Chapter

Potential of Amaranth in Alleviating Malnutrition in Indonesia

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Abstract

An extricable link between biodiversity and nutrition security has been magnified by many researchers over the past three decades as humans have utilized more than 10,000 edible species from the totally expected to be 300,000 plant species. A strong reliance on handful of major crops has inherent agronomic, ecological, and nutritional risks and is probably unsustainable in the long run. On the other hand, global food production is still a main challenge for the future of mankind. New strategies such as the exploration and utilization of underutilized crops have been affirmed as some of the promising fields to meet world food needs. As such crop, amaranth (*Amaranthus* spp.) has the potential to be prospected as potential plant in alleviating malnutrition in most of the developing countries, especially in Indonesia (location: 6°N to 11°S and from 95°W to 141°E) also known as the biggest archipelago country in the world. Malnutrition with its two constituents of protein-energy malnutrition and micronutrient deficiencies has been recognized as a persisting public health challenge in many developing countries, e.g., Africa, Asia, and Indonesia. This paper highlights the advantage of amaranth in terms of their nutrition and further application in nutraceuticals.

Keywords: grain, malnutrition, protein, vegetable, weedy types

1. Introduction

An extricable link between biodiversity and nutrition security has been magnified by many researchers over the past three decades as human has utilized more than 10,000 edible species from the totally expected to be 300,000 plant species. Nevertheless, there are only few or up to 150 of those edible ones that have been commercialized significantly on the global scale. Among huge alternative crops existing, humans depend only on 12 plant species that supply dietary energy with a strong dependency on 4 species only, namely, rice, wheat, maize, and potato. Thus, reliance on handful of major crops has inherent agronomic, ecological, and nutritional risks and is probably unsustainable in the long run [1].

On the other hand, global food production is still a main challenge for the future of mankind. Rapid deforestation, feeding the world population, and climate change have made it to be much more challenging [2]. The dramatic decline of tropical rain forests and habitat destruction aiming for settlement, cash crop plantation such as oil palm and rubber, and building of infrastructures would lead to massive biodiversity loss. This consequently would adversely affect human's life quality [1].

While the area of planting has been dramatically reduced, on the opposite, the agricultural production is expected to be increased by 70% as a result of a 40% increase in world population [1]. The impact of climate change for most of the developing countries would exacerbate the food security challenges due to higher frequency of droughts and flood [3].

2. Potential of underutilized crops

It is mainly known that almost 900 million people are hungry worldwide. In adjacent to that, 195 million children under 5 years of age are stunted. Of this total number, 90% live in 36 countries, mostly in the developing ones [4]. New strategies such as the exploration and utilization of underutilized crops as well their genetic assessment and plant genetic diversity interlinked with plant breeding have been affirmed as some of the promising fields to meet the world food needs [4]. Thus, re-directing the global agricultural system to ensure better nutrition is critical. The current global trend in agricultural system produces enough food quantitatively in total; however, the rapidly growing population demands not only an increase in quantity but also in terms of highly nutritious food with good protein quality [4, 5]. In regard to this, it is imperative that both researchers and development professionals apply new and sustainable approaches to enhance the quality and to increase the variety of food produced and consumed around the world. Other innovative methodologies embedded in agriculture and food science will also be essential to upscale dietary diversity and nutrition [4].

Over the past two decades, moreover, nutraceuticals have been much more explored as some vegetables and fruits bear great potential to be further prospected as antioxidant, anticancer, anti-allergic, and antihypertensive agent and as a food for patients with autoimmune diseases [6]. Thus, an alternative approach other than the major staple crops, valorization of valuable, however underutilized, crops have been in the focus of many (food) researchers and agronomists [1]. In many areas, such underutilized particularly the weedy edible types have been playing a major role in fulfilling the micro- and macronutrients and protein requirements [7]. Therefore, this paper highlights the potential and utilization of *Amaranthus* sp. in developing countries, especially in the most densely populated countries such as in Indonesia.

