tender stems can be used as vegetables, and the leaf can be used as green fodder or manure. It also has a medicinal function.

In total, 50 000 ha are used for water chestnut cultivation in China, 20 000 ha of which occur in Guangxi province, accounting for 40 percent of production. Water chestnut is a traditional aquatic vegetable cultured in the middle and lower reaches of the Yangtze River, in regions including Jiaxing of Zhejiang province, Jiangyan of Jiangsu province, and Hanchuan, Caidian, Jiangxia and Honghu of Hubei province.

Water chestnut is grown in regions with a temperate climate, and is planted in wet, muddy environments, including ponds and marshes. The climate should not be too cold, with an optimal temperature range of between 25 °C and 36 °C. Water depth should be 60 cm. Water chestnut should be cultivated when water temperature is stable and above 12 °C. It can be cultured either by direct seeding or by transplantation. Direct seeding is suitable for fertile rivers and ponds with water depths of 2–3 m. The plant is spread evenly in the water when the seed germ is 1–2 cm long. Transplanting is suitable for large, deep ponds. After selecting a fertile, shallow pond, the dry pond should be prepared and fertilized with animal manure. After transplantation, the water depth should be kept shallow, and gradually increased corresponding with seedling growth. The seedling pond is stocked with 4 kg/ha of seed, which can be transplanted to 0.33 to 0.4 ha of water surface. Seedlings are transplanted at the age of about 60 days, when they have about 10 top leaves, with the rhomboid about 15 cm and 2–3 branches. Often, 10 seedlings are banded together with grass rope and submerged. They then grow and their leaves spread on the surface. Plant density should be managed carefully, as if planted too densely, productivity can decrease.

Water chestnut originated in the warm or tropical regions of Europe and Asia, and was subsequently domesticated and cultivated in China and India, followed by the Russian Federation, Japan, Viet Nam and the Lao People's Democratic Republic. In China, water chestnut is mainly distributed throughout the south, particularly in the lower reaches of the Yangtze River and the Pearl River delta. Lake Taihu in Jiangsu and Honghu Lake in Hubei province are the regions best known for the cultivation of water chestnut. Culture of water chestnut is also reported in the middle and upper reaches of the Yangtze River. In 2016, water chestnut was cultivated over 50 000 ha, with production of about 240 000 tonnes. There are many varieties of water chestnut available in China. Traditional pond farming techniques had a low average yield of 27–67 kg/ha, with a value of around USD 39 per hectare. Greenhouse cultivation results in higher yields, at 166–200 kg/ha, worth USD 48–107 per hectare.

Farmers and technical extension officers have stated the need to start breeding programmes, and for further research supporting the conservation of germplasm resources. The area under cultivation should also be expanded. Integrated water chestnut and fish culture should be actively promoted, leading to further economic and social benefits. In order to increase incomes within the sector, farmers should start cooperatives, provide added value processed products, and increase marketing.

2.3.5 Gorgon nut (Euryale ferox)

Gorgon nut (*Euryale ferox*) is the only extant species in the genus Euryale. It is a perennial flowering plant belonging to the water lily family Nymphaeaceae. It has occasionally been regarded as a distinct family, Euryalaceae. As annual herbaceous aquatic plants, their submerged leaves are arrow shaped or elliptical reniform and their floating leaves are leathery, varying from elliptic reniform to orbicular with stout petioles and pedicels. The flower petals are purplish red, with lanceolate sepals, oblong lanceolate or lanceolate in shape. The berry is globose and purplish red with spherical black seeds. *E. ferox* is an important aquatic plant, which can be used as a vegetable and a medicine. It can be used for cooking porridge and soup, and its dried ripe seeds can be used as medicine to treat problems in the digestive system.

Gorgon nut is a perennial water lily, which can be grown at a water depth of up to 5 metres. It grows from a short rhizome, and produces a rosette of large, spiny leaves that, when mature, float on the surface. It is frequently cultivated for food in China and India. *E. ferox* thrives in warm, sunny environments and is neither cold resistant nor drought tolerant. It can be grown at temperatures ranging from 20 °C to 30 °C, with an ideal water depth of 30–90 cm. Gorgon nut can be cultivated in waterbodies with a slow water flow, including ponds, reservoirs and lakes. It should be cultured in a waterbody with an adjustable water level, which should be easy to irrigate. It requires fertile soil with high organic matter content. It reproduces through seeds.

