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Alternative Sources of Plant Protein in Southeast Asia

'BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Alternative Sources of Plant Protein in Southeast Asia independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, 14.4.2023

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Abstract

This thesis is focused on alternative plant protein sources in Southeast Asian countries. The work is aimed towards finding underutilised or neglected plant species that are primarily rich in protein and secondarily rich in micronutrients in order to improve food security in Southeast Asian countries and mitigate the global warming crisis around the world. The Southeast Asian countries are considered: Brunei, Myanmar, Cambodia, Timor-Leste, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, and Vietnam. The introductory part of the work informs about how the key is protein consumption for human nutrition, how the proteins are composed and whether plants can provide a sufficient amount of protein and amino acids. The second part describes an overview of the studied area – climate, vegetation, agriculture, eating habits and climate crisis concentrated on food production in Southeast Asia. The third part focuses on a total of 53 underutilised or neglected plant species that could be used as a supplement to regularly use or substitute for overused crops as a valuable source of protein intake. The summary table was arranged to give basic information about the plants in terms of name (Latin, English, local), family, edible parts, protein content per 100g of given plant part, processing, and interest for which this plant species was chosen. The plant species belonged to a total of 23 different families; the most predominant families were Fabaceae (37.7 %), Amaranthaceae (9.4 %), and Poaceae (7.5 %). In the last section, six species, namely: *Terminalia catappa* Linn., *Vigna umbellata* Thunb., *Parkia speciosa* L., *Nelumbo nucifera* Gaertn., *Psophocarpus tetragonolobus* L., *Tamarindus indica* L. were selected based on underutilisation, its potential to become more frequently used crop, and at least 20 % protein content of its mass. In this section, botany, ecology and cultivation, nutritional values, and mode of use of these plants were described in detail.

Key words: Alternative protein sources, neglected, underutilised, nutrition, plant proteins, Southeast Asia

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List of the abbreviations used in the thesis

EEA – essential amino acid

SEA – Southeast Asia

NUC – neglected/underutilised crop

1. Introduction

Dietary protein is essential for human survival, growth, and development. Regardless of age, a human should be getting at least 0.8 g of protein per 1 kg of bodyweight (Trumbo et al. 2007). However, the fact is that approximately 1 billion people suffer from protein deficiency globally, from which 780 million people suffer from malnutrition (Action Against Hunger 2023). The reasons for these facts are poverty or food security.

According to World Health Organisation (2022), around 2.3 billion people are moderately or severely food insecure. This has not been an exception in Southeast Asia (SEA). Due to high population growth, urbanisation, and greenhouse gas emissions, Southeast Asian countries have been losing food security. Rice and corn are the main food crops planted and SEA has been dependant on rice export and more on the import of other crops. This trend is not only jeopardising their economies but also limits the diversity of price-affordable goods at the market and that leads to rice overconsumption by lower income communities which is causing protein and micronutrient deficiencies (Nicola et al. 2020; Lin et al. 2022).

Moreover, 68 % of the food industry greenhouse gas emissions (methane +CO_2) in Southeast Asia are from animal production. If we take into account the production of nuts and seeds, legumes, fruits and vegetables, and grains, it accounts to roughly 20 % of the food industry emissions (Global Nutrition Report 2022). The greenhouse gas emissions are proven to have a direct impact on global warming and extreme weather occurrence, which decreases crop yield or even destroys it. Production of crops is generally more environmentally friendly than animal production. More crops and less animal production consumption could mean less greenhouse gas emissions, thus less extreme weather occurrence and higher food security (Lin et al. 2022).

The present study is based on the research of underutilised and neglected plant species high in protein or micronutrients, native or introduced to Southeast Asia, that have the potential to help improve food security and mitigate the global warming crisis.

2. Aims of the Thesis

This thesis aims to investigate available literature and electronic information sources to analyse the alternative sources of plant proteins and the used processing methods.

Specific objectives

1. To determine the overall characteristics of plant protein.
2. To evaluate plant protein sources in the Southeast Asian region and their linkages to food security.
3. To research the possible use of underutilised and neglected plant protein species in the Southeast Asian region.

3. Methodology

A systematic literature review was performed using an electronic search of ScienceDirect, Scopus, Web of Knowledge, and Google Scholar. Primary search terms used were: ""proteins"", "plants", "underutilised crop", "plant processing". Plants were selected according to their distribution in Southeast Asia, protein and micronutrient content, and underutilisation and were tabulated for a better overview. Finally, some representative species from the selected one were chosen to be further described based on their protein content, which must be at least 20 g of protein per 100g and the plant's potential to become more used in agriculture.

4. Literature Review

4.1. Nutrition & Nutrients

Nutrient is a chemical substance required by an organism to maintain basic body functions. Human diet consists of macronutrients (carbohydrates, fat, protein, water, fiber) and micronutrients (vitamins, minerals). The term macro means we as humans need the nutrients in greater amounts (tens or hundreds of gams of them), the term micro suggests that we will need much less then macronutrients (grams, milligrams, in some cases micrograms) (Kim et al. 2019). These nutrients and its balance in consumption is essential for human survival, therefore wellbeing. Every micronutrient mentioned bellow is essential and for every micronutrient, there is recommended dietary allowance (RDA) (Ward 2014).

4.1.1. Proteins

Proteins have a unique function in human body. It is the only source of bound nitrogen and sulphur and are responsible for synthesis/formation of cells-specific, physiologically significant low-molecular-weight compounds, such as nitric oxide, glutathione, carnitine, carnosine, serotonin, melanin, melatonin, etc., as well as tissues and organs, enzymes, hormones, and other molecules (Wu 2013). It is also essential for humans because it is responsible for cell reproduction, thus muscle growth. Proteins are long chains of molecules containing both amino and carboxylic acid functional groups, called amino acids. Amino acids are connecting into peptides, peptides into oligopeptides, oligopeptides into polypeptides, and polypeptides into proteins. Fifty amino acids chained together make polypeptide and one polypeptide is considered a protein (Dietzen 2018).

4.1.1.1. Amino Acids

Amino acids are a cornerstone for protein assembly. There are hundreds of amino acids occurring in nature, but only 20-21 are involved in the synthesis of proteins in the human body. Amino acids are divided into essential, non-essential, and conditionally essential categories based on their nutritional qualities. All 21 amino acids are necessary for proper function, from which only 9 cannot be synthetised in human body. These amino acids are – histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine (Shevkani & Chourasia 2021). These amino acids are necessary to gain from food. The full spectrum can be absorbed by eating eggs, beef, poultry, fish, dairy, soy, buckwheat, and quinoa. The amount of each essential amino acid intake should be of similar amount. Human body can absorb only the amount of essential amino acids according to which one is of the least value. The other essential amino acids which are of bigger value then of the least are catabolised by enzymes in the liver (Munro 1978).

4.1.1.2. Proteins and Human Nutrition

Animal protein sources (fish, meat, eggs, and milk) are considered high-quality protein sources due to their high amino acid content. Plant foods, on the other hand, are now being promoted because of 1) their lack of cholesterol, 2) the presence of health-beneficial bioactive compounds (e.g., lectins, enzyme inhibitors, phytosterols, saponins, phenolic compounds, dietary fiber, etc.), and 3) their roles in ensuring sustainable agriculture and food security (Shevkani & Chourasia 2021). Shevkani and Chourasia (2021) also point out that consumption of plant proteins should be encouraged due to the accompanying health benefits and plant protein being much lighter and easier to digest.

Although, a mixed diet providing both animal and plant protein is preferred. According to findings of Molnár et al. (2022), plant-based diet with low amount of meat consumption, called "flexitarian diet" is great balance in macronutrients and micronutrients in the amounts needed for the body. The plant-based side supplies body with antioxidants and fiber and meat side with minerals and essential amino acids.

4.1.1.2.1 Plant Protein

Plants are as well sources of dietary proteins and source of other essential vitamins, micronutrients, dietary fiber, and water. The drawback is that plants always miss or are low on at least one essential amino acid. But with the right combination, full amino spectre can be achieved (Wu 2013).

Most plant proteins from commercial agriculture are nowadays used as feed for livestock to produce animal proteins from milk, eggs, and meat. In some cases, only 15 % of the plant proteins are turned into animal protein and the rest 85 % is wasted. In terms of land use, only 10 % of the land would be used to grow food crops to produce the same amount of protein using livestock (Aiking 2011). The amount of water to produce animal protein is about 100 times higher than producing plant-based protein (Pimentel &

Pimentel 2003). As the planet's population grows, the demand for protein will also increase. The supply of animal proteins will reach maximum production capacity at some point, and this will be great potential for the agri-food industry (Day 2013).