3. Indonesia *vs.* malnutrition

Indonesia—the biggest world archipelago—is located at the tropical equator and situated between the Indian and Pacific oceans and the Asian and Australian continent. It extends from latitudes 6°N to 11°S and from 95°W to 141°E. The greatest distance from west to east and north to south is 5110 km and 1888 km, respectively [8]. The archipelago consists of almost 17,504 islands, with five major islands, namely, *Borneo*, *Sumatra*, *Papua*, *Celebes*, and *Java* (from the biggest one). While smaller islands such as Bali and Nusa Tenggara are stretched starting from the middle to the eastern part of Indonesia.

Almost 65% of its population live in rural areas and depend highly their livelihood on the agricultural basis activities as one of the five biggest *gross domestic product* (GDP) contributions is based from agriculture and cash crop such as palm oil and rubber. The GDP from this sector grew at 2.3%, annually. The major *staple* crops are rice, which are mostly consumed by the western part of Indonesia, while the eastern parts such as *Nusa Tenggara* islands have a distinct climate with a much warmer and drier climate and are suitable for many savannas. Thus, their staple crops are slightly distinct, and the inhabitants depend a lot on maize and cassava as they are much more suitable to a drier environment.

The major crops grown in Indonesia are rice, maize, soybean, peanut, cassava, and chili; meanwhile, the major vegetables grown in the country are chili; yard-long bean; cabbage; kidney bean; cucumber; Chinese cabbage; green mustard; amaranth (*A. tricolor* L.), which is mostly perceived as "spinach"; French bean; eggplant; garlic; and carrot. Most of the vegetable cultivation is mainly concentrated on Java Island as their infrastructures are better prepared rather than outside Java or any other dispersed islands. Within the agricultural sector, the food crop sub-sector employed about 27 million people or equal to 75% of the agricultural labor force [8].

It is also accounted as the fourth biggest world population with 270,054,853 people. The population is unevenly dispersed within the archipelago. There are 32 provinces stretching from Aceh to Irian Jaya; however, about 60% of it resides on Java—the smallest island among the big five—but Kalimantan which accounts for 28% of Indonesia's total land area, as a matter of fact, is home to only 5% if the total population. The population density on Java is about 800–1000 people per km^2, but Irian Jaya has only 7 people per km^2 [8]. In terms of economic, Indonesia is classified as one of the three biggest Southeast Asian countries—after Singapore and Malaysia—with a vibrant economic growth, namely, in the range of 5.1%, yearly [9].

The United Nations Food and Agriculture Organization (UN-FAO) agrees that to secure access for all to adequate supplies of food that is healthy, safe, and of high quality, and to do so in an environmentally sustainable manner. Nevertheless, with the rapidly growing population, how our current global food system will sustain itself remains a challenge. Additional (man-made) external factors, such as climate change, urbanization, social conflict including refugee from war-inflicted countries mostly in Africa and in the Middle East, extreme poverty, as well as overly stressed ecosystems and biodiversity, make it more obvious that there has never been a more urgent time for collective action to address food and nutrition security at the global stage [4].

In terms of biodiversity richness, Indonesia is counted as the second biggest biodiversity *hotspots* in the world, and ranked after the Amazon basin in South America. Despite its biodiverse-rich environment and economic growth as it was mentioned before, it is estimated that 87 million of population in Indonesia remain vulnerable to food insecurity [10]. Multi-stakeholders in Indonesia have been aware that nutrition must be at the forefront of the major goals of agriculture and production systems, so that *agricultural biodiversity* can serve as an avenue to improve dietary and nutritional diversity as well as in improving life quality and maintaining health [4]. Meanwhile, the *agricultural biodiversity* itself is perceived as biological variety exhibited among crops, animals, and other organisms used for food and agriculture, in conjunction to the web of relationships that bind these forms of life at ecosystem, species, and genetic levels. This includes not only crops and livestock directly relevant to agriculture but also many other organisms that have indirect effects on agriculture, such as soil fauna, weeds, pests, and predators [4].

Malnutrition with its two constituents of protein-energy malnutrition and micronutrient deficiencies has been recognized as a persisting public health challenge in many developing countries, e.g. in Africa, Asia, and including Indonesia. It is the direct cause of about 300,000 deaths per year and is indirectly responsible for about half of all deaths in young children. Certainly, poverty, political and economic situation in one country, and unhealthy environment including bad sanitation have worsened the problem [10]. Moreover, the loss affected due to malnutrition in Indonesia has been estimated to be 2–3% of Indonesia's gross domestic products or GDP or equal to more than US$ 5 billion yearly as a result of poor education standard, low IQ score, reduced productivity over time, and diminishing physical capability.