Gorgon nut is native to Eastern Asia. Within China, it is found in Jiangsu, Hubei, Hunan, Zhejiang and Anhui provinces. It is divided into two varieties based on location. Plants from southern China produce bright purple, white and red flowers, while plants from northern China only produce bright purple and red flowers. The southern gorgon nut is predominantly used for culinary purposes, while the northern variety is used more in traditional medicine.

Euryale has been cultivated in China for more than 1 200 years. Traditional cultivation methods are still used in China, requiring extensive management. Therefore, it is necessary to implement standardized pollution-free production methods and to establish a system for quality standards. Cooperatives should develop marketing techniques and business models, including branding, uniform packaging and appropriate pricing. These strategies will greatly improve the ability of small-scale farmers to manage market risk and to increase their profits. Further research and cooperation should be carried out to develop the machinery used in gorgon nut processing.

2.3.6 Water spinach (Ipomoea aquatic)

Water spinach (*Ipomoea aquatic*) is a species of Convolvulaceae. It is an annual or perennial herbaceous vine. Water spinach has high economic value, and is used for various purposes, including as a vegetable, a medicine or for water purification. It is highly nutritious, containing high levels of various vitamins and mineral salts. Notably, water spinach contains significantly more of vitamins A, B1 and C than tomatoes. Leaves contain an average of 1.5 g/kg of vitamins, more than any other green vegetable. As such, it is an extremely important green leafy vegetable, especially during hot summers when other vegetables can become scarce. It can also be used in medicine, as it contains chemicals that can regulate blood sugar; it can also be used in dietotherapy for diabetes treatment.

Water spinach plants have a shallow root system, as well as hollow stems, which support complex, short, flat or nearly round branches. The colouring ranges from dark to light green. It reproduces sexually through seeds or vegetatively through stem cuttings. Water spinach grows well in hot, humid environments. Seeds require temperatures in excess of 15 °C. Vine leaves grow best between 25 °C and 30 °C. Plants can tolerate high temperatures of 35–40 °C. The plants require high air humidity, sufficient moisture and sunshine, and fertile, nitrogenous soils (Yuan, 2012).

Water spinach is native to China and has been widely cultivated as a vegetable. It can also be collected from the wild. It is distributed throughout tropical Africa, Asia and Oceania. Some varieties are propagated by seeds, but the vegetative propagation of certain varieties leads to better quality, softer texture and a higher yield.

Water spinach is mostly cultivated on floating beds in wetlands, ponds or paddy fields. During the growth period, normal yield of the first crop can be 33–50 kg/ha; the second harvest can reach 67 kg/ha after an interval of 20 days. Normally, there are six harvests in a year, for an annual production of around 333 kg/ha, with an output value of more than USD 133. Bobai County in Guangxi province is known as the "hometown of water spinach". Within Bobai, there is a water spinach production site with a planting area more than 167 ha. With soilless culture and winter greenhouse technology, the annual yield per hectare increases from 2 tonnes to 2.8–3.6 tonnes, with a value exceeding USD 5.26 million. Despite the current cultivation area and management techniques, there are still some problems facing water spinach production. These include immature planting techniques and practices used by small-scale farmers, and severe cropping and seedling death problems resulting from disease or mismanagement. In future, the development of the water spinach industry will focus on seed cellars, winter storage, mulch planting, greenhouse cultivation and other advanced technologies to promote production efficiency. The main production areas will build large-scale water spinach planting bases according to local conditions and produce high-standard pollutant-free vegetables, establishing an aquatic ecological industry.

