Chapter

Amaranth as a Pseudocereal in Modern Times: Nutrients, Taxonomy, Morphology and Cultivation

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Abstract

Amaranth is a cereal that has been around since ancient times. Its history is deeply embedded in the cultures of the pre-Colombian new world. There are reasons to believe that the Aztecs used it extensively. The grain is able to tolerate harsh weather conditions and also has a high nutrient profile, particularly proteins. Its lysine content in particular is noteworthy. Amaranth has been seen as a means of curbing malnutrition and food insecurity owing to these properties. There are several pseudocereals that have competed with Amaranth for the top spot as a candidate to prevent several nutrient deficiencies. Millet, barley, quinoa and buckwheat are some of those nutrient-dense pseudocereals. However, the nutrient profile of Amaranth is far superior, and the ease of its cultivation has led to it being selected as a grain for cultivation in continents such as Africa where malnutrition and food insecurity are significantly prevalent. Thus, due to the rising nutritional, health and wellness needs of the global population and to provide nutrition for the malnourished, Amaranth appears to be the most viable selection out of all cereals and pseudocereals.

Keywords: Amaranth, food insecurity lysine, malnutrition, proteins, pseudocereals, superfoods

1. Introduction

Amaranth is considered as one of the "superfoods" of the coming century due to its exceptional qualities in various aspects. However, the crop is not a novel discovery, and it has faced quite a number of obstacles in order to get to where it is today in terms of nutritional status and acceptance by modern day consumers as a food which is able to provide nutrition. Despite the setbacks and disuse, Amaranth has had three redeeming qualities that have earned its standing as a "superfood." The grain is resistant to a number of weather conditions. It also contains quite a high nutrient profile, particularly proteins, and the amino acid lysine, making it a viable supplier of micronutrients to populations facing malnourishment around the globe. The third most important quality is the range of climates and conditions it can grow under. Prior to going into details about Amaranth, it is important to look into the history and nature of similar pseudocereals as a whole in order to understand the importance of Amaranth for modern times.

1.1 A brief history of selected pseudocereals and ancient grains

Amaranth, millet, barley, quinoa and buckwheat are some of the nutrient-dense foods found in the world today. Most of these pseudocereals and ancient grains were regarded as poorer in quality. As a result, these grains were shunned as "poor man's food." However, due to the recent emergence and awareness of their nutritional values, these pseudocereals and ancient grains are making their way back into the diets of people around the world who determinedly want to revert to healthy diets and lifestyles.

Millet's origins could be traced to Neolithic China. Foxtail millet (*Setaria italica*) and common millet (*Panicum miliaceum*) are recognized as some of the most important and ancient domesticated crops in the world. The world's earliest known millet remains were found in Cishan around 40 years ago [1]. The storage contained more than 50,000 kg of grain storage pits, which were not easily taxonomically classifiable at that time. However, since then, it has been suggested that the earliest significant system of common millet cultivation was based around this site in Cishan, and the main crop that was being cultivated therein was common millet [2]. The cultivation and widespread use of millet as a food source has been attributed with the development of early Chinese civilizations that surrounded the Yellow river [2]. The oldest noodles unearthed in the world were also made from foxtail millet and common millet and were found near the Qinghai province in China [3]. The noodles dated back to 4000 years ago [3]. Various other types of millets, such as Kodo millet and pearl millet, were further cultivated in regions throughout the world such as Africa and Asia.

Scientists do not necessarily agree on the origins of barley, and the currently accepted theory states that it has been cultivated first in the Near East [4]. The first ancestor of barley is believed to be similar to *Hordeum spontaneum*, and the earliest remains of barley discovered so far, date back to 8000 B.C., which were found near the Bus Mordeh phase of Ali Kosh, near Deh Luran and Tell Mureybat in Syria [5]. As agriculture spread from Western Asia toward the valley of Indus, so did barley. Archeologists have found detailed tablets on the correct methods of planting barley, and a prescription for a poultice included barley ale from the scribes of Sumer [6].

Barley has also seen extensive use in ancient Egypt, both as a source of nutrition and a medicine [7]. While being used in many forms to decrease the healing time of wounds, it was also used as medicine for eye diseases and phlegm [7]. Most astonishingly, barley has been used as a marker to diagnose pregnancy and for the purposes of prenatal sex determination—the validity of which has not been proven so far [7]. Much like millet, barley spread across the world and still continues to be a main source of food in many of its parts, including India. Barley tea is prepared using the roasted kernels to make a nonalcoholic drink. This is referred to as a medicinally valuable drink throughout literature [8].