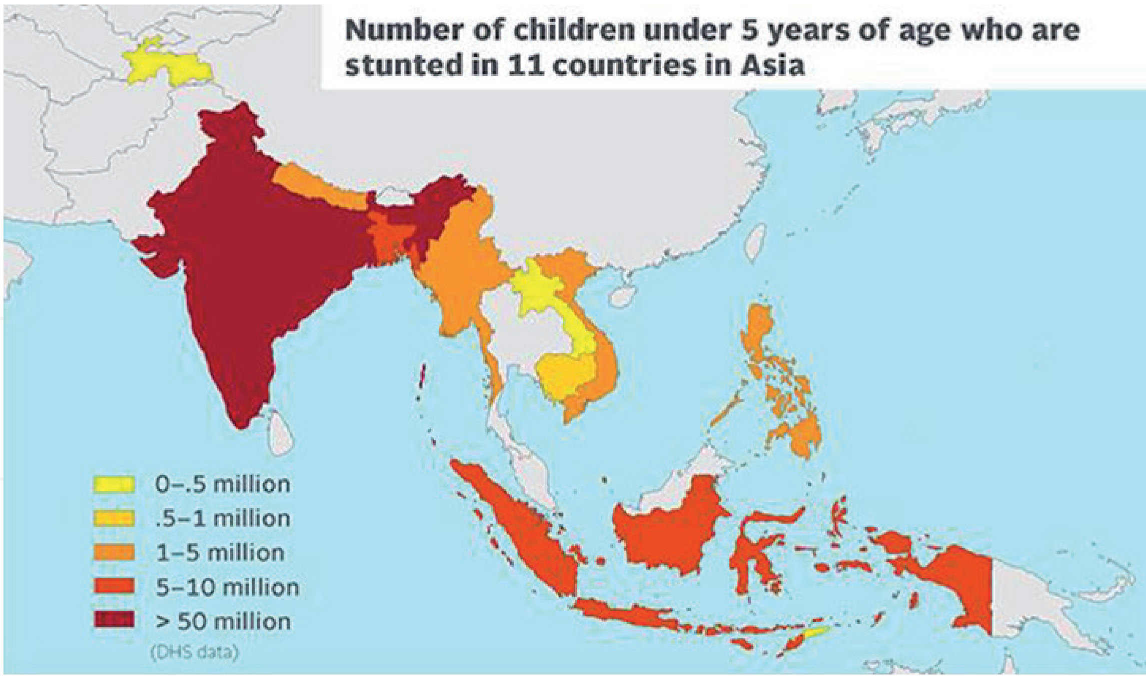

Figure 1.
Malnutrition map in Asia (source: [12]).

The physical condition of malnourished children is indicated generally with wasting and stunting. Wasting children loss their weight progressively. Chronical weight loss among children leads to stunting. It has been reported that over the past 6 years, the stunting situation has not yet been improved as there are 37% children under 5 years in Indonesia are malnourished, while more than 12% of children are suffering from wasting; with most of them live in the rural areas [10]. According to a USDA-based technical report, Indonesia is on an "alert" regarding the malnutrition among children under 5 years of age as indicated with the orange color (**Figure 1**). Furthermore, the highest prevalence number was found on the drier part of Indonesia such as East Nusa Tenggara with up to 58% [11].

4. What is amaranth?

The family of *Chenopodium* including amaranth is known as a good source of protein-rich green leafy vegetables [13]. Amaranth in the ancient Greek means "everlasting" or "unfading." The plant occurred about 5000–7000 years ago in the New World with *A. hybridus* as the putative progenitor. Out of 70, most of them are native to the Americas, while only 15 species are recognized to be native to Africa, Europe, and Asia. Phylogenetically, the genus was originally clustered into two sections: *Amaranthus* and *Blitopsis* Dumort. Later on, it was divided into three sections, and more recently, the genus has been distinguished into three *sub*-genera and nine sections, based on inflorescence and flower characters [14]. The most recent finding has separated it into three *sub*-genera, namely, *Acnida*, *Amaranthus*, and *Albersia*, by using genome-wide molecular markers [15].