2.3.7 Reed (Phragmites australis Trin.)

Phragmites is a genus containing four species of large perennial grasses found in wetlands throughout temperate and tropical regions globally. They commonly grow in irrigation ditches, along riverbanks, in marshes and along pond shores. They have many applications and a high economic value in certain areas. The leaf, stem, rhizome and shoot can be used as medicine. The stem can be used for paper-making, for weaving mats and curtains, and for greenhouse materials. After processing, the stem can also be used to make crafts.

Phragmites australis has transverse rhizomes, which can be propagated in crisscrossing patterns and used as netting. When thicker rhizomes are used, a floating structure can be formed, which can support the weight of people or animals. The rhizome has very strong vitality, and can remain viable for long periods underground. Rhizomes from 1 m in length can develop into a new branch once conditions are suitable. The plant can also be propagated with seeds, which can spread with the wind. Their adaptation to water is such that the plant can grow in depths ranging from a few centimetres to more than 1 m. In rivers and lakes of a depth of 20–50 cm, with slow flow, reeds can form a tall grass community known as grass forest. In China, reeds are prominent in the Liaohe River Delta, Songnen Plain, Sanjiang Plain, Hulun Buir, Xilin Gol Grassland, and Baiyangdian reed area in north China. In Inner Mongolia, they can be found in Xinjiang Bosten Lake, Yili River Valley and Tacheng Emin Valley. The main Chinese breeding base is in Shuyang City, Jiangsu province, as well as Zhejiang and Anhui provinces.

Annual reed yield is generally about 50 kg/ha, and can reach 93 kg/ha at optimal temperatures. Baiyangdian district, in Hebei province, is known as the “the kidney of the north”. In this district, the reed area was 8 000 ha in the 1980s and 1990s. At present, the area has reduced to 5 066.6 ha, and the annual output has fallen from 110 000 tonnes to about 70 000 tonnes. Previously, many reed products were exported to Japan. Reed mat remains very popular in the Chinese domestic market. Currently, both international and domestic utilization technology is mature, but with a poor financial return compared to other industries. Therefore, the sector needs the support of the government to encourage demand for reed products. These include as fuel, plates, food packaging or as a raw material in the food-processing industry. Processing technology used for traditional reed products should be improved. Traditional varieties may be further developed. Research is needed to explore the international market and the associated expansion of export channels. The production of environmentally friendly paper, plates, building materials and decoration materials should be developed.

2.4 Drivers affecting the freshwater aquatic macrophytes farming sector

Aquatic plants have traditionally been used as vegetables, proving an important source of food for people globally. They are also used as building materials and animal fodder and can also provide ecosystem services. Many farmers receive higher incomes from aquatic vegetables than other crops, and FAMs can be grown in locations that other crops cannot. As there is an increasing demand for healthy vegetables, herbs and medicinal plants, FAMs are receiving renewed attention. Ecosystem services provided by FAMs have occasionally led to ecotourism; many visitors have been attracted to wetlands in which FAMs are used for landscape beautification. Finally, FAMs play a key role in aquatic ecosystems, specifically in water purification.

2.4.1 Improved income to farmers

In China, some farmers report higher incomes from FAM production, relative to traditional rice farming. Aquatic vegetable production requires similar technologies to rice farming. Profits from aquatic vegetable production can be at least double that from rice due to market preferences. Farmers receive training, including demonstrations, to cultivate aquatic vegetables. They also receive technical support from extension officers or cooperatives. Once the cooperatives are established, additional benefits will include the standardization of production, increased quality and marketing support. Cooperatives also help to reduce costs and provide benefits for members.

2.4.2 Healthy food for human consumption

During the pre-farming period, plants were collected and used. FAMs were among the first food plants to be introduced and cultivated. Aquatic plants including rice, water spinach (*Zizania aquatic*), lotus root and cress have been among the most important group of food crops. In addition, gorgon nut, arrowhead, chufa, water shield and water chestnut are other commonly grown aquatic vegetables.

There are many kinds of aquatic vegetables available worldwide, both fresh and processed. They are healthy and high in nutrients. Some aquatic vegetables have medicinal functions. As knowledge of their benefits has increased, so has customer demand, and their prices have increased as a result.