Quinoa is another pseudocereal that has high nutritional properties and values. Before the Chilean and Andean countries began importing wheat, quinoa was one of the staple foods in those regions. The findings in Ayacucho, Peru and Uhle give a basis for the domestication of this plant [9]. Quinoa has thus been in cultivation from pre-Colombian times. During the Colonial period, Inca Garcilaso de la Vega has commented as follows on quinoa: "the second of the grains grown on the face of the earth gives what they call 'quinoa' and it is known in Spanish as 'millet' or small rice: because the grain and color are somewhat similar." This establishes the fact that quinoa has been associated by the Spaniards of the time with Amaranth, which is noted by Bernabe Cobo with how the quinoa within the Iberian Peninsula is very similar to the grain which grew in Europe. Quinoa species were given different names in the context of the variety. The names differed according to color and included names such as "isualla, "kana llapi" and "cchusllnca" for wild quinoa, red quinoa and yellow quinoa, respectively [9].

The origins of buckwheat also remain debatable. However, Campbell makes a strong argument for the wild ancestor of buckwheat originating from northeastern Yunnan, China [10]. Nevertheless, evidence of buckwheat has been found in the Siba culture, or the Qinghai-Tibet plateau recently, the carbon dating result of which dated from 3610 to 3458 years before the present, making them the oldest found within the country [11]. This supports the fact that buckwheat has originated within China and in particular, the Qinghai-Tibet plateau. From there, buckwheat spread to Europe through Russia, most likely being introduced to Siberia and Germany first. It is not believed that buckwheat was cultivated within India in ancient times, but there is evidence to support that buckwheat was cultivated within the Himalayas.

1.2 The importance of Amaranth in modern times

Out of all the modern day pseudocereals, Amaranth is a strong and upcoming candidate which is foreseen as a remedy to malnutrition and food insecurity. In fact, as mentioned previously, Amaranth is now considered a "superfood" because it is high in protein, dietary fiber, vitamins and minerals. While grains being regularly consumed today possess a high caloric intake, they are micronutrients and protein profiles are not as holistic. A summary of the various nutrient profiles of *Amaranthus* spp. is shown in **Tables 1**–**3**. Popularity in the cultivation and consumption of Amaranth seed in the modern times began almost four decades ago with the rediscovery of its superior nutritional attributes.

1.3 Taxonomic classification and morphology

As a plant-based food, it is important to highlight and look into the taxonomic information and morphological characteristics of Amaranth for reference and identification purposes. Taxonomically, plants that belong to the Amaranthus genus have been classified as per **Table 4** [13].

The genus *Amaranthus* has been classified into three subgenera, namely *Acnida*, *Albersia* and *Amaranthus* [14]. However, taxonomic classification within the Amaranthus genus has been regarded as a somewhat difficult task by the scientific community, due to the lack of clearly distinguishing characteristics. Similarities between the large number of species, small, difficult-to-see diagnostic parts, intermediate (hybrid) forms and the broad geographical distribution have been attributed to the general use of multiple synonyms [15]. Due to the need arising for microclassification or infrageneric classification, the *Amaranthus* genus has been artificially classified into the following, mostly based on the usages [16]:

- **Vegetable** *Amaranthus* include *Amaranthus tricolor* var. tricolor, *Amaranthus tricolor* var. tristis
- **Grain** Amaranthus: *Amaranthus hypochondriacus*, *Amaranthus caudatus*, *Amaranthus cruentus*
- **Weed** Amaranthus: *Amaranthus spinosus*, *Amaranthus viridis*, *Amaranthus retroflexus*

Morphology-wise, the defining characteristics of Amaranth are the inflorescence and the flowers. Hence, taxonomic classification is done mostly by careful