Taxonomically, *Amaranthus* sp. is often difficult to characterize as it has few useful distinguishing features among the large number of species. The so-called *Amaranthus hybridus complex* includes the three grain species and their two potential wild ancestors: *A. hybridus* and *A. quitensis*. These five species are proposed to be closely related and readily cross within the complex due to a specific hybridization character, which is also often regarded as common phenomenon in this genus. Thus, outcrossing rates ranging from 5 to 30% has been reported [16].

Meanwhile, a lower rate was performed by *A. caudatus* L., which was in the range of 25%, solely [16]. Although the taxonomic identification in *Amaranthus* is confusing, genetic markers are expected to provide a distinct and inexpensive solution for species identification. Based on the recent studies using *simple sequence repeat* (SSR) marker and genotyping by sequencing, it is commonly agreed that *A. hybridus* is a common ancestor to the three cultivated grain amaranths, although it has not yet been fully resolved if the three species occurred from one single or multiple domestication event. However, phylogenetic and population genetic analysis suggested a clear geographic grouping of *A. hybridus* from South America with *A. quitensis* and *A. caudatus* and *A. hybridus* from central America with the two northern crop species. This suggests separate domestication events in the different regions [15].

The utilization of amaranths depends greatly on geographical preferences. People on the humid tropical continents such as Asia and Africa use the young and succulent leaves as vegetables, meanwhile people on the northern hemisphere consume the grain amaranths. Due to its vivid color, amaranths are also cultivated as ornamentals. Most amaranth is mainly found in the form of weedy types including true weeds such as *A. retroflexus* L. Besides the two main types, some dual-purpose types, such as *A. cruentus* L. and *A. caudatus,* also exist. The dual purpose means that both their young, succulent leaves and their grains are also edible. They are mostly appreciated in most of African and Asian countries [14]. Here, we tried to highlight the two cultivated types of amaranth and the potential of the weedy edible ones.

Several morphological studies have been conducted in order to clarify its taxonomy, and several systematic botanical revisions based on leaf anatomy and morphology, pericarp structure, stem morphology, and anatomy have been also proposed [14]. A high variability of morphological variation and high nutritional qualities were reported in the Indonesian weedy accessions, particularly the *A. dubious* that may exist as diploid (n = 16 or n = 17), or it may sometimes exist as natural tetraploid as this was supported with distinct phenotypical features found in polyploidy: e.g., different leaf texture, bigger leaf size, darker green color, and much resembling spinach (*Spinacia oleracea*). Polyploidy means the heritable condition of having more than two complete sets of chromosome and is counted as an important evolutionary and speciation process in many plants and some animals. In amaranths, polyploidy would affect morphological performance such as vigorous plant performance, biomass heterosis, and shorter and thicker stemmed than those normal diploids, up to increase of seed size, although with no significant changes in the nutritional content. However, no polyploids were found by the Indonesian weedy edible based on the flow cytometer measurement [17].

In terms of its adaptability, amaranth possesses wide adaptability due to its C_4 plants' characteristics meaning that they are highly productive plants. It can be cultivated from temperate to tropical conditions and distributed in at least 50 tropical countries in Asia and Africa [13]. Andini [18] proposed that it is mainly classified as short-day plants, meaning that an eight hour of photoperiod is required to make them to flower. However, the vegetable types resemble the long-day plant as well. Based on the field experiment conducted under temperate regions with different photoperiods, it was revealed that they require 12 hours of photoperiod in order to initiate its flowering. Such distinct features support the wide ecogeographical distribution in amaranth at the global level.

5. Nutritional values in amaranth

The incorporation of high-protein and mineral-containing crop would improve dietary diversification and enhance food quality or nutritional values. Amaranth is acknowledged as rich and inexpensive source of dietary fiber, mineral, vitamins, protein, and antioxidants [19]. As it has been highlighted previously that there are up to 70 species included in the genus, however, only 17 species are classified as edible, and they accounted as the most important leafy vegetables with excellent nutrition for the lowland tropics of Africa and Asia [13].