2.4.3 Conservation of biodiversity

FAMs inhabit natural ecosystems and are part of the gradual transition from terrestrial to submersed habitats. FAMs themselves are rich in biodiversity and exhibit many plant, leaf and flower shapes. Aquatic plant sites are often biodiverse, as they provide habitats for a range of animals, including waterfowl, insects and plants. These sites can also provide key ecosystem functions.

2.4.4 Beautify the environment

Aquatic plants are used in landscaping and garden design, providing key water-garden features with attractive colours and lines.

In Chinese gardens, water features often evoke a unique, thought-provoking mood. The “Qu Yuan Feng He” is one of ten famous scenic spots in West Lake, Hangzhou province, and is an example of successful FAM use. From the layout of the whole park, the beauty of the artistic conception of “blue, red, fragrant and cool” is highlighted. It contains blue lotus leaves, red lotus, incense smoke and an overall cool ambiance. In the landscape design, aquatic plants make the edge of the waterbody appear gentle and moving, weakening the demarcation line between the waterbody and the surrounding environment, so that the waterbody naturally integrates into the overall environment.

At present, common aquatic plants used to beautify the environment include emergent plants, such as lotus, *Iris wilsonii*, *Lythrum salicaria*, *Acorus calamus*, cattail and arrowheads. Floating plants include water platter, water lily, pond lily, gorgon nut and banana plant. Currently, many new plant species and their varieties are widely used in water features. For example, several new varieties of water lilies have been cultivated.

2.4.5 Purification of water quality

Aquatic plants are used for water purification (Brix, 1997; Sirakov *et al*., 2015). Aquatic plants play an important role in controlling water pollution and eutrophication. They are uniquely organized and have important ecological restoration functions, including the improvement of water quality by eliminating pollutants (Li *et al*., 2010). Submerged macrophytes can promote the deposition of suspended solids and pollutants in water. FAMs can reduce nutrients in the water through absorption, transformation and accumulation, which restricts phytoplankton production and prevents sediment resuspension and issues related to water transparency. Nutrient pollution and subsequent eutrophication leads to lower dissolved oxygen content, which under extreme conditions can lead to mass fish mortality.

2.4.5.1 Aquatic plants in nitrogen, phosphorus removal

Lake eutrophication is a serious environmental problem globally. Generally, aquatic macrophytes regulate nutrient concentrations in shallow lakes, thus reducing the risk of eutrophication. Large submerged macrophytes have a significant environmental capacity, with a strong self-purification capability. They have a large biomass and can continuously exchange energy and materials with the environment, resulting in water purification. FAMs are used in tertiary treatment of some municipal wastewater systems, and FAM wetlands have been used to filter agricultural runoff.

The Aqua Biofilter™ project builds artificial wetlands, anchoring floating islands made from FAMs, especially sedges of *Carex* spp. Significant reductions in nitrogen, phosphorus, heavy metals and suspended solids are reported. Water clarity is increased. The islands provide a habitat for wildlife. This system was tested in Lake Taihu, a eutrophic lake in China, as well as several pilot projects worldwide.

2.4.5.2 Aquatic plants in the removal of heavy metals

Aquatic plants can effectively absorb heavy metals, including zinc, chromium, lead, cadmium, cobalt, nickel and copper. These pollutants are concentrated in plant tissues, which are harvested and disposed of. Aquatic plants grow quickly and often have high biomass, and can therefore absorb a large amount of substances, effectively reducing pollutant levels. Studies have shown that the concentration of heavy metals in plants can be an indicator of the overall level of pollution in an environment, so FAMs can be used for monitoring.

2.4.5.3 Aquatic plants in the removal of toxic organic pollutants

FAMs can effectively degrade organic pollutants and thus can help to protect the environment. Aquatic plants can absorb some small organic pollutants, and can regulate microorganism composition by promoting the precipitation of organic matter.