Plant protein is cheaper, and thus plant-based diet could be a way to save money for people in rural regions, where meat, dairy, and eggs are scarce or expensive. Also, excessive animal protein consumption has proven to be connected with health risks as cardiovascular diseases, neurodegenerative diseases, and other conditions (Talebi et al. 2023).

4.1.1.3. Protein intake

The human body of different people needs different amounts of protein according to age, sex, physical activity, health, and nourishment (Lonnie et al. 2018). Minimal daily protein intake, according to Trumbo et al. (2007) regardless of age is set to be 0.8 g/kg of bodyweight. Less than that could lead to protein deficiency and consequences connected to it. For people with higher caloric expenditure, their protein intake should be up to two times multiplied (up to 1.6 g/kg of bodyweight). According to Schoenfeld & Aragon (2018), the human body can efficiently absorb between 0.25 – 0.4 g/kg of protein per meal and can digest roughly 10 grams of protein per hour. The best way to digest dietary protein is to divide meals into four even portions with the same amount of protein and eat approximately every 4 – 6 hours.

4.1.1.4. Protein deficiency

It is important to know the difference between malnutrition and protein deficiency. Meanwhile malnutrition is meant as a insufficiency of all macronutrients intake, protein deficiency is meant only on insufficiency of one macronutrient intake – protein (WHO 2023).

Neglecting protein intake has a bad impact on cell reparation and cell replication. That is why proper amount protein intake, especially for children is a key aspect of nutrition for growth and development (Herring et al. 2018). Protein deficiency in short run can have temporary effects, such as weaking and loss of muscle tissues, oedema, marasmus and can weaken immune system to be more vulnerable to infectious diseases. Protein deficiency in long run can leave permanent damage as kwashiorkor (swelling, hair and teeth loss, depigmentation) or brain damage and organ failure (Khan et al. 2017).

4.1.2. Micronutrients

Micronutrients are considered vitamins and minerals. Both of these groups of micronutrients are essential. Vitamins are divided in two groups – water soluble and fat soluble. Fat soluble vitamins include A, D, E, K. Water soluble vitamins are considered B1, B2, B3, B5, B6, B7, B9, B12, and C (FDA 2022). Minerals are usually also divided in two groups, by quantity in which we need them. Macrominerals are considered those which we need in greater amounts (100 mg and more per day) – sodium, magnesium, phosphor, calcium, chloride, potassium, and sulphur. Microminerals or trace minerals (less than 100 mg per day) are considered iodine, selenium, zinc, iron, manganese, and copper. (Harvard T.H. Chan 2023).

4.1.2.1. Vitamins

Vitamin A – or retinol which plays key role in cell replication, eyesight, bone growing and development. It can be gained in provitamin A (carotene). That is found primarily in spinach, carrots, broccoli or any green, yellow, or orange vegetables (Krinsky 2003). RDA for vitamin A is 0.8 mg/day for adults (FDA 2022).

Vitamin B1 – or thiamine is essential to human body for converting carbohydrates into glucose (Krebs cycle) and thus produce energy. It also helps metabolise fats and protein. Vitamin B1 is present in whole grains, beans, pork, or fish. (Bemeur & Butterworth 2014). RDA for thiamine is 1.2 mg/day for adults (FDA 2022).

Vitamin B2 – or riboflavin is responsible for normal mitochondrial function (mitochondria are cells energy storage). It also accounts to reduction of inflammation of nerves. Riboflavin rich are organs and eggs. Grains and cereals are fortified with vitamin B2 (McCormick 2012). RDA for riboflavin is 1.3 mg/day (FDA 2022).

Vitamin B3 – or niacin is acting as a coenzyme in nucleonic energy reactions, it is added to wholegrains along with vitamin B2. RDA is 14 mg/day for adults (FDA 2022)

Vitamin B5 – or pantothenic acid is responsible for fatty acids metabolism. Vitamin B5 is in wide range of food, B5 deficiency is not common besides malnutrition. Best sources are oats, chestnuts, or plantain. RDA is 5 mg for adults (FDA 2022)

Vitamin B6 – or pyridoxine is responsible for building amino acids and metabolism of spingoid lipids. Vitamin B6 is as well present in widespread of food. Best source is wholegrains. RDA of vitamin B6 is 1.7 mg/day for adults. (FDA 2022).

Vitamin B7 – or biotin is involved in carboxylation reactions which are responsible for breathing. Egg yolks, grains, or beans are great source of biotin. RDA is 30 mg/day (Harvard TH Chan 2023).

Vitamin B9 – or folate is helping human body to build protein chains, produce DNA, and control blood levels. Green leafy vegetables, beans, or wheat is great source of folate. Folate deficiency can cause anaemia (Harvard TH Chan 2023). According to FDA (2022), adults should intake 0.4 mg of folate equivalents per day.

Vitamin B12 – or cobalamin is helping nerve cells to maintain healthy and forming DNA. Can be found in dairy, meat, eggs. People with low access to animal protein or vegans can gain it from fortified cereal. RDA of B12 is 2.4 μg/day (FDA 2022).

Vitamin C – or ascorbic acid is key for functioning of immune systems. It helps cells to destroy free radicals, that can cause cancer and other diseases. Citrus fruits are the best source of vitamin C. RDA is 90 mg/day but can be considerably exceeded with no risk of harm (Institute of Medicine 2000).

Vitamin D – regulate levels of calcium and phosphate. It can be gained by reaction of inner skin cells and sun, so people from tropical regions do not have deficiency unless they have malabsorption. RDA is 15 μg/day (Institute of Medicine 2010).

Vitamin E – or tocopherols have antioxidant effects and help cells from free radicals. Vegetable oils and nuts are best source. RDA is 15 mg/day for adults (Institute of Medicine 2000).

Vitamin K – responsible for blood clotting. Green leafy vegetables are the best source. RDA is 0.12 μg/day (FDA 2022).

4.1.2.2. Minerals

Sodium is crucial for blood pressure and blood volume. Vegetables or dairy products have fair amounts of sodium. Sodium is added to almost every product in form of salt and RDA of 2300 mg/day can be easily exceeded. Long term excess of sodium can lead to atherosclerosis (FDA 2022).

Potassium – helps maintain fluid inside cells. Dried fruits and leafy green vegetables are good sources of potassium. RDA is 4700 mg/day (NIH 2022).

Calcium – needed to build and strengthen bones and function of muscles. Dairy, almonds and beans, specifically winged bean is good source of calcium. RDA is 1000 mg/day (FDA 2022).

Chloride – necessary for creation of stomach acid, and regulation of fluids in and out of cells. Table salt is the best source of chloride, along with sodium. RDA is 2000 mg/day (EFSA 2019).

Phosphorus – its main use in body is for formation of teeth and bones. Red meat, legumes or nuts are the best sources of phosphorus. RDA is 3500 mg/day (Harvard TH Chan 2022).

Magnesium – regulates muscle and nerve function and plays role in protein composition. Green leafy vegetables, seeds and nuts are great source of magnesium. RDA is 350 mg/day (NIH 2022).

Sulphur – is needed by human body to build and repair DNA. Also, it protects body from free radicals and assists in food metabolism. Meat, nuts, lentils, or oats are good sources of sulphur. There is no RDA for sulphur (Marcus 2013).

Iron – Is essential for production of red blood cells. Major sources of iron are meat, legumes, and nuts. RDA for men is smaller for men (8.7 mg/day) and higher for women aged 19 to 49 (14.8 mg/day) due to menstruation blood loss (Janaswamy 2020).

Manganese – Is involved in metabolism of carbohydrates and creation of glucose. Major sources of manganese are cereals, vegetables, or tea (Janaswamy 2020). RDA for adults is 2.3 mg/day (FDA, 2022).

Copper – Is helping with creation of glucose and repairment of cells. Copper can be found in cereals, poultry, eggs, and vegetables (Janaswamy 2020). RDA has been reduced from 2 mg to 0.9 mg/day in 2022 (FDA, 2022).

Zinc – Is responsible for strength of immune system and helps to maintain normal levels of testosterone. Deficiency can lead to weakening of immune system. Zinc can be gained from meat, poultry, eggs, cereals, beans, and lentils (Janaswamy 2020). RDA for is 11 mg/day (FDA 2022).

Selenium – Is key mineral for building enzymes and production of thyroid hormone. Selenium can be gained from nuts, red meat, or garlic (Soetan et al. 2010). RDA for selenium is 55 μg/day (FDA 2022).

Iodine – Its major role is helping in proper function of thyroid gland. Seawater is rich on iodine and all salts available at the market are iodine enriched (NIH 2022). RDA of iodine is 0.15 mg/day (FDA 2022).