From the agronomical point of view, amaranth can be grown successfully under varied soil and agroclimatic conditions of tropical lowlands with an elevation ranging from 100 to 800 m *a.s.l*. up to subtropical region such as the Indo-Gangetic Plains, which has sharp congruences in temperatures or between summer and winter seasons. In India, amaranth is being known as "Kharif" crop, and during summer season with the temperature reaching up to 45°C, among all Indian vegetables available in the region, only amaranth can endure such high temperature. This feature shows the heat resistance in amaranth [20]. In Indonesia, cultivation area can be divided into three categories: (a) lowland (altitude 0–200 m), (b) medium (altitude 201–800 m), and (c) highland (altitude above 800 m) with almost 30% plantation in Indonesia located on the highlands [8].

Amaranth in Indonesia is very popular and ranked as the third mostly produced green leafy vegetables. The number of amaranth's production is ranked as the third in Indonesia (**Figure 2**). Vegetable amaranth is part of the Indonesian's daily dishes, and its taste resemblance to that of spinach. It is mostly cultivated on small plots less than one hectare belonging to subsistence farmer. The plots are located along the riverside or open fields scattered at the periphery of suburban areas and can be harvested within an interval of 4 to 6 weeks per harvest season. The yield is in the range of 2–5 tons ha^{-1} per harvest season, but it is available throughout the year, frequently traded in Indonesian traditional markets and usually sold in small bundles consisting of 10–20 plants. Growing amaranth is counted as one of the economically important vegetables in Indonesia. Moreover, vegetable amaranths provide a high concentration of vitamin A, and their nutritional benefit was incorporated by the eradication of children's dark blindness in 1973–1980 in Indonesia [13].

Siemonsma and Piluek in [13] estimated that up to 225 primary use vegetables and more than 100 wild species exist, including a large number of weedy

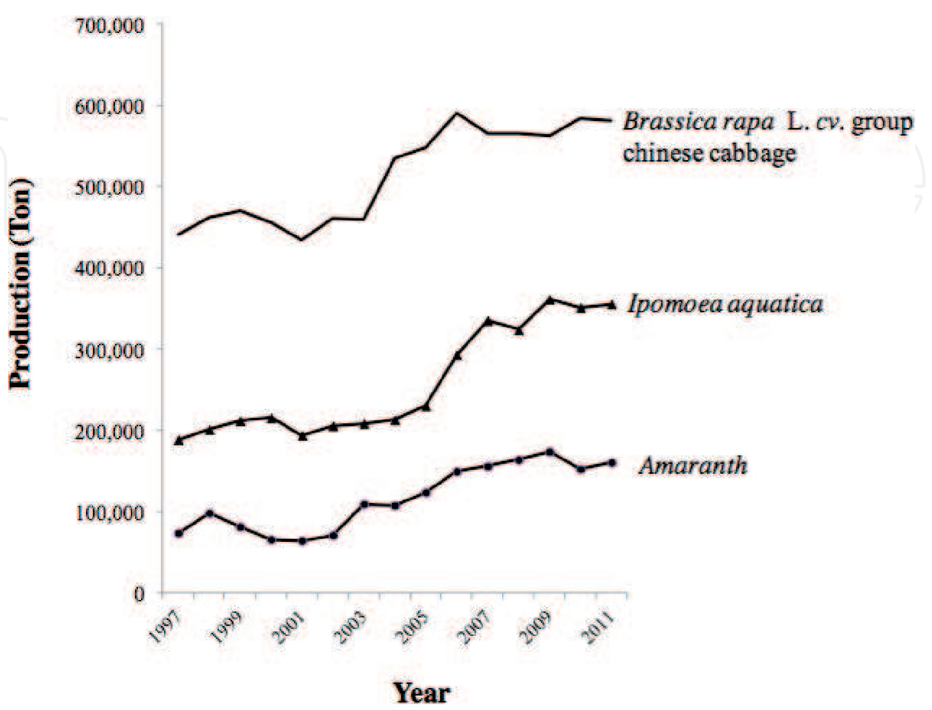

Figure 2.
Production number of three major leafy vegetables in Indonesia [source: depicted from 37].

companions. The high biodiversity in Indonesia may open opportunities for breeding new type of amaranths with desired characters such as high-protein content. In terms of protein nutritional quality, some parameters, such as protein digestibility, available lysine, protein utilization, and the composition of well-balanced essential amino acid in food sources, especially the availability of lysine, methionine, and tryptophan, are counted as important aspects [5]. Generally, vegetable amaranths have received lower attention than the grain ones [21]. Although their nutritional superiority is not too much distinct from the grain ones as the leaves of amaranths were found to be a good source for lysine, which is required during the growth of young children or under 5 years old.