2.4.5.4 Protection of riverbanks and conservation of water sources

FAMs can be planted along shorelines to prevent erosion. Root systems can fix soil in place in the ebb zone, where the water level changes between its highest and lowest levels. This can reduce surface runoff. Moreover, they can reduce or stop water flow and associated riverbank erosion. The surrounding solid soil is therefore protected. Rhizome and leaf growth can improve soil quality by increasing soil organic matter content and improve soil structure and water-holding capacity, thus increasing erosion resistance. Therefore, planting aquatic plants on the bank can maintain soil function and revetment and can improve soil fertility in riparian zones. It is an effective, feasible form of ecologic conservation and restoration.

2.4.6 Provide pharmaceutical raw materials

About 262 kinds of aquatic plants have medicinal value (Wu *et al*., 2010). Aquatic plants with medical functions are used as raw materials for Chinese patent medicines, for which there is a large demand. FAMs widely used for medical applications include *Houttuynia* spp. The cultivation area of *Houttuynia* is gradually expanding. Other widely cultivated FAMs include lotus, gorgon nut. Most medicinal aquatic plant resources are wild.

2.4.7 Provide feed ingredients

Aquatic plants can improve soil quality when composted for green manure. They can also be good animal forage, as they are nutritious and fast growing. For example, economically valuable FAMs, including green algae, floating lotus, water peanut and water hyacinth, can be cultured in integrated systems with fish, shrimp, ducks and geese. Aquatic environments are maintained in this ecosystem rehabilitation model. Using integrated systems can provide farmers with a higher income than monoculture.

2.5 Relevant stakeholders

There are many stakeholders involved in the management of FAM aquatic genetic resources. Several private companies carry out their own collection, preservation, protection, utilization, survey and management. There are also national public welfare institutions and private for-profit organizations. National public welfare institutions have been set up by governments to protect aquatic botanical gardens, which are popular with the public. For example, Wuhan Botanical Garden, China, is the world's largest aquatic plant germplasm repository.

2.5.1 Farmers

Farmers are the major player in aquatic vegetable production and industrialization. They primarily consider production methods and economic return, but also take the environment and sustainability into account. Chinese farmers are not only diligent in learning farming technology in aquatic vegetable production, but also consider marketing and responsible use. They also insist for policy and regulations on aquatic vegetable quality, as well as branding and united management.

2.5.2 Cooperatives

Farmers' cooperatives are typical organizations, which often form spontaneously at the grassroots level.

They focus on similar species and products with similar production models. More experienced farmers tend to take a leading role, helping other farmers to improve production management. Cooperatives are operated in standard production in a cohesive manner, with collective marketing models. Additional benefits include group purchase of inputs and seedlings, the exchange of management and production skills, collective branding and quality standards, and joint marketing and distribution.

2.5.3 Private companies

Private, for-profit organizations include aquatic botanical gardens or companies. One example is the China Hangzhou Tianjing Aquatic Botanical Garden Co., Ltd, a comprehensive aquatic plant garden integrating production, scientific research, science popularization, consultation, conservation of endangered species and ecological restoration. Other companies focus on seedling production and breeding of aquatic vegetables, as well as their processing and transportation. These companies and gardens are professionally involved with aquatic plant production and ecosystem rehabilitation, and some have contributed to the protection and breeding of rare species or the industrialization of economic species.

The Hangzhou Tianjing Garden is renowned for wetland design, the production of aquatic plants, and the development of new varieties. The garden has collected 1 200 species of aquatic plants, including 800 varieties of lotus and 200 varieties of water lily, 80 of which were imported from the Thailand Royal Lotus Garden. The company works to preserve several protected aquatic plant species, including *Ranalisma rostrata, Isoetes orientalis*, *Brasenia schreberi*, and the aquatic fern *Trapa incisa*.

2.5.4 Research institutes and organizations

There are many public research institutes and organizations involved in the research and conservation of aquatic plants. These include South China Botanical Garden of the Chinese Academy of Sciences, Beijing Botanical Garden, Nanjing Zhongshan Botanical Garden, Lushan Botanical Garden, and the Shanghai Chenshan Botanical Garden. Some colleges and universities have a long history of aquatic plant production research relating to the classification and development of improved varieties. These include Yangzhou, Nanjing and Wuhan universities. Some famous aquatic vegetables were promoted for industrialization with scientific support from public research institutes. The China Botanical Garden Alliance was founded in 2013, and the branch for aquatic plants has become an important component of the alliance and attracts many scientific research institutions to introduce improved varieties for industrial development.