4.2. Overview of Southeast Asia

4.2.1. Introduction

Southeast Asia is a subregion of Asia, comprising 11 countries divided into mainland (Cambodia, Laos, Thailand, Vietnam, and Myanmar – until the year 1989 known as Burma) and island (Malaysia, Singapore, Brunei, the Philippines, Indonesia, and Timor-Leste – depended on independence on Indonesia in 1975) zones. It is bordered by China to the north, India and Bangladesh to the west, and Oceania to the east and south (Hill 2002). The region has a population of over 680 million people and is home to some of the world's most populous cities, including Jakarta, Manila, and Bangkok. Around 42 % of the population is Muslim and 30 % is Buddhist. Less than 1.4 % of the population is Hindu. The official languages of the region vary from country to country. Besides official languages, speakers of more than thousand languages are assigned to Southeast Asian countries. Many people speak English as a second language due to its widespread use in education, business, and tourism (Asia Society 2023).

The Southeast Asian population grows steadily with average of 1.02 %. Timor-Leste leading with 1.6 %, Philippines with 1,5% and Laos with 1,4% annual population growth in year 2021. The only country with negative annual growth rate is Singapore with -4,2% (World bank data, 2022). It is expected that the region's population will reach 721 million by the year 2030 and the demand for food will rise up by 40 % by year 2050 (OECD 2021). With this whopping population growth, demand for food is still growing and new approaches need to be taken to feed the population of Southeast Asia sustainably, safely, and effectively.

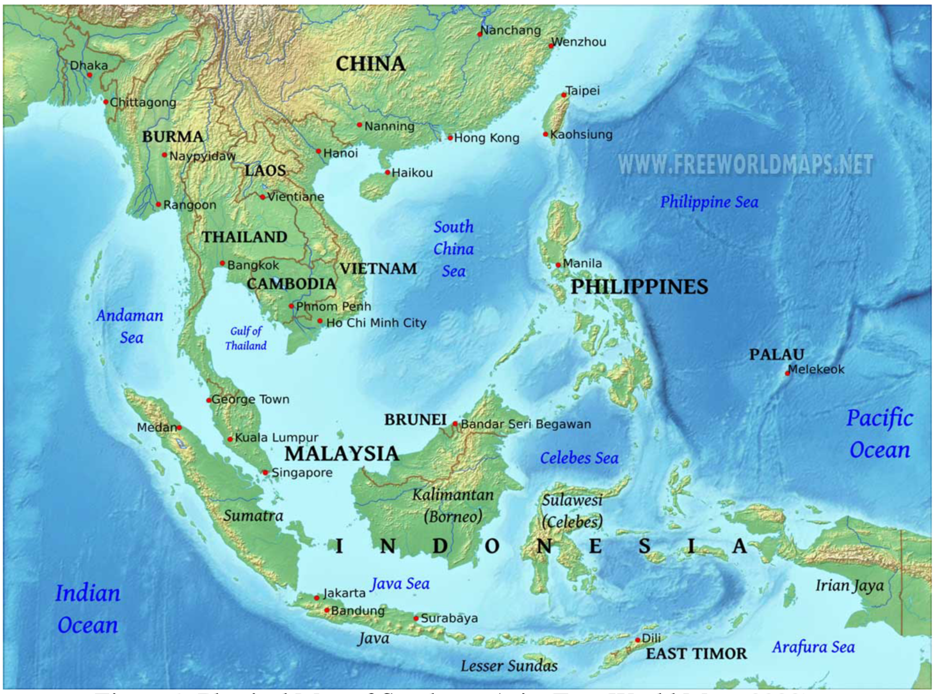

Figure 1. Physical Map of Southeast Asia (Free World Maps 2023)

4.2.2. Climate

Southeast Asia has a tropical climate that is characterised by high temperatures and humidity throughout the year. The region experiences two distinct seasons: the wet season and the dry season.

In the wet season, which typically occurs from May to October, temperatures are generally slightly cooler due to the higher amount of rainfall and cloud cover. According to CCKP (2023), in many places, daytime temperatures range from 25°C to 30°C, and night-time temperatures range from 20°C to 25°C. However, some areas may experience occasional heatwaves during this season. In the dry season, which typically occurs from November to April, temperatures are generally higher and can range from 30°C to 35°C (86°F to 95°F) during the day and 25°C to 28°C (77°F to 82°F) at night. Some areas may experience higher temperatures, particularly in urban areas where the heat island effect is present (Chuan 2005).

Humidity in coastal areas to lowland regions ranges from 70 % to 90 %, with the highest levels during the rainy season. Inland areas have slightly lower humidity levels but still generally high humidity (Chuan 2005).

Precipitation is influenced by the rainy (monsoon) season, which brings heavy rainfall. Rainy season runs from May to October, with the heaviest rainfall occurring in the months of July and August. During this time, tropical storms and typhoons can also bring significant amounts of rainfall to the region. The precipitation differs with location and altitude. Mountain ranges receive more rainfall then low-laying coastal areas. In general, the eastern part of Southeast Asia, which includes countries like the Philippines and Indonesia, receives more rainfall than the western part, which includes countries like Thailand and Myanmar. Overall, Southeast Asia receives an average of 2,500 to 3,500 millimetres of rainfall per year, making it one of the wettest regions in the world. Malaysia has the highest mean precipitation, with 3000 mm annually (CCKP 2023). This high level of precipitation is essential for the region's agriculture and ecosystems, but it can also lead to flooding and landslides in some areas (Chuan 2005).

4.2.2.1. Climate Change & Climatic Crisis

Climate change is defined as a change in the condition of the climate that can be determined by changes in the mean and/or variability of its attributes and that lasts for a prolonged period of time, generally decades or longer (IPCC 2018).

Countries located in tropical regions are most prone to be impacted by climate change. According to the findings of Weiss (2009), the mean temperature in Southeast Asia has risen by 0.1-0.3 °C every decade since the year 1950, and the intensity of extreme weather like droughts, heatwaves and tropical cyclones has increased. This trend also includes the rising sea level. Due to increasing global temperature, the glaciers and ice sheets are melting, and the phenomenon called "thermal expansion of water" is occurring and making the sea level rise. This could be damaging for low-lying coastline areas which are densely populated (Paw & Thia-Eng 1991).

The latest reports by GNR (2022) show that the biggest environmental impact from the food industry in Southeast Asia has meat production with 51 % greenhouse gas emissions. Fish, milk, and egg production account for 17 % of greenhouse gas emissions in Southeast Asia. Other non-animal productions, including oil, sugar, nuts and seeds, legumes, fruit and vegetables, roots, and grains, account for the remaining 32 % of greenhouse gas food industry emissions in Southeast Asia. The Southeast Asian country with the highest animal production emissions is Viet Nam with 83,5 % of its greenhouse gas food industry emissions. The footprints consider all food production, including inputs such as fertilisers and feed, transport, and processing, e.g., of oil seeds to oils and sugar crops to sugars.

More frequent extreme weather occurrences due to air pollution and higher greenhouse gas years have been recently proven to have an impact on food quality and safety, eventually leading to low nutritional status. Because of the high greenhouse gas concentration, prominent rice cultivars in Southeast Asia have decreased protein, micronutrient, and vitamin B content. Because food production is critical to ensuring food supply, it is critical to comprehend the probable relationship between climatic conditions and food production (Lin et al. 2022).

4.2.3. Vegetation

Southeast Asia is home to a diverse range of vegetation types, ranging from dense rainforests to mangroves and savannas. According to reports of FAO & UNEP (2020), forests cover around 2.64 million km^2 from 4.5 million km^2, which is around 58.7 % of the total land area. Corlett (2005) and Zhu (2019) have stated that there are 6 main vegetation types found in Southeast Asia:

Tropical rainforests: These are the most prominent vegetation types in Southeast Asia. Tropical rainforests can be found in Indonesia, Malaysia, Thailand, Vietnam, and the Philippines. It covers around 30% of the Southeast Asian land area. They are characterised by tall trees, dense undergrowth, and high humidity. The soil is poor on nutrients due to the rapid decomposition of organic matter, the vast majority of nutrients is stored in the vegetation, which makes the land not suitable for agriculture purposes (Lourenço 2003). However, tropical rainforests, especially in Malaysia, are being cut down to be replaced with oil palms (Norwana et al. 2011).

Mangrove swamps: These are found along the coastlines of Southeast Asia, particularly in Indonesia, Malaysia, and Thailand. They are salt-tolerant trees and shrubs that grow in shallow tidal waters. Mangroves offer habitat and food for species, as well as storm protection and water filtering; mangroves also release approximately four times more oxygen into the atmosphere as well as the uptake and storing of carbon dioxide than other plants, which aids in the battle against climate change (Cadena & Ochoa-Gómez, 2023). Moreover, some species of mangroves grow fruits that are edible and are considered underutilised (Honculada-Primavera 2000).

Marine ecosystem: This concerns coral reefs in the shallow waters off the coastlines of Southeast Asia, most densely in Malaysia, Philippines, Thailand, and Indonesia. Coral reefs are essential for protecting coastlines from storms and erosion and sustaining a quarter of the ocean's marine life. Coral reefs produce up to 50 % of the earth's oxygen. However, due to climate change and commercial fishery, every year more and more corals in the Southeast Asia are dying. Nearly 95 % of all coral reefs in Malaysia and Philippines are threatened (Chelliah al 2015). Moreover, seagrass, dulse, kelp, sea lettuce, or marine algae, generally known as sea vegetables are planted along coastlines. They make a superior source of micronutrients and a good source of protein (Yaakub et al. 2018).

Grasslands: These are grassy areas with scattered trees, found in great portions, mainly the northern parts of Southeast Asia with more temperate climate including Cambodia, Laos, Vietnam, and Northern Thailand. Grasslands are often conversed to agriculture land or tree plantations (Ratnam et al. 2016).

Peat swamp forests: These are found in Indonesia, Malaysia, and Brunei and are characterised by trees that grow in waterlogged soils. Peatlands soil is very rich in micronutrient composition, and thus the forests are drained, burned, and plantations are developed. These actions make up 1.3-3.1 % of global emissions from fossil fuel burning (Hooijer et al. 2010). Moreover, more than 2.8 million hectares in Sumatra, Indonesia have been cut down for industrial plantations (Miettinen & Liew 2010).

Alpine vegetation: These are found at higher elevations in Southeast Asia, particularly in parts of Malaysia and Indonesia. They are characterised by small shrubs and grasses adapted to cooler temperatures and harsher conditions. Alpine vegetation is used mostly for coffee and tea plantation (Anhar et al. 2021).

Nevertheless, regardless to the vegetation types, greatest and most fertile agricultural plains are located on natural bodies of water or river deltas, like for example Mekong Delta in Vietnam or the Chao Phraya Delta in Thailand where lays one of the most productive rice fields in Southeast Asia. However, these sites are constantly damaged due to flooding (Kotera et al. 2015).

4.2.4. Agriculture

Rice is the most important cereal planted in Southeast Asia (SEA). Historically, SEA had relied on cereals and rice especially. Rice has been the first cultivated crop in SEA. Historically, it had central role in agriculture and urban development (Gao et al., 2020). However, this trend persists even to present. According to WAP (2023), world production of rice by 2022 is estimated 503.27 million tonnes from which Southeast Asian countries accounted to 116. 52 million tonnes, therefore 23 % of world production. However, there are few more commercially grown mainstream food crops that are cultivated in all Southeast Asian countries, which are corn, cashew, peanuts, soybean, sunflower seed, wheat, cocoa, sugarcane, and eggplant. Nevertheless, the way of extensive agriculture in Southeast Asian countries conduct and poor management practices are exhausting the land and causing soil infertility. But still, Maze is found to be one of the greatest crops to be intercropped, and according to findings of Khongdee et al. (2022), Southeast Asian countries as Indonesia, Thailand, Vietnam, or the Philippines had experimented with maise-based intercropping with legumes (lablab bean, mung bean, cowpea, rice bean, soybean), cassava, or potatoes and many more to find out it helped with soil erosion, less water was running off and the soil fertility was prolonged.

4.2.5. Nutrition and Eating Habits

According to research conducted by Lipoeto et al. (2012) in rural and urban areas in Manilla and Calabanga (Philippines), Selangor and Kuala Selangor (Malaysia), Padang, and Limapuluh Kota (West Sumatra, Indonesia) on adults aged 18 to 77 years, urban areas have partially given up traditional diets for Western-style diet. However, people in rural areas have mostly shown retention in the traditional diet, which is basically composed primary ingredients as eggs, rice, fish, pork, chicken, and vegetables. The meals were than fried rice, fried fish/pork/chicken or rice noodles with coconut milk and curry. It has proven that rural communities depend on rice, as it is almost part of every meal. Addition of legumes would have beneficent effect on their needed nutrient intake (Polak et al, 2015).

4.2.5.1. Food Security

According to World Bank (2023), food security can be defined as possibility for all people, at all times have access to nutritious food of a certain quality standard, that meets their dietary needs and allows them to live an active and healthy life. Food security has three important pillars: availability of food, access to food and food utilisation. Food security has been a concern in SEA due to urbanisation, climate change, and population growth. Malnutrition in all of its manifestations is a recurrent issue throughout Southeast Asia. According to UNICEF statistics (2021), 27.4 % of Southeast Asian children under the age of five are stunted, 8.2% are wasting, and 7.5 % are overweight.

Southeast Asian countries have been becoming partially dependant on import, especially after Covid-19 pandemic after losing percentage of workers in agriculture. (Nicola et al. 2020). Furthermore, Southeast Asian countries extensively cultivate small variety of crops, mostly rice. This has been an issue in Indonesia and its food security. According to Rozaki (2021), a country that focuses too much on rice will become rice-dependant and exposes country to risk when domestic production cannot match demand. Hence, food diversification is required to decrease rice dependency.

4.2.5.2. Government Policies to Improve Food Security

In the past two decades, changes have been undergone to improve food security in SEA. Governments have been introducing policies to tackle food security (Lin et al. 2022). Agriculture development programmes have been introduced to increase food production and support farmers. In particular, Indonesia's "Food Estate" program supports developing large scale faming projects, invests in research and development of irrigation systems, seeds and fertilisers, and infrastructure (Lasminingrat & Efriza 2020). Price controls and subsidies have been introduced to ensure food availability for low-income households. Many countries, such as Thailand or Vietnam have implemented price controls and subsidies on staple foods, such as rice or maise to keep the prices stable (Arunmas 2021). Food reserves and stockpiling is another practice of Southeast Asian countries to ensure food security during natural disasters or supply chain disruptions. Philippines government agency National Food Authority (NFA) had implemented rice stockpiling to ensure stable rice supply throughout the country (Lassa et al. 2019). Furthermore, nutrition programs and have been introduced to reduce malnutrition among vulnerable populations, especially children and pregnant women. Trade/import policies are introduced to ensure a stable supply of food and prevent price spikes. Malaysia has imposed taxes on certain food items to protect local producers (ITA 2022).

Although governments of Southeast Asian countries have various policies to protect local producers, policies face challenges such as budget constraints, corruption or inadequate enforcement or implementation. Moreover, production subsidies and export restrictions have been proven to be good only as short-term solutions. SEA governments should be really focusing on agricultural research, development, agricultural infrastructure and shifting of governance towards system transformation, allowing the agricultural sector to have the ability to respond quicker to short-term economic or environmental shocks (Lin et al. 2022).

4.2.6. Neglected and Underutilised Crops

It is necessary to assess how to indicate a neglected/underutilised crop (NUC). Generally, NUC is considered a cultivated, semi-domesticated, or wild plant species that are not included in the group of main staple crops because they do not match global market needs in most situations (Scarano et al. 2021). Another reason for these plant species to be underutilised or neglected is that on global scale it is not considered important. But on a regional scale, between the local communities who depend on agricultural produce, the plants provide food security. The point of promoting NUC is to diversify nutritional intake and to provide economic and environmental benefits. Nutritional intake diversity is key, especially in the early stages of life. The macronutrients and micronutrients are crucial in survival, proper growth, and development. There has been connection with child stunting, anaemia and other diseases and dietary patterns in Lao PRD and Myanmar. Rice overconsumption with nonsufficient food diversity leads to micronutrients and protein deficiency. NUC could be intercropped, and part of old established crops grown in rotation to protect and enhance agrobiodiversity (Li et al. 2020).

The following Table 1. lists neglected and underutilised crops in Southeast Asia. These crops are either originating or have been introduced and are fully domesticated in Southeast Asia. Local communities are usually using them as a significant part of their diet. These plant varieties might be used in nutritional initiatives to promote food security and reduce malnutrition in the rural population (Singh et al. 2022).