Constituent, *Amaranthus* material	Content
Ascorbic acid	
A. caudatus leaf methanol extract	3.86 ± 0.20 mg/100 g
A. hybridus paste from leaves	28 ± 1 mg/100 g
A. lividus stems/leaves/flowers: water/methanol/ethyl acetate extracts	0.191 ± 0.007/0.196 ± 0.014/nd mg/g dw
A. hybridus raw/cooked	321.4 ± 1.0/227.7 ± 0.7 mg/100 g
A. cruentus dried leaves: water extract	445 ± 0.21 mg/kg dw
A. caudatus seeds: raw/cooked/popped/germinated and dried 30°/60°/90°	29.8/2.3/18.3/13.7/11.4/nd mg/kg
A. cruentus seeds: raw/cooked/popped/germinated and dried 30°/60°/90°	23.0/nd/16.1/14.3/10.7/nd mg/kg
A. cruentus vegetables: market maturity/heading (β-carotene, depending on N fertilizer)	94.60 ± 5.60 to 78.90 ± 4.50/160.50 ± 7.10 to 149.90 ± 8.20 mg/100 g fw
A. caudatus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	12.5/23.6/1.0/0.7/13.1/9.3/9.1 mg/kg
A. cruentus seeds: raw/high protein flour/cooked/popped/ germinated and dried 30°/60°/90°	21.3/44.9/1.2/0.7/22.9/20.2/17.9 mg/kg
Niacinamide	
A. caudatus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	28.0/66.5/2.4/nd/30.0/23.7/23.8 mg/kg
A. cruentus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	15.9/32.2/0.8/nd/17.1/15.5/15.2 mg/kg
Pyridoxine	
A. caudatus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	4.5/7.6/2.2/0.5/4.3/4.4/2.5 mg/kg
A. cruentus seeds: raw/high protein flour/cooked/popped/germinated and 30°/60°/90°	6.1/8.5/3.1/0.6/5.5/4.5/1.9 mg/kg
Riboflavin	
A. caudatus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	2.4/4.9/1.0/1.7/5.3/4.6/1.6 mg/kg
A. cruentus seeds: raw/high protein flour/cooked/popped/germinated and dried 30°/60°/90°	4.1/6.5/1.6/2.0/8.3/6.5/2.1 mg/kg
Total folate	
4 varieties: seeds	52.8–73.0 μg/100 g dw
4 samples: whole meal flour unstored/stored 3 months	59.9–70.6/43.7–61.2 μg/100 g dw
4 samples: flour fraction/bran fraction unstored	45.5–53.6/60.5–81.6 μg/100 g dw
4 samples: noodles/cookies/bread (60% wheat 40% a.)	38.9/36.3/35.5 μg/100 g dw

Table 1.
Vitamin components in various Amaranthus spp. (modified from [12]).

examination of the tepal number and morphology. With regards to the general morphology, Amaranth species display erect or spreading annuals with a rough or prickly appearance. Grain amaranths have different colors in regard to flowers, stems and leaves, with shades of purple, orange, red and gold. The seeds are plentiful, while small, and occur in massive numbers, with colors such as cream, gold and pink [17]. The stems are often reddish in color and contain arranged leaves with colorful flowers [18]. The stems are longitudinally grooved and terminate in

Carotenoids	
A. cruentus: treated vegetables (total)	11.3 to 24.2 mg/100 g
A. caudatus: leaf methanol extract (total)	15.33 mg/100 g
A. cruentus: dried leaves water extract (total)	132 ± 8 mg/kg dw
A. lividus: stems/leaves/flowers: methanol/ethyl acetate extracts (β-carotene)	1.24 ± 0.020/0.37 ± 0.013 mg/g dw
A. gangeticus leaves: fresh/pressure cooked 10 min/boiled in water 10 min (β-carotene)	7.36/5.391/2.4 mg/100 g fw
A. cruentus vegetables: market maturity/heading (β-carotene, depending on N fertilizer)	7.45 ± 0.47 to 8.04 ± 0.87/2.48 ± 0.33-4.86 ± 0.57 mg/100 g fw
Chlorophylls	
A. cruentus: treated vegetables (chlorophyll a)	53–132 mg/100 g fw
A. cruentus: treated vegetables (chlorophyll b)	18.0–43.7 mg/100 g
Betacyanins	
A. spinosus stems: amaranthine/isoamaranthine/betanin/isobetanin	15.3/5.87/1.77/0.50 mg/100

Table 2.
Carotenoids, chlorophyll and phytates in various Amaranthus *spp. (modified from [12]).*

Phytate	
A. caudatus (Centenario and Oscar Blanco) raw grain (phytic acid)	0.3%
A. caudatus seeds raw/extruded	82.0 ± 0.10/82.0 ± 0.13 mg 100 g
A. cruentus seeds	5.0–5.8 g/kg
A. hypochondriacus seeds	5.4–6.2 g/kg
A. cruentus seed: raw flours/high-protein flour fraction/cooked/popped/germinated (dried at 30,60, and 90°)	4.0/4.4/3.3/3.4/3.1–3.2 g/kg
A. caudatus seed: raw flours/ high-protein flour fraction/cooked/popped/germinated (dried at 30, 60 and 90°)	4.1/4.4/3.3/3.5/3.2–3.3 g/kg
Amaranthus: eight varieties	0.52–0.61%
A. cruentus raw seed flours	21.1 μmol/g
Resinols in Amaranthus seed bran	
(+)-Pinoresinol	53 μg/100 g
(−)-Secoisolariciresinol	98 μg/100 g
(+)-Lariciresinol	45 μg/100 g
(−)-7-Hydroxymatairesinol	519 μg/100 g
Syringaresinol	47 μg/100 g
Secoisolariciresinol-sesquilignan	3.7 μg/100 g
(+)-Medioresinol	114 μg/100 g
7-Oxomatairesinol	207 μg/100 g
(−)-Matairesinol	33 μg/100 g
Todolactol	19 μg/100 g
Isohydroxymatairesinol	20 μg/100 g
α-Conidendrin	5.9 μg/100 g
Nortrachelogenin	15 μg/100 g