2.5.5 Government

The Chinese Government plays an important role in policy-making and infrastructure improvement, as well as rural economy reform and agriculture structure modification. The government mainly supports the planning and zoning of the production base; supports the national parks and vegetable production zones; provides financial support for processing companies; organizes technology training programmes for farmers; links scientific institutions including research institutes and universities; provides guidance on branding and quality control practices; and establishes the local market for improved product distribution by integrated storage, processing workshops, cold chain, e-commerce platforms, and quality and hazard examination centres.

An example of governance in relation to FAM resources is the National Plant Germplasm System (NPGS), a cooperative in the United States of America, which involves the government at the federal and state levels, as well as the private sector. It collects and stores plant germplasm resources and serves as a commission on crop germplasm resources and as a germplasm information network. Thirty-one institutions constitute the NPGS collection and storage system. The system is maintained by the Beltsville Agricultural Research Center, the Plant Sciences Institute, the National Germplasm Resources Laboratory (NGRL), and the Germplasm Resources Information Network (GRIN). Among the 31 institutions involved in NPGS, NGRL investigates, introduces, constructs and manages national plant germplasm systems, and manages and maintains GRIN. Separately, the National Botanical Quarantine Office is responsible for the quarantine of imported plants. The National Plant Germplasm Repository System and local introduction stations collect, introduce, evaluate, preserve and distribute imported germplasm. Collection stations of crops and genetic materials collect, evaluate, preserve and distribute specific crops or genetic material. The National Center for Genetic Resources Preservation supports the long-term conservation of plant and animal germplasm resources.

In China, the National Infrastructure of Plant Germplasm Resources is responsible for germplasm resources of crops and trees, including bamboo, rattan, flowers, medicinal plants, tropical crops, important wild plants and forage plants. The infrastructure is hosted by the Institute of Crop Sciences and the Chinese Academy of Agricultural Sciences. It involves 228 institutions affiliated to the ministries of agriculture and education, the state administrations for forestry and traditional Chinese medicine, and the Chinese Academy of Sciences. It is supported by 1 688 personnel. After years of collaboration, a relatively complete system of policies and regulations has been set up. The National Infrastructure of Plant Germplasm Resources supports relevant government bodies in formulating and promulgating laws and regulations. These regulations include the Seed Law of the People's Republic of China; Provisions for Crop Germplasm Resources Management; Regulations of the People's Republic of China on Wild Plants Protection; and the Directory of Nationally Protected Wild Plants. In addition, it supports the standardization of activities, including the collection, collation, identification, registration, preservation, exchange, sharing and utilization of plant germplasm resources. It has also formulated management rules for national germplasm banks and nurseries, established the unified coding system for plant germplasm resources, established a review and registration system for excellent germplasm resources, and established the germplasm resources distribution and utilization system. Thus, rather mature policies and regulation systems for plant genetic resources have been introduced, laying a foundation for the effective management and efficient use of plant genetic resources in China.

2.6 Risks of the introduction of freshwater aquatic macrophytes into non-native areas

Globally, FAMs have been introduced to areas in which they are non-native. Sometimes these introductions are deliberate and other times accidental, with positive and negative consequences. FAMs have been introduced in some regions to improve their uneven natural distribution, as well as to enrich germplasm resources and to accelerate ecosystem regeneration. When successfully domesticated, aquatic plant species can have multiple well-performing varieties, which can be farmed commercially over large areas.

The risk of invasiveness should be considered during the introduction of aquatic plants. The introduction of an aquatic plant may result in one of three scenarios. A species may not survive in the new area; it may thrive without causing environmental damage; or it may cause environmental damage, possibly affecting economies and human health.

A biological invasion is the rapid spread of a non-native species, causing environmental damage. The spread of an invasive species may be facilitated by human actions or can occur naturally. If a plant outcompetes native species, thus occupying their niches, it may dominate and fundamentally alter the ecosystem. The rapid development of worldwide trade and globalization has increased the intensity of these invasions. Biological invasion is a leading cause of biodiversity and habitat loss, and has worldwide social, economic and environmental impacts.