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
1) *Vigna subterranea*	Bambara groundnut	thaw din (Thailand)	Fabaceae	tuber	24 - 25.5	boilied , fermented, sprouted	high percentage of essential amino acids (EAAs): lysine, leucine, isoleucine, methionine	1,3
2) *Eleusine coracana*	Finger millet	ke chan vit (Vietnam)	Poaceae	grains	5 - 8	milled into flower, malted	highest calcium content among all cereals (344 mg/100 g)	2
3) *Ipomea batatas*	Sweet potato	camote (Philippines)	Convolvulaceae	tuber leaves	1.6 - 2.3 2.99	baked, boiled	high in fiber, antioxidants, vitamin A, vitamin C, beta-carotene	4,5
4) *Colocasia esculenta*	Taro	gabi, ube (Philippines)	Araceae	corm leaves	1 - 1.6 4 - 5	corm boiled, leaves raw	good source of dietary fiber, vitamin C, vitamin B6, and vitamin E	6
5) *Psophocarpus tetragonolobus*	Winged bean	thaw phu (Thailand) pe myit (Myanmar) dau rong (Vietnam) kacang batol (Malaysia) kecipir (Indonesia)	Fabaceae	seeds tuber shoots leaves pods	35.9 11.6 5.9 5.8 3	raw, boiled, stir-fried, roasted	high amount of protein, containing all 9 EAAs, rich in copper, iron and potassium minerals, vitamin C	7,8
6) *Coix lacryma-jobi*	Job's tears	cheik (Myanmar) tigbí (Philippines) skuay (Cambodia) deuay (Thailand, Lao DPR)	Poaceae	seeds	12.2 - 16.7	raw, boiled	rich in EAA leucine, poor on EAA lysine, containing antioxidants, containig selenium mineral	9
7) *Hibiscus sabdariffa*	Roselle	krachiap (Thailand) som pho di (Lao PDR) cay but giam (Vietnam)	Malvaceae	seeds calyces dried leaves	22 - 23 5.37 5.37	leaves, calyces eaten raw seeds eaten roasted, brewed	seeds are rich in amino acids such as lysine, arginine, leucine, phenylanine, and glutamic acid seeds are used as a coffee sustitute	10,11,12
8) *Piper sarmentosum*	Wild betel	cha phlu (Thailand) pak i leut (Lao PDR) pokok kadok (Malaysia) la lot (Vietnam) pinang (Indonesia)	Piperaceae	leaves	3-3.5	row, boiled	great source of micronutrients - vitamin C, thiamine, niacin, ribloflavin, caroten, calcium	13

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
9) *Moringa oleifera*	Moringa	marum (Thailand) dan da lun (Myanmar) malunggay (Philippines)	Moringaceae	dried leaves fresh leaves pods seeds	29.4 6.7 2.5 36	seeds eaten raw, cooked, leaves eaten raw, steamed, fried pods eaten boiled, steamed, fried	leaves and seeds contain full spectre of EAAs, leaves have 7 times more vitamin C than oranges and 15 times more potassium than bananas	14,15
10) *Elocharis dulcis*	Water chestnut	haew (Thailand) nan (Vietnam) kastanye air (Indonesia) apulid (Philippines)	Cyperaceae	dried corm	8	raw, steamed	despite low protein content in raw corm (2 %) contains full EAAs spectre low on EAAs - leucine, lysine, isoleucine, great source of fiber, reduce cholesterol levels	16
11) *Momordica charantia*	Bitter melon	pare (Indonesia) peria (Malaysia) kho qua (Vietnam)	Cucurbitaceae	fruit seeds leaves	0.84 26.96 - 27.82 19.5 - 20.06	raw, fried, steamed, baked	seeds contain high quality proteins - albumin (49.3 %), globulin (29.3 %), glutein (3.1 %) fruit with seed contain full spectre of EAAs	17
12) *Artocarpus altilis*	Breadfruit	sukun (Indonesia, Malaysia, Brunei) rimas (Philippines)	Moraceae	fruit	1.1 - 2.4	fried, boiled	high in fiber, high in micronutrints such as potassium, vitamin C, vitamin B1, vitamin B5	18
13) *Fagopyrum esculentum*	Buckwheat	khauz sa (Laos) phakbung-som (Thailand) mach hoa (Vietnam	Polygonaceae	seeds	12 - 15	milled into flower	Grown in northenmost parts of Southeast Asia, high fibre content	19
14) *Pachyrhizus erosus*	Jicama	bangkwang (Philippines)	Fabaceae	tuber	0.87	boiled, milled into flour - 6 % protein content	high level of dietary fiber and starch Vitamin C - 4 times more than carrot	20,21
15) *Nelumbo nucifera*	Laxmi lotus	sen hong (Vietnam) keang (Thailand) thaamara (Malaysia)	Nelumbonaceae	seeds rhizomes leaves stems	20 2.7 1.7 1.58	seeds eaten boiled leaves eaten raw stems eaten raw	seeds contain high quality essential amino acids - lysine, leucine, phenylalanine, high in micronutrients - zinc, calcium, vitamin E	22,23

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
16) *Pandanus amaryllifolius*	Pandan	pandan (Philippines) pandan wangi (Malaysia), (Indonesia, Singapore)	Pandanaceae	leaves	2 - 2.2	raw, boiled	contains high levels of phosporus mineral and beta-carotene	24
17) *Artocarpus heterophyllus*	Jackfruit	nangka (Indonesia, Malaysia) langka (Philippines)	Moraceae	fruit, seeds	1.8 - 2.84	raw, boiled	alternative to pulled pork meat for having same texture	25, 28
18) *Lablab purpuerus*	Hyacinth bean	da huong la (Vietnam)	Fabaceae	pods with seeds	15.8	boiled, stir fried	raw seeds contain high amount of alkaloids, seeds must be cooked properly for alkaloids to be destroyed	26
19) *Nypa fruticans Wurmb*	Nipa palm	chak (Cambodia) lambanog (Philippines) arak nipah (Indonesia)	Araceae	sap, fruit	2 - 2.9	raw, brewed	rich on carbohydrates - sucrose minerals - potassium and sodium	27
20) *Basella alba*	Ceylon spinach	remayong (Malaysia) alugbati (Philippines)	Basellaceae	leaves, stem tips	1.9	raw, stir-fried	100 grams of raw leaves contain more than 100 % of daily recommended dose of vitamin A and vitamin C, rich in minerals - iron, magnesium, manganese	29
21) *Vigna radiata*	Mung bean	monggo (Philippines) kacang hujau (Indonesia) foremungu TimorLeste	Fabaceae	seeds seed sprouts	15 - 24 3 - 3.2	raw, boiled	rich in fiber, carbs, vitmin B9, has full spectre of EAAs, but lower on threonine and methionine	1,3
22) *Amaranthus cruentus*	Red amaranth	bayam merah (Indonesia) phak khom (Thailand)	Amaranthaceae	leaves	2 - 7	raw	high in vitamin C and iron	31,32
23) *Canavalia cathartica*	Ground jack bean	dau dao (Vietnam) danglin (Philippines)	Fabaceae	seeds	18.6 - 21.7	roasted, boiled	one of the most underutilized legumes native to Southeast Asia, high content of dietary fiber	33

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
24) *Vigna unguiculata*	Cowpea	thaw phum (Thailand) paayap (Philippines)	Fabaceae	seeds	24 -25.8	raw, stir-fried, steamed	high in EAAs, low on sulphur amino acids - good combination with cereals, high in carbohydrates, it is subspecies of yardlong bean - has more micronutrients	1, 34
25) *Cajanus cajan*	Pigeon pea	kacang dal (Indonesia) kadyos (Philippines)	Fabaceae	seeds	20.9 - 22	raw, fried	excellent source of protein and iron, vitamin A and B-6, calcium, magnesium, potassium	35
26) *Sesbania bispinosa*	Dhaincha	dok sano (Thailand) pka snao (Cambodia) dien dien gai (Vietnam)	Fabaceae	pod	10	raw, deep-fried	good source of dietary fiber, vitamic A, C and B spectrum	37
27) *Phaseolus lunatus*	Lima Bean	kacang kratok (Indonesia) patani (Philippines) kefamenau (Timor-Leste)	Fabaceae	seeds pods	23.7 12	boiled, fried	extremly high on rare mineral molybdenium, 100 g of beans contain 313 % of recommended daily dose	38
28) *Neptunia oleracea*	Water Mimosa	rau nhút (Vietnam) phak runon (Thailand) kanchait (Cambodia)	Fabaceae	young shoots	6.4	raw, stir fried	high in calcium and iron, also it is used or phytoremediation - decontamination of soil or water from heavy metals	39
29) *Tamarindus indica*	Tamarind	asam jawa (Indonesia) sukaer (Timor-Leste) sampalok (Philippines) trai me (Vietnam) bekham (Thailand) magyee (Myanmar) khaam (Laos)	Fabaceae	seeds seed kernel pulp	18.1 21.7 9.15	raw, boield, roasted, dried, processed into flower (26.9 % protein content)	the flesh of tamarind fruit is processed into pulp that is solluted into water and drank to help regulate body temperature, seeds are highly nutritious	40, 62
30) *Abelmoschus esculentus*	Okra	kachang bedndi (Malaysia)	Malvaceae	seeds fruit	25 2	fried, raw	seeds contains lectin protein - inhibits growth of cancer cells, great source of vitamin B-9 - preventing neutral tube defects in fetus	41