Lariciresinol-sesquilignan	21 μg/100 g
(−)-Arctigenin	8.2 μg/100 g
Amines in *A. hypochondriacus* (Nutrisol) leaves	
Cinnamoylphenethylamine	0.48; 0.71 μg/g
Caffeoyltyramine	0.16; 0.72 μg/g
p-Coumaroyltyramine	5.26; 5.26 μg/g
Feruloyl-4-O-methyldopamine	10.87; 7.38 μg/g
Amines in in *A. mantegazzianus* (Don Juan) leaves	
Cinnamoylphenethylamine	4.47; 22.31 μg/g
Caffeoyltyramine	0.53; 10.27 μg/g
Feruloyl dopamine	0.60; 5.67 μg/g
Sinapoyltyramine	0.65; 0.35 μg/g
p-Coumaroyltyramine	114.31; 113.99 μg/g
Feruloyl-4-O-methyldopamine	9.49; 31.64 μg/g
Enterolactone: Amaranthus extracts	0.52 μg/100 g

Table 3.
Other nutrients in various Amaranthus spp. (modified from [12]).

Kingdom	Plantae—Plants
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Caryophyllidae
Order	Caryophyllales
Family	Amaranthaceae
Genus	Amaranthus L.

Table 4.
Taxonomic classification of Amaranthus spp.

an apical large branched inflorescence [19]. Grain amaranth plants are dicots with thick, tough stems similar to those of sunflowers. The height can vary between 1.524 and 2.134 m when mature.

Leaves vary in shapes and sizes and are usually either green or purple with slender stalks. These are alternate, usually simple, with entire margins and distinct markings but without stipules, depending on the species. Flowers are either solitary or aggregated in cymes, spikes, or panicles and typically bisexual and actinomorphic. A few species have unisexual flowers. The bracteate flowers are regular with 4–5 petals, often joined. There are 1–5 stamens. The hypogynous ovary has 3–5 joined sepals [20]. The flowers have 0–5 perianth segments and 2–3 styles [20].

Seeds are borne in a utricle, which are classified as dehiscent, semi-dehiscent, or indehiscent types. The amaranth seed is quite small (0.9–1.7 mm diameter) and seed weights vary from 1000 to 3000 seeds/g. Seed colors can vary from cream to gold and pink to black. The tiny, lens shaped seeds are usually pale in color. The seed heads vary from 30 to 112 cm in diameter at the base and varied in height from 13 to 61 cm [20].

The vegetable *Amaranthus* can be identified by inflorescence features such as mostly or exclusively axillary glomerulus, or short spikes, origin of the flower bud from leaf axil, three tepal lobes, three stamens, brownish black seed, indeterminate growth habit [20]. Grain *Amaranthus* are characterized by the apical large complex inflorescence comprising aggregates of cymes, five tepal lobes, stamens, seed with variable coat color and well-defined flange, utricle circumscissile [21]. Certain species within weeds show commonalities with the grain and vegetable forms, and some weed species are cultivated as food sources [22].

There is a recurring conflict based around the origins of the grain Amaranth, and the scientific community has introduced a variety of hypotheses around this debate. There are various hypotheses, none of which have been quite adequately tested as of yet. The single progenitor hypothesis [22] claims that the grain amaranths could be the result of a single progenitor species domestication that has been introgressed with other wild amaranths resulting in separate grain species. Another hypothesis claims that multiple different grain species were resultant of separate domestication incidents around separate regions, pertaining to different wild species. *A. cruentus* is from *A. hybridus* presumably in Central America, *A. hypochondriacus* is from *A. powellii* in Mexico and *A. caudatus* is from *A. quitensis* in South America [22]. A third hypothesis proposes that each of the three domesticated species were derived from independent domestication events from genetically different populations of *A. hybridus* [23].