Biological invasions of FAMs can cause significant economic damage. For example, the spread of alligator weed (*Alternanthera philoxeroides*) and water hyacinth (*Eichhornia crassipes*) are serious issues in China (Ma Danwei, 2008). These invasions are difficult to control. Although useful plants in their own right, they are highly invasive and can completely blanket the surface of waterbodies, blocking sunlight and outcompeting native species. As their biomass increases, and underwater parts die, the process of decay can lead to high bacterial oxygen demand and anoxic conditions. This further exacerbates ecological damage.

Controlling an invasion requires expensive mechanical, chemical and biological removal techniques. According to a United Nations study, financial losses in the United States of America, India and South Africa are USD 150 billion, USD 130 billion and USD 80 billion, respectively (Chen, 2002).

2.7 Research, education and training

2.7.1 Study on the germplasm resources of aquatic plants

The study of genetic resources of cultivated FAMs and their wild relatives is a complex system, encompassing research, education and training. It includes the collection, collation, preservation, identification, evaluation, exchange, utilization and innovation of genetic resources. The information management of genetic resources has been enriched through the collation of existing information and classification systems (Wang *et al*., 1997). Preservation includes the maintenance of genetic variant integrity, information on existing germplasm resources, and preventing genetic drift and gene loss. Collection of endangered varieties, retrieving lost varieties, rescuing endangered species, and conserving rare and precious varieties are important for the study of FAMs (Dong, 1999; Liu, 1999). Preservation also includes reintroduction. The exchange of genetic resources includes the sharing of material or information between preservation units, breeding institutions or farms, both nationally and internationally. Utilization and multiplication is the transition of taking promising genetic resources from evaluation or preservation stages to commercial breeding and propagation. This involves outstanding germplasm resources, breeding germplasm resources with special properties, and the study of germplasm resources with nutrition or medical functions. Innovations include a suite of modern practices in the manipulation of genetic resources, through molecular and breeding approaches, to achieve new varieties with improved characteristics (Wang *et al*., 1997). Molecular approaches include methods such as gene polymerization, type optimization for large groups, molecule or isozyme markers for the creation of additional allogeneic lines, alien substitution lines, and translocation lines to achieve plant germplasm material with clear genetic composition (Dong, 1999; Liu, 1999).

2.7.2 Education and training

Academic organizations, including research institutes and universities, carry out multiple education and training activities related to FAM genetic resources. These activities mainly focus on the collection, preservation, protection, utilization and survey of aquatic genetic resources. The construction and management of a resource repository are also important.

2.8 Collaborative approaches and exchange of information

The rapid development of biotechnology has resulted in the increased use of plant genetic resources. This includes the selection for plant traits and quality and the alleviation of food supply, human health and environmental issues. There are, however, differences in access and benefit sharing in relation to FAM resources, particularly between developed and developing countries, with the majority of FAM resources derived from developing countries. As a result, relevant international organizations and economists have discussed the establishment of a fair, effective multilateral system. Regulations for the fair share of genetic resources have been established by the Convention on Biological Diversity. These regulations have been introduced through market protection and utilization mechanisms. This legislation particularly benefits developing countries, but enhances worldwide enthusiasm for the protection and sustainable use of plant genetic resources.

Platforms exist at various levels to support international collaboration for the development and management of FAM genetic resources. Often, these platforms are not specific to aquatic plants. These platforms support the investigation, collection, preservation, evaluation, cataloguing and sharing of genetic resources. Furthermore, they also have a role in the introduction, exchange and protection of plant germplasm resources between countries (Upadhyaya, Gowda and Sastry, 2008), and contribute to the enrichment of diversity using genetic resources from abroad.