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
31) *Aleurites moluccanus*	Candle Nut	kemiri (Indonesia, Malaysia) kamii (Timor-Leste)	Euphorbiaceae	seeds	8 - 19	cooked	in larger amounts laxative, raw seeds are containing alkaloids and are poisonous	42
32) *Dioscorea alata*	Winged Yam	alata (Philippines)	Dioscoreaceae	tuber	8.9	boiled, baked	good source of carbohydrates - 25 g/100g	43
33) *Vigna unguiculata sesquipedalis*	Yardlong bean	sitaw (Philippines)	Fabaceae	pod mature seeds	2 - 2.6 14.18	raw, boiled	great sorce of protein, vitamin A, B-9, C, phosporus, magnesium, manganese	1,44
34) *Terminalia catappa*	Sea Almond	ketapang (Indonesia, Malaysia)	Combretaceae	fruit with seed	20.14 - 25.4	raw, roasted	seed contains amino acids such as leucine, phenylalanine, isoleucine, histidine, valine, tryptophan, threonine, methionine, lysine and tyrosine	45, 60
35) *Sonneratia caseolaris*	Mangrove Apple	buah pedada (Malaysia)	Lythraceae	fruit	1.2 - 2.3	raw, steamed	in Singapore is considered endengered, in Malaysia its fruits are consumed mostly by locals and it is available only on street market	46
36) *Caulerpa lentillifera*	Sea Grapes	latok (Malaysia) rong nho (Vietnam) bulung (Indonesia)	Caulerpaceae	whole plant	17.5 - 24.21	raw	it is considered as a super-nutrient for its enormous micronutrient content	47
37) *eucheuma cottonii*	Eucheuma seaweed	guso (Philippines)	Solieriaceae	whole plant	6.21	raw	high in vitamins C, B1, B2, B3 high in calcium, iron, magnesium	49

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
38) *Ulva lactuca*	Sea Lettuce	lumot (Philippines) xa lach (Vietnam)	Ulvaceae	whole plant	9.4 - 10.8	raw, boiled, dried	10x daily dose of iron, 0,7 x daily dose of calcium in 100g of raw sea lettuce, also high in sodium, magnesium, potassium, iodine, manganese, phosphorus and vitamins A, B1, C	50
39) *Caulupera racemosa*	Caulerpa	khea lex r pa (Thailand) lato (Philippines)	Caluperaceae	whole plant	8.8 - 19.9	raw, cooked	antioxidant - used in cancer tratment and cardiovascular disorders	48
40) *Canavalia gladiata*	Sword bean	thaw dab (Thailand) khao (Laos) dau rua (Vietnam) tioeuhs (Cambodia	Fabaceae	seeds	26	boiled, stir fried	raw seeds contain poisonous protein, needs to be cooked, high on vitamin B spectre	51
41) *Amaranthus hybridus*	Smooth pigweed	bayam potong (Indonesia)	Amaranthaceae	leaves	16.38	steamed, raw	in traditional medicine used as anti-inflammatory drug	31
42) *Amaranthus hypochondriacus*	Prince's-feather	kulitis (Philippines)	Amaranthaceae	seeds	15	raw, cooked	seeds can be popped as popcorn	31
43) *Amaranthus blitoides*	Mat amaranth	mat (Indonesia)	Amaranthaceae	seeds	14 - 16.8	raw	cointains full EAAs spectre	31
44) *Amaranthus tricolor*	Edible amaranth	rau den ba mau (Vietnam)	Amaranthaceae	leaves	15.6 - 16.5	raw	seeds contain omega 3, 6, 9 acids - oleic, linoleic acid	31
45) *Canavalia rosea*	Beach bean	kha nawa leiy ro seiy (Thailand) kacang pantai (Indonesia) pataning dagat (Philippines)	Fabaceae	seeds	27.1 - 34.1	roasted	can grow in very dry and hot conditions, it is salt tolerant	52
46) *Archidendron pauciflorum*	Djenkol bean	jinkol (Indonesia) krakos (Cambodia) jering (Malaysia), (Thailand) da nyin pen (Myanmar)	Fabaceae	seeds	14.1	raw, roasted, boiled, fried	its mildly poisonous in raw state, containing djenkolic acid, it is traded only on local markets	53

(continued)

Table 1. Neglected and underutilized crops of Southeast Asia

Scientific Name	English Name	Local Name	Family	Edible Part(s)	Protein g/100g	Processing	Interest	Reference
47) *Canavalia ensiform is*	Jackbean	kacang parang (Malaysia) habas, lagaylay (Philippines) tiehs (Cambodia) thua khaek (Thailand) dau ra (Vietnam)	Fabaceae	seeds	23 - 30	boiled	toxic when eaten raw in larger amounts	54
48) *Vigna umbellata*	Ricebean	dau nho nhe (Vietnam) be nauk, be pwe (Myanmar) kacang uci (Indonesia) thaw daeng (Thailand)	Fabaceae	seeds	20.2 - 26.03	boiled, raw	balanced amounts of all EAAs, high amount of zinc, iron, potassium and calcium	1, 55, 61
49) *Paspalum scrobiculatum*	Kodo millet	araka (Philippines) aachi (Vietnam, Thailand)	Poaceae	seeds	9-11	milled into flower	native to India, good source of phosphorus, iron, vitamin B-complex, high on EAAs	56
50) *Parkia speciosa*	Stink bean	petai (Indonesia, Malaysia, Singapore) sator (Thailand)	Fabaceae	seeds pods	16.8 - 27.5 6	boiled	its consumption lowers blood sugar and blood pressure	57
51) *Setaria italica*	Foxtail millet	sekoi (Malaysia) jawawut (Indonesia)	Poaceae	seeds	10 - 12.3	boiled, baked	rich in vitamin B12	58
52) *Canarium indicum*	Nangai nut	kenari (Indonesia) canari, nangai (Malaysia)	Burseeaceae	seeds	13.5	raw, roasted	native to Indonesia, good source of magnesium, manganese, iron, vitamin E	59
53) *Sesbania grandiflora*	Vegetable hummingbird	katurai (Indonesia) so dua (Vietnam) khae daeng (Thailand)	Fabaceae	leaves	8.25	raw, boiled	rich in vitamin C, B9	36

1. – (Verma et al. 2022) 2. – (Devi et al. 2011) 3. – (Tan et al. 2020) 4. – (Sun et al. 2014) 5. – (Mohanraj & Sivasankar 2014) 6. – (Temesgen & Ratta 2015) 7. – (Sriwichai et al. 2022) 8. – (Ekpenyong & Borchers 1982) 9. – (Zhu 2017) 10. – (Salami & Afolayan 2021) 11. – (Hainada et al. 2008) 12. – (Balarbare 2019) 13. – (Sun et al. 2020) 14. – (Gopalakrishnan et al. 2016) 15. – (Stadtlander & Becker 2017) 16. – (Zhang et al. 2021) 17. – (Ibrahim et al. 2020) 18. – (Bakare et al. 2012) 19. – (Prakesh & Yadav 2016) 20. – (Juarez & Lopez 1994) 21. – (Huang et al. 2023) 22. – (Seruthi et al. 2019) 23. – (Bangar et al. 2022) 24. – (Adkar & Bhaskar 2014) 25. – (Ranasinghe et al. 2019) 26. – (Pandey et al. 2021) 27. – (Saengkrajang et al. 2021) 28. – (Thokchom et al. 2019) 29. – (Adhikari et al. 2012) 30. – (Shi et al. 2016) 31. – (Andini et al. 2013) 32. – (Wolosik & Markowska 2019) 33. – (Bhagya et al. 2006) 34. – (Abebe & Alemayehu 2022) 35. – (Sharnma et al. 2011) 36. – (Bhokre et al. 2011) 37. – (Gomase et al. 2013) 38. – (Palupi et al. 2021) 39. – (Atabaki et al. 2020) 40. – (Ishaku et al. 2016) 41. – (Gemede et al. 2015) 42. – (Rosa et al. 2022) 43. – (Baah et al. 2009) 44. – (Quamruzzman et al. 2022) 45. – (Santos et al. 2016) 46. – (Dari et al. 2022) 47. – (Zhang et al. 2019) 48. – (Bhulyan et al. 2016) 49. – (Matanjun et al. 2008) 50. – (Rasyid 2017) 51. – (Vadivel et al. 2010) 52. – (Aswathi & Abdussalam 2020) 53. – (Molla et al. 2021) 54. – (Solomon et al. 2017) 55. – (Kaur 2015) 56. – (Chandel et al. 2014) 57. – (Chhikara et al. 2018) 58. – (Huchchannanavar et al. 2019) 59. – (Janick & Paull 2008) 60. – (Sandoval 2017) 61. – (Katoch 2012) 62. – (Bagul et al. 2018)

In total, 53 different plants of 23 different families were collected in Table 1. The majority (37.7 %) belongs to the Fabaceae family, second most common family (9.4 %) was Amaranthaceae, and third most common family (7.5 %) was Poaceae.

From the 53 plants, 60.3 % were possible to consume either raw or processed (dried, cooked, milled, processed into jam or juice). 28.3 % were possible to consume only processed and 11.3 % were possible to eat preferably raw. The seeds were most preferably boiled or roasted, because in most cases, the seed contains small number of poisonous alkaloids which need to be destroyed by heat. Fruits were usually eaten raw without any thermal processing, just processed into jam or juice. The leaves, pods, stems and tubers were most commonly used as vegetable or made into salad. Some of the pods and all tubers must have been processed thermally, most commonly boiled.

Protein content was established in the 53 plants, for as many edible parts as possible. Protein content was established by searching research with multiple measurements to gain most precise numbers. The highest protein content was found in seeds, then leaves and pods. Fruits contained the least protein. For 36 plants, the protein content in at least one of the edible parts excessed 10 g/ 100 g, for 21 plants the protein content was found to be more than 20 g/100 g, and for 4 plants, the amount of protein excessed 30 g/100 g.

Six plants were chosen to be more described further in the text. These plant species were chosen based on protein content which must be at least 20 % of its mass and its potential to be more used in agriculture.

4.2.6.1. Selected Plant Species

These six plant species, namely: *Terminalia catappa* Linn., *Vigna umbellata*, *Parkia speciosa* L., *Nelumbo nucifera* Gaertn., *Psophocarpus tetragonolobus* L., *Tamarindus indica* L are further detailly described. All these six plants are either native or are introduced to Southeast Asian vegetation. These plants are adapted and suitable to grow in Southeast Asian region. All the plants are considered as neglected or underutilised and are either grown and consumed by local communities or grow in the wild and are just speculated to be commercialised in the future.

4.2.6.1.1 ***Terminalia catappa* Linn.**

English name: Sea almond

Family: Combretaceae

Description: *Terminalia catappa* is a tropical tree species commonly known sea almond tree, or tropical almond tree belonging to the family Combretaceae. It is native to Northern part of Australia and Indonesian and Malaysian shores, where it is known as Ketapang (Wheatley, 1992). The tree can grow between 25 – 40 metres tall and has a spreading canopy with glossy leaves. The flowers are small, from which form 1 – 5 oval shaped fruits (Jensen, 1995).

Ecology and cultivation: Sea almond grow in tropical maritime climates ranging between 13 – 36 °C with annual rainfall between 1000 – 3500 mm and latitude to 500 above sea level. The lower latitude sea almond grows, the bigger yield. The tree is soil-undemanding, is salt resistant and prefers direct sunlight (Sandoval 2017).

Nutritional values: A 100g sample of seed contains: 20.14 – 25.4 g protein, 52 – 56 g lipid, 14.9 – 17.2 g carbohydrate, up to 14.6 g of digestible fibre, calcium (447 mg), iron (5.3 mg), phosphorus (821 mg), vitamins B1 (0.45 mg), B2 (0.15 mg), B3 (0.6 mg) (Janick & Paull 2008).

Mode of use: The bark and leaves are used in traditional medicine to treat diabetes, high blood pressure or digestive problems. The green (immature) fruit is pressed to gain oil and the purplish red (mature) flesh of the fruit is processed into jam and the seeds are roasted and eaten as an almond substitute (Sandoval 2017). The nuts are important local food source, but they are only available on local market level, that is why sea almond is considered underutilised. In Philippines a whine is made by fermenting mature fruits (Thomson & Evans 2006).

Figure 2. Fruit of Sea almond (Thomson & Evans 2006).

Figure 3. Sea almond tree (Thomson & Evans 2006).

4.2.6.1.2 ***Vigna umbellata*** **Thunb.**

English name: Rice bean

Family: Fabaceae

Description: Rice bean is a tropical to temperate grain legume grown mostly in the northern part of mainland Southeast Asia – Vietnam, Cambodia, and Laos. Rice bean is perennial, although for agricultural purposes, grown as annual. It is usually 30 – 100 cm in height. Stems are branched with trifoliate leaves. On axillary racemes flower bright yellow blossoms which turn into 10 cm long pods that contain around 8 seeds. The seeds are around 7 mm long and usually differ in colour, from light green to yellow to brown according to amount of sunlight, water, and soil quality (Dahnipahle et al. 2017).

Ecology and cultivation: Rice bean is more tolerant to adverse conditions as drought, acidic soil, or waterlogging. It thrives on shallow or degraded soils. When put in high quality soil, the seed yield is reduced (Khadka et al. 2009). Rice bean prefers annual rainfall 1000 – 1500 mm with temperatures from 18 – 30 °C and direct sunlight.

Nutritional values: The raw sprouted seeds of rice bean for 48 hours showed the best result having 26.81 g of protein per 100 g (Kaur 2015). Another study conducted by Katoch (2012) shows rice bean seeds being a great source of minerals; having around 330 mg sodium, 1590 mg potassium, 480 mg calcium, 320 mg magnesium, 500 mg phosphorus, 3.5 mg zinc, 4.2 mg copper, 7.8 mg iron, and 6.2 mg manganese per 100 g. The seeds also contain full spectre of essential amino acids with outstanding amounts of leucine, phenylalanine, lysine, and valine.

Mode of use: Rice bean is often considered neglected and underutilised, but it plays an important role in local communities in Southeast Asia. The dry seeds are boiled and eaten with rice or replaced rice in soups, hence its name. The seeds can also be processed into dhal (stripped out of the hull and split). Young pods and leaves can be eaten raw or as a vegetable, along with sprouted seeds (Joshi et al. 2008).

Figure 4. Flowering of Rice bean (*Vigna umbellata*) (Pascal 2016)

4.2.6.1.3 ***Parkia speciosa*** **L.**

English name: Stink bean/Bitter bean

Family: Fabaceae

Description: *Parkia speciosa*, in Southeast Asia better known as petai is an evergreen umbrella-shaped tree with pinkish to reddish bark that can grow up to 40 metres (Chhikara et al. 2018). The flowers are in a shape of a light bulb on the end of a long stem which attracts bats, which pollinate petai the most. The fruits come in up to 50 cm long pods, which contain 10 – 18 large seeds. The green seeds have a heavy, unpleasant smell and bitter garlic-like taste; hence the names stink bean or bitter bean. It is native to Sumatra Island and Borneo (Zaini & Mustaffa 2017).

Ecology and cultivation: Petai grows in lowland humid tropics with an elevation below 1400 metres and prospers mostly in the temperature range of 20 – 28 °C. It prefers rainfall of 1000 – 2000 mm annually. It prefers direct sunlight and is soil-undemanding (WFO 2023).

Nutritional values: Stink bean nutritional values differ according to the maturity of the husk. The younger pods with underdeveloped seeds contain around 6% protein of its weight and mature seeds' protein content moves between 16.8 – 27.5 %. Carbohydrates make up around 33 % and fats 7.5 % of its weight. The key minerals are calcium (186 mg), iron (2.5 mg), phosphorus (115 mg), magnesium (29 mg), and potassium (341 mg). The key vitamins are vitamin C (19.3 mg), vitamin E (4.15 mg), vitamin B1 (0.28 mg) per 100g (FTA, 2023) (Chhikara 2018).

Mode of use: *Parkia speciosa* is mostly sold on local markets and eaten by local communities, it is believed that the seeds have miraculous effects because of the high antioxidant values (Ahmad et al. 2019). It is used to treat diabetes, kidney and liver damage and also as an external wound healing agent. In terms of culinary use, *Parkia speciosa* is eaten raw or cooked, pods mostly raw with salt and the beans could be used for flavouring because of their pungent garlic odour or even as a side dish to fresh shrimp with sambal (chilli paste) (FTA 2023).

Figure 5. light bulb-shaped flower of Parkia speciosa (Mustaquim 2023)

Figure 6. Parkia speciosa pods and beans (Abdullah et al. 2011)

Figure 7. Parkia speciosa tree (Baro 2016)

4.2.6.1.4 *Nelumbo nucifera* **Gaertn.**

English name: Laxmi lotus/Sacred lotus

Family: Nelumbonaceae

Description: Laxmi lotus, also called sacred lotus refers to Hindu goddess Lakshmi, the goddess of fortune, power, and prosperity, who is depicted standing on lotus (Shen-Miller 2002). Nelumbo nucifera is a tropical perennial aquatic plant native to Southeast Asia growing out of mud in freshwater ponds. In the mud grows rhizomes which anchor the plant not to be carried away by water. From the water emerges long stem which connects rhizomes with foliage and flower. From the flower develops conical fruit with seeds that are developing each in one socket (NPBS 2023).

Ecology and cultivation: Nelumbo nucifera grow in wetlands as ponds, lakes, lagoons, swamps, and water reservoirs with fair amount of water, at least 60 cm in depth. The water should have temperature between 25 – 35 °C for seed to propagate and throughout the lifespan of lotus, water temperature should not drop below 10 °C. Lotus requires maximum amount of sunlight (Guo 2009).