1.4 Amaranth cultivation around the world: a brief history

The initial evidence of Amaranth cultivation dates back to the mid-Holocene period (8000–7000 BP) [24]. In Central America, seeds of *A. hypochondriacus* and *A. cruentus* were found which date back 1500 and 6000 years, respectively, from Mexico [25]. The three main grain Amaranth species cultivated throughout different regions in America are A. *cruentus*, which is cultivated throughout North America, particularly in and around Southern Mexico and Guatemala, *A. hypochondriacus*, which is cultivated through the western part of America, particularly from southwestern America to central Mexico, as well as *A. caudatus*, which is cultivated closer to Southern America, particularly near the Andes and Northern Argentina [17].

Amaranth has its history deeply imbedded in the cultures of the pre-Colombian new world. There are reasons to believe that the Aztecs used it extensively. There have been references to tributes of tons of Amaranth grain being sent to Tenochtitlan (present-day Mexico City) for emperor Montezuma [17]. The Aztecs would mix the crushed grain with human blood or milk and consume it during their rituals and festivals [17]. As such, the grain was interwoven with paganism and the rituals of the Aztecs. The Spanish conquistadors were shocked by this and banned the use and cultivation of Amaranth, pushing cultivation into small pockets, and eventually into disuse [17]. Nevertheless, as time went on, the conquistadors would distribute the seed as far as India, Nepal and China. The crop is popular among the hill tribes of these countries, and Amaranth is most intensively cultivated in these areas of higher elevation as of today [17]. Additionally, amaranth has been indoctrinated into Indian culture, earning names such as “rajgira” and “ramdana” (king seed and seed sent from god, respectively) [17]. Indian cuisine such as “laddoo” incorporates a mixture of popped amaranth seeds and honey [17].

Amaranth species such as *A. tricolor*, *A. dubius* and *A. cruentus* are grown as potherbs or vegetables within the African and Southeast Asian regions [26]. Research regarding utilizing Amaranth species as an alternative food crop to support the global demands is already underway, and new advances toward Amaranth cultivation are being carried out in countries such as Lithuania [27]. Furthermore, research has been conducted into cultivating *A. hypochondriacus* hybrids within the Iranian region as a new food crop, which have been successful [28]. The heat resistance of Amaranth spp. has made it an acceptable food crop for Taiwan which has high rainfall and humidity conditions coupled with temperatures that can reach up to 40°C [29]. Amaranth is grown as a leafy vegetable in Nigeria [30]. Additionally, recent research in Italy has confirmed that the country possesses conditions that *A. hypochondriacus* derivatives find suitable for cultivation [31]. While specialized research is being carried out around cultivation patterns to obtain optimal results in the Russian republic Dagestan [32]. Others have followed suit, specializing their research in order to obtain optimal conditions for the crop based on the conditions within the land, including such institutes as the Rodale Research Center (RRC), the central source for Amaranth and related research of America, in Pennsylvania, Emmaus. Recent publications include studies into variations in protein content, studies into Genomic reductions, germination characteristics and germplasm conservation.

1.5 Amaranth in the future

Due to the demanding needs of the twenty-first century's population and their need for nourishment, the efficiency of crops such as corn, rice and maize are being questioned. As such, scientists worldwide are making new ventures into the potential of alternative grains that could supply food to the world in the years to come. Quinoa, buckwheat and other forgotten pseudocereals are being presented into the limelight due to their high nutrient content and their ease of growth. Amaranth is at the forefront when it comes to all these aspects.

The first world Amaranth conference was held in 2018, gaining 135 participants from East and Southern African countries where the grain is most needed. Topics discussed were mainly centered on nutrition, production of quality food on African land, processing, and supporting communities to change mentalities developed around Amaranth as a poor man's crop. The underutilization of the crop seems to be the main issue, especially in countries which need its nutritional benefits the most. However, steps are being taken to change the public's view and are effective as evident by the attendance of the African continent.

2. Conclusions

Due to the rising needs of the global population to control world hunger and to provide nutrition for the malnourished, Amaranth becomes a viable selection due to a number of reasons. Its weed-like nature and ability to withstand environmental conditions is one of these reasons. Another is its ability to provide micronutrients and macronutrients at significant amounts as a single crop, as opposed to the current food crops of the world. Amaranth contains lysine at high levels in particular, compared with other cereals and pseudocereals. The third most striking characteristic is its adaptability to change and the wide range of environments it can grow under, making it a competitive crop that can be utilized across the globe in order to cater to both the poor and the rich. This fact alone solidifies its position as a versatile food crop which could eventually become a staple food of the twenty-first century.

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Conflict of interest

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