Research on the extent of the diversity of amaranths aiming to choose some of the weedy types as prospective genetic resources for useful traits has been conducted. The work reported the superiority of weedy edible amaranths harvested in the wild of Gayo Highlands, such as *A. blitum* L., *A. dubious*, and *A. viridis*, compared to the most commercial one (*A. tricolor* L.). Until now, they are still being classified as underutilized and particularly used as famine food. Therefore, screening of potential lines with novel characteristics in amaranths should be initiated and promoted for any further breeding and conservation attempts. In most of weedy types, the content of leaf-protein and total amino acids were 12–29 g 100 g^{-1} DM and 84–93 g 100 g^{-1} DW protein, respectively. Such amount of protein was 2.3 higher than the most cultivated type (*A. tricolor* L.) [22]. In terms of adaptability, they are also more robust as they require very low agricultural input, easy nursery, and heat resistance, and all these have made them a potential to be incorporated as parental lines for high-protein amaranth [22].

Furthermore, a large number of trace elements such as iron (*Fe*), calcium (*Ca*), phosphorus (*P*), and zinc (*Zn*) were found in amaranth in the range of 15, 239, 33, and 0.6 mg per 100 g fresh leaves. Such trace amounts are significantly needed in order to establish a wide range of metabolism or functions in the body. Besides, amaranth is also known to be a good source of ascorbic acid and β-carotene with values ranging from 39 to 111 mg and 5.41 to 8.3 mg per 100 g fresh leaves, respectively. It can be concluded that a consumption of 100 g of fresh amaranth in the diets is recommended—particularly for those vegetarian—in order to fulfill daily nutritional requirements [19, 20].

Despite the health positive benefit effects exhibited in Amaranth, the antinutritive content such as oxalate and nitrate might be the hindrances in exploiting amaranth as food resource. The leaves were reported to have a relatively high amount of oxalate, which is in the range of 7.8–12.0 mg g^{-1} and 1.8–4.4 mg g^{-1} of nitrate. Although it is known that the level of toxicity of oxalate is quite low and a minimal lethal dose for humans is considered to be in the range of 5 g for an adult, vegetables are mostly found as the source of high levels of nitrate because the content of this salt could reach up to 3.25%. Such high values might be harmful to humans as nitrate has been described as potential carcinogenic via transforming first to nitrite and then to nitrosamine [23]. Therefore, cooking properly and discarding water from boiling the vegetables might be counted as preventive measurement.

6. Nutraceuticals in amaranth

Since 1980, *Amaranthus* has been rediscovered as potential crop for the twenty-first century with promising food ingredients that can substitute cereal proteins [24]. Generally, the three major crops (rice, wheat, and maize) provide the largest proportion of daily nutrition and calories for billions of people, but they lack of essential minerals and vitamins for a balanced nutrition. Because of its similarity with "true cereals," thus, amaranth is referred as "pseudocereals," having a superior nutritional quality, and highly recommended for those who are suffering *celiac disease* or from hypersensitivity against gluten or prolamin content [25].

Amaranth can be grown for their seeds and are called as grain amaranths. The three most representing are *A. cruentus*, *A. caudatus*, and *A. hypochondriacus*. Since 1980, it has been rediscovered due to its extra ordinary nutritional characteristics, particularly as an alternative crop when cereals and vegetables can't be grown due to abiotic challenges [24]. The protein content found in the grain amaranth was relatively high, namely, 13–19% DM; thus, this is close to the optimum required in the human diet as described by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) [26]. Moreover, the amount of lysine and sulfur is two to three times higher than wheat, rice, and maize and greater than legumes, respectively. Recent reviews were published, and they reported the health benefit effects derived from the oil or grain, such as reducing blood pressure activity (*hypocholesterolemic*), enhancing the immune system, antitumor effect, action on reducing glucose levels in blood, effects on enhancing liver function, reducing blood pressure, anti-allergic, and possessing antioxidant activity against cancer [25].