Nutritional values: According to findings of research conducted by Sruthi et al. (2019) and Bangar et al. (2022) most nutritious in terms of protein content are the mature seeds of Laxmi lotus (up to 20 %), followed by rhizomes (2.7 %), and by leaves and stems, having similar amount (1.58 – 1.7 %). From all of the plant parts, seeds have best proportions of micronutrients content. Minerals as zinc (1.3 mg), iron (1.3 mg), magnesium (165 mg), phosphorus (171 mg), vitamins as B1 (2.24 mg), B6 (0.3 mg), E (0.46 mg) have relatively high amounts per 100 g.

Mode of use: Sacred lotus has a strong cultural importance. In local Southeast Asian culture, it is believed that it has therapeutical and healing effects. This has been proven to be true by study by Mukherjee et al. (2009), by phytochemical tests. The seeds, rhizomes and leaves have antioxidant, anti-inflammatory, antidiabetic, antimicrobial and antidiarrheal effects. Culinary use-wise, rhizomes are consumed raw or added into soups or curries. Young leaves are boiled and eaten with rice. Petals and stamens are used to make tea. The most nutritious part – seeds are roasted or boiled and then could be processed into syrup or paste, that is usually used to make lotus seed noodles (Liu et al. 2022).

Figure 8. Nelumbo nucifera flowering (IWF 2023)

Figure 9. Nelumbo nucifera flower with seeds (Priya et al. 2021)

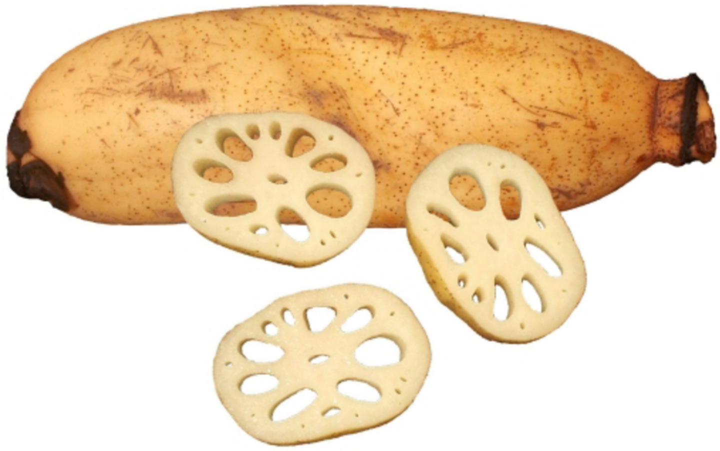

Figure 10. Rhizome of Nelumbo nucifera (DPIA 2023)

4.2.6.1.5 ***Psophocarpus tetragonolobus*** **L.**

English name: Winged bean

Family: Fabaceae

Description: Winged bean is a perennial (commercially planted as annual) twining legume, which grows in hot, humid areas. It is listed as underutilised crop in Southeast Asia. It produces wide trifoliate leaves and variety of white, purple, blue to red flowers on weak vining stems. At maturity, winged bean produces 15 – 23 cm long pods with four wing shaped leaves lengthwise to the pods: hence the name, winged bean. (Bassal et al. 2020).

Ecology and cultivation: Winged bean can live at altitudes ranging 0 – 200 m. It is soil undemanding and can prosper even on land with low amount of nutrients (Mohanty et al. 2013). Annual rainfall for winged bean is at least 700 mm and it requires temperatures of 15 °C to 30 °C, although ideal temperature for growing is 25 °C (Singh et al. 2022).

Nutritional values: The whole plant is edible and is consumed by local communities. Most nutritious in terms of protein content are the mature seeds of winged bean (up to 37 %), followed by tuberous roots (11.6 %), leaves and shoots, having similar amount (5.8 – 5.9 %), and leaves (3 %) (Ekpenyong & Borchers 1982). Winged bean seeds contain the most micronutrients and are predominant on vitamins: B9 (66 μg), C (18.3 mg), B1 (0.14 mg), B6 (0.11 mg), and on minerals: calcium (84 mg), iron (1.5 mg), magnesium (34 mg), manganese (0.22 mg) (Singh et al. 2022).

Mode of use: Unripe seeds are eaten in soups, mature seeds are most often eaten cooked and added into curries, sambals and dhals or can be dried and ground into flower. Young shoots, leaves and young pods are eaten raw, added to salads. Tuberous roots resemble sweet potatoes, have nutty flavour, and are used as a substitute for potatoes (Eagleton et al. 2023).

Figure 11. flowering of winged bean (Kang 2017)

Figure 12. Mature fresh pods with seeds (left) and dried pods with seeds (right) of winged bean (Makoto 2023)

4.2.6.1.6 Tamarindus indica L.

English name: Tamarind

Family: Fabaceae

Description: *Tamarindus indica* is a tropical evergreen leguminous tree growing between 20 – 30 m tall, greyish bole 2 m in diameter with petty compound leaves on hairy petioles. Flowers are ranging from pink to pale yellow and flower buds are falling off soon, then fruits develop. Fruits grow in a pod, up to 20 cm long with brown colour. Inside, there are up to 10 seeds wrapped brown pulp with sweet and bitter taste (Pal & Mukherjee 2020). It is native to eastern tropical Africa but has spread to other tropical regions as Southeast Asia (Azad 2018).

Ecology and cultivation: Tamarind is usually growing at more elevated grounds, more than 1500 m above sea level. That is caused by annual rainfall, which is always higher in higher altitudes. The minimal requirement of annual rainfall for tamarind is 1500 mm (Azad 2018). Tamarind requires slightly acidic, moist, fertile, and sandy soil. Younger trees should not be exposed to full sun but older require full sun. It can withstand high temperatures for shorter period of time, prospers in temperatures around 18 – 30 °C, thrives at temperature around 25 °C (Gebauer & Ebert 2003).

Nutritional values: Tamarind pulp is surprisingly high in protein with 9.15 % of its mass, with fair amounts of calcium (21.57 mg), iron (1.05 mg), magnesium (10.54 mg), sodium (112 mg), and potassium (188 mg) (Ishaku et al. 2016). Predominant vitamins are C (3.5 mg), B1 (0.43 mg), B2 (0.15 mg), B3 (1.94 mg) (USAD 2019). The seeds including kernel have up to 21.7 % protein content. Tamarind seeds flower is very popular and can have up to 26.9 % protein content. The micronutrient content is similar with the pulp and seeds (Bagul et al 2018) (Gitanjali et al. 2020).

Mode of use: Fruit pups are used in traditional medicine thanks to its antioxidant and anti-inflammatory properties. In Cambodia, the bark is used to cure diarrhoea, In Indonesia, oil is extracted from the seed and is used as a hair tonic (Paull & Duarte 2012). It is also used to make jams, jellies, syrups, and cakes. Hot beverages made out of the dried pulp, processed into paste are traditionally used to mitigate heat stress by vasodilation (dilation of blood vessels) (Hasan et al. 2022). The pulp can also be used in curries or chutneys. Seeds are roasted and eaten as a side dish or can be processed into flower (Gitanjali et al. 2020).

Figure 13. Botanical morphology of Tamarindus indica. (a) T. indica tree (b) T. indica bark (c) T. indica leaves (d) T. indica flowering (e) T. indica pods (f) T. indica pulp (g) T. indica smooth seeds (Komakech et al. 2019)

5. Conclusions

This work had focused primarily on underutilised and neglected plant species containing primarily high amount of protein or at least containing decent amount of protein and high amount of micronutrients. These plant species are underutilised and neglected because they can be unappealing or not as profitable as staple crops on national level. But on a regional scale, between the local communities who depend on agricultural produce, the plants provide food security and nutrition. Some of them also have a cultural meaning.

In this work were analysed 53 species of plants from 23 different families, native or introduced to Southeast Asia. These plants could serve as a source of protein and micronutrients. The most predominant families were Fabaceae (37.7 %), Amaranthaceae (9.4 %), and Poaceae (7.5 %). As much as 21 plants from the selected species have at least 20 % protein content. In all cases, seeds have the highest protein content from all the plant parts, whereas fruits have the lowest.

From these 53 plant species, six were chosen to be described thoroughly, namely: *Terminalia catappa* Linn., *Vigna umbellata* Thunb., *Parkia speciosa* L., *Nelumbo nucifera* Gaertn., *Psophocarpus tetragonolobus* L., *Tamarindus indica* L. The plant species have been chosen based on underutilisation, its potential to become more frequently used crop, and protein content which has to be at least 20 % of its mass.

Animal protein will always be better source of amino acids and micronutrients. But the advantage of plant protein is in its availability, affordability, frugality to the environment and easier production. Their consumption would improve food security and even contribute to diversification of the diet. To promote these underutilised and neglected plant species, or any else, the perception of these foods needs to be changed.

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