The interdependence among different countries for the conservation and utilization of plant germplasm resources is ever increasing (Fowler and Hodgkin, 2004; Roa *et al.,* 2016). This is realized through the exchange and sharing of aquatic plant genetic resources (Galluzzi *et al*., 2016). International conventions on plant genetic resource exchange have been formed to ensure that this is done in an orderly manner (Cooper, 2010; Wu *et al*., 2013; Xu, Yin and Li, 2014). Although the mechanisms for exchange and sharing of aquatic plant genetic resources vary across countries (Dennis *et al*., 2007; Yadav *et al*., 2014; Verma *et al*., 2014), they are broadly consistent.

Most aquatic vegetables are bred asexually. Knowledge of reproduction theory and relevant technologies, as well as breeding and plantation experience, is essential for the further development of FAM cultivation. Aquatic genetic resource management programmes should include the establishment of a databank, an e-learning platform and relevant publications.

Two systems for plant genetic resource utilization and protection have been put in place over the last few decades. One such programme deals with wild species and native plants, which have not yet been genetically improved. The other is an intellectual property system, which protects breeders' rights to new crop varieties.

The International Convention for the Protection of New Varieties of Plants is an international document that regulates the trade of new varieties, with the goal of protecting plant breeders' rights. A patent system on new plant varieties has since been established, and the range of varieties covered has been gradually expanded. Provisions relevant to the patent system can be found in the Agreement on Trade-Related Aspects of Intellectual Property Rights, a World Trade Organization framework document.

The Convention on Biological Diversity is an international document on plant genetic resource conservation and sustainable use. It asserts that all countries should undertake the international obligations for biodiversity protection, while stressing the principle of "fair sharing of benefits of genetic resources". To fully implement the Convention and related laws, an international conference on the sharing of plant genetic resources, involving dozens of countries, was held in Beijing in May 1999. This formulated the Common Policy Guidelines for Arboretums on Access and Benefit-sharing of Genetic Resources, which proposed to respect the sovereignty of all countries over their genetic resources. This safeguarded the interests of resource origin countries and other resource holders and advocated to establish and improve genetic resource-sharing mechanisms, encouraging and facilitating plant genetic resource conservation and sustainable use.

2.8.1 Dissemination guidelines

Multiple institutional agreements, taking the types of plant genetic resources into account, exist to promote plant germplasm resource conservation, with varying dissemination management practices. The National Clonal Germplasm Repository's shared dissemination policy disseminates plant germplasm for crop researchers and industrial breeders, in both government and the non-governmental sectors (Zhang *et al*., 2006). Applicants can search their germplasm of interest and submit an application through the Germplasm Resources Information Network, or GRIN. They can also apply for direct sharing with storage institutions. The sharing of plant germplasm resources is free, but all applicants must state their purpose when applying for material sharing. Domestic applicants applying to exchange germplasm are prioritized. Foreign requesters may also apply to the plant germplasm storage institution for the sharing of resources, while observing federal quarantine provisions and relevant restrictions in the United States of America and recipient countries. The applicant must provide an import permit and, if necessary, an English translation of the permit. The phytosanitary personnel of the United States Department of Agriculture will not issue the phytosanitary certificate until it receives the import permit from the country where the applicant is located. Materials that have not been quarantined by the relevant phytosanitary staff cannot be exported to other countries, and even some states within the United States of America. Resource providers also need to learn about phytosanitary requirements and other transportation permits or documents required by the applicant's country or region. The applicant should provide relevant documents for the international transport of the germplasm.

2.8.2 Methods of applying for sharing germplasm material

Different kinds of germplasm materials have different dissemination management methods. For plant germplasm resources stated as shared online, applicants can apply through GRIN by submitting the application form, or by directly contacting the storage institution by e-mail or post. Applicants are required to submit an experimental report on the shared germplasm to the resource provider. For some plant germplasm materials with relatively high research values, sharing needs to be realized through exchanges, cooperative research or other methods agreed upon by both parties. Corresponding contracts shall be signed, in which the rights and obligations of both parties will be explicitly stipulated. Material transfer agreements should be signed when sharing between countries.

In general, for each material the applicant applies for, the depositary institution will provide a written test certificate. Some historical information of the material includes passport information, genealogy and related data, which can all be found online. Therefore, the depositary is not responsible for the performance or identity of the material disseminated.

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