The medicinal importance of amaranth has been known since the ancient time. In Russia, it has been applied as a mixture with tea as it can be used in prophylactic and therapeutic purposes as well as applied in stomach cleaning, diuretic, cough, headaches, and tumor. These advantageous health effects are often attributed to different antioxidant components [21]. Antioxidants are recognized as important nutraceuticals, which bring health-positive impacts because of phenolic compounds that are attributed with radical-scavenging activity [27]. The oil in amaranth is an important source as an effective natural antioxidant supplement as it contains a relatively high amount of unsaturated fatty acids—such as linoleic acid, oleic acid, a small amount of linolenic acid, and a unique presence of squalene. Thus amaranth oil can be applied as supplements and beneficial for correcting hyperglycemia as part of an antioxidant therapy [21]. Another *niche* application is that amaranth can be considered as food colorants, as it contains betacyanin and betalains. These natural pigments can be used as dyes, and they also have antioxidant, anti-inflammatory, and anti-aging [21, 25]. A relatively high amount of betacyanins (305 mg per 110 g) can be obtained from spiny amaranth (*A. spinosus* L.). It is still classified as true weeds, although it is also classified as medicinal plants in some regions [28].

The seed flour of *A. hypochondriacus* was attributed with antioxidant activity; some of them are rutin (4.0–10.1 $\mu g\ g^{-1}$), nicotiflorin (4.8–7.2 $\mu g\ g^{-1}$), and isoquercitrin (0.3–0.5 $\mu g\ g^{-1}$), and they have high potential to be prospected as bioactive agent applied in cancer treatment. In other sources, it was reported that rutin (quercetin-3-*O*-rutinoside) and quercetin (the precursor of rutin) are ubiquitous flavonoids and usually found in nature. Rutin may be useful for the prevention and treatment of colorectal carcinogenesis, while quercetin could be a constituent of chemotherapeutic drugs for prostate and skin cancer treatment due to its growth inhibitory effect to tumor cells. The amount of rutin in seeds ranged from 0.08 to 24.5 $g\ kg^{-1}$, and the grain species belonging to *A. hybridus* and *A. cruentus* were found to be the best sources of rutin [21]. Meanwhile, the leaves had a higher amount, namely, up to 24.5 $g\ kg^{-1}$ dry matter. Lunasin, a kind of bioactive peptide sequence found in the seed of *A. hypochondriacus*, is closely attributed with anticarcinogenic properties. Its concentration was found to be 11.1 $\mu g\ g^{-1}$ in the extracted protein. Its anticarcinogenic property has been researched in vitro by inducing apoptosis against *HeLa* cells using the glutelin extract digested with trypsin, and it can inhibit the transformation of NIH-3 T3 cells to cancerous nodules [25].

Moreover, tocopherols (counterparts of vitamin E) and tocotrienols available in the seed are also closely linked with antitumor activity, antioxidant activity, cholesterol-reducing agent, and serum cholesterol regulatory levels that may reduce the synthesis of low density lipoprotein cholesterol between 30 and 70% attributed with the oil of *A. cruentus*. The amounts were found to be in the range of 8–546 ppm. Lectins contained in different varieties of Amaranthaceae including in *A. hypochondriacus* were reported having a positive immunosuppression and cytotoxicity, and they are widely applied in immunology, cell biology, and cancer research [25].

7. Conclusions

Amaranth, which is originated in America, has a wide ecogeographical distribution. It is a multipurpose plant, whose succulent leaves are tasty and tender, while its grains are consumed as cereals. Both plant parts are edible and can have an extraordinary amount of protein and essential amino acids, especially the lysine. This is found in very limiting numbers especially among the true cereal plants; due to this excellent nutritional character, amaranth can be prospected as a potential plant for the twenty-first century in combating malnutrition problem in many developing countries, especially in Indonesia. Indonesia, as the third big biodiverse-rich country in the world that also faces the malnutrition problem, especially among young children, should utilize the untapped genetic variation richness of *Amaranthus* and further explore the variety that exists as potential parental lines targeting to breed amaranth with high-protein content.

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Conflict of interest

The authors declare no conflict of interest.

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