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Exploring the Multifunctionality of Amaranthus: A Review on Its Role in Food Medicine Biotechnology

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ABSTRACT

Amaranthus is a versatile genus of plants that has attracted significant scientific interest due to its rich nutritional profile, pharmacological potential, and biotechnological applications. Traditionally used as both grain and leafy vegetable, amaranth serves as an excellent gluten-free pseudocereal with high-quality protein, essential amino acids, minerals, and vitamins. Its edible leaves offer strong antioxidant properties, making it a valuable functional food especially in malnutrition-prone regions. Ethnopharmacological evidence reveals its usage in treating diarrhea, respiratory disorders, anemia, excessive bleeding, and metabolic diseases. Phytochemicals such as saponins, betalains, phenolic acids, flavonoids, and bioactive peptides contribute to its anti-inflammatory, antioxidant, hypolipidemic, antimicrobial, and anticancer properties. Biotechnological applications of Amaranthus include the production of natural pigments for food coloring, nutraceuticals, cosmetics, and preparation of animal fodder from plant residue. Additionally, its oil is rich in squalene, a highly valued compound with skin-protective and cholesterol-lowering properties. Despite its immense potential, the crop remains underutilized due to low yield, antinutritional factors, and lack of commercial processing technologies. Further research is needed to improve its agronomic traits, processing methods, and clinical validation. This review highlights the multifunctional role of Amaranthus and emphasizes the need to explore it further as a sustainable crop for future food security, pharmaceutical development, and industrial innovation.

Keywords: *Amaranthus, Functional Food, Phytochemicals, Antioxidant, Biotechnological Applications.*

INTRODUCTION

Amaranths are some of the earliest vegetables that have existed, globally, as grains, leafy vegetables, dye plants, ornamentals, and weeds, in tropical, subtropical, and temperate climates.[1] *Amaranthus* is a plant genus comprised of about 74 annual species, with a wide morphological diversity, distinctly characterized by monoecy and dioecy.[2] They are a promising group of plants that could deliver plant-based proteins, high-quality nutrients, unsaturated fatty acids, and other essential organic minerals derived from their leaves, seeds, and roots.[3-4]

Amaranths adapt easily to adverse environmental conditions because they manufacture food through the C4 photosynthetic pathway.[5] They have evolved certain physiological characteristics that make them easily cultivated, allow them to survive attacks from pathogenic organisms, and enhance their phenotypic plasticity and genetic diversity.[6] Several bioactive compounds derived from the *Amaranthus* species have been reported on extensively in the literature. These include phenolic phytochemicals, lectins, anthocyanins,

Journal of Advancement in Pharmacognosy
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flavonoids, and antioxidant nutrients capable of entrapping free radicals that may impair the proper functioning of biological systems.[7-11]
These plants have indeed been known to offer beneficial health-promoting characteristics for millennia. Guidelines for nutritional supplements, functional foods, and pharmaceutical items are based on their formulations.[12] Amaranth has recently sparked significant attention in science and technology. This is because of its beneficial biological qualities, diverse phytochemical makeup, and broad therapeutic potential. A pseudocereal cultivar has two traits i.e. amaranth, integrating food and health-promoting qualities.[13] When a comparison is made to true cereals, amaranth grain is a highly nutritious pseudo cereal with a higher protein content. It's a well-balanced diet with special attributes that have been proven to have medicinal value. Modern international food security depends on the logical and successful research of self-sustaining indigenous plants.[14]

Protein is the primary component of all living cells, playing a crucial role in various aspects of cell structure and function. In plants, proteins are synthesized using inorganic sources like ammonia, nitrates, and nitrites. Among pseudo cereals, amaranth grain stands out as a highly nutritious option with superior protein quality compared to true cereals like wheat and maize.[15]

The functional properties of amaranth proteins are greatly influenced by their structural characteristics. Multiple researchers have conducted studies exploring the physicochemical, functional, and thermal properties of amaranth protein. In addition to its nutritional benefits, amaranth offers various medicinal advantages. Plant-derived proteins and peptides have been extensively studied as alternative therapies for cancer treatment and other chronic diseases.[16] Recent research has shown that bioactive substances found in amaranth can suppress cancer development through different mechanisms, encompassing the initiation, promotion, and progression stages.

Peptides from both plant and animal sources exhibit antioxidant activity, as demonstrated by in vivo and in vitro experiments. While a complete understanding of peptide antioxidant activity is not yet achieved, some studies suggest that it is linked to protease action and the extent of the hydrolysis process.[17] Structural characteristics of peptides, such as amino acid composition, molecular size, and hydrophobicity, have been identified as contributors to their antioxidant activity. Certain naturally occurring peptides and polypeptides present in amaranth display free radical scavenging and inhibitory effects on oxidation.[18] These active molecules are distributed across different protein fractions, namely albumin, globulin, and glutelins. Studies have shown that hydrolysis with the alcalase enzyme enhances the functionality of protein isolates and protein fractions by releasing peptides or amino acids with such activities. The cholesterol-lowering effect of amaranth protein has been observed by incorporating amaranth protein isolate into the diet of hamsters.[19-20]

Journal of Advancement in Pharmacognosy
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Fig 1. Amaranth – Green Tails

Plant Characteristics

Amaranth has been well known since the time of the Aztecs, Mayans, and Incas.[21] In the 16–17th centuries, it spread widely in various other countries as a cereal, vegetable, weed, or crop. Amaranth seeds were used as food, but also as a sacred plant. It was used in many religious and ritual ceremonies.[22] It is a valuable plant whose potential is still not sufficiently exploited. This should be clearly emphasized because it has a huge economic value due to the various benefits it can bring to producers, food processors, and consumers. Amaranth is a member of the *Amaranthaceae* family comprising about 70 species of annual plants.[23-26] In many countries, *Amaranthus* species are cultivated for use as cereals, vegetables, or ornamentals, a few species are considered weeds. A review of the current literature suggests that mainly *Amaranthus cruentus, Amaranthus hypochondriacus*, and *Amaranthus caudatus* are grown for food purposes.[27] *Amaranthus blitum* Linn., *Amaranthus gangeticus* Linn., *Amaranthus mangostanus* Linn., *Amaranthus tricolor* Linn. Are cultivated all over India as a vegetable. Amaranth leaves are used in salads and to prepare other dishes, in African countries amaranth leaves are sometimes recommended for medicinal purposes.

Chemical Composition of Amaranth

The main biological compounds found in amaranth are proteins, fats, carbohydrates, vitamins, and minerals. The protein content (~18%) of amaranth seeds is higher than that of traditional cereals and varies according to the variety of the plant, the climate, and soil conditions and the method of fertilization. Among proteins, albumins are the largest fraction. Protein contains all the essential amino acids required by the body, especially a lot of lysine and tryptophan. Starch is the main carbohydrate found in amaranth. The amount of starch in amaranth seeds is approximately 45–65%. An important group of compounds found in amaranth is the fiber fraction (high level) its soluble (mainly pectins) and insoluble parts. The insoluble fraction consists of lignin, cellulose, and hemicelluloses, which have a beneficial effect on the digestive system. The amount of fiber in seeds, depending on the source of origin, averages 2–8% of dry weight. The nutritional value of amaranth seed is mainly caused by lipids (~7% with a good ratio between saturated and unsaturated fatty acids and high protein content with the essential amino acids composition better than that in FAO/WHO standards. Among unsaturated fatty acids, the most abundant are linoleic (~62%), oleic (~20%), linolenic (~1%), and arachidonic acid.[28] Amaranth contains saturated fatty acids (palmitic (~13%), stearic (~2.6%), arachidic (~0.7%), and myristic (~0.1%) in small amounts. Among the lipid fraction of amaranth, tocopherols, tocotrienols, and sterols play an important biological role.[29] Squalene has been identified in the seeds and leaves of the plant, and they are also very rich in vitamins (especially the B group) and minerals. The percentage content of squalene in oil derived from amaranth is 2–8% or 6–8%[30] depending on the source and author. Amaranth seeds are a very good source of minerals, representing an average of 3.3%

of their weight. The levels of calcium, potassium, and magnesium are quite high, with iron, phosphorus present in the largest amount.[31]

Supplementary Value of Amaranth

Amaranth seeds have a high nutritional value. The most important product obtained from amaranth is grain, which is a source of flour used in the baking industry. Different plants such as millet, corn, sorghum, pseudocereals (amaranth), quinoa, and teff are the main components of a gluten diet.[32] The lack of gluten fraction makes the amaranth flour suitable for the production of dietetic food (gluten-free products) recommended for people who are allergic to gluten. In a recent paper, technological and nutritional properties of an innovative gluten-free double-layered flat bread enriched with amaranth flour were examined. New formulations were developed in which rice flour (6%) and starch (6%) were partially replaced with amaranth.[33] Nowadays, such products of good quality are desirable because the number of people with celiac disease is increasing. Amaranth seeds are mainly used to produce flakes, flour, groats and muesli, and oil. The high protein quality of amaranth means that it can be used alone or as a food fortifier in cereal grain mixtures. Recently, amaranth has been also used as a new alternative ingredient to compose functional cookies. The procedure basically relies on partial replacement of whole-wheat flour with formulations based on amaranth flour. The nutritional value of the fortified cookies (with amaranth flour) was found to be higher than that of traditional wheat flour cookies.[33] Oil pressed from amaranth seed is also very popular. Amaranth oil is well known as a functional food. A very important property (advantage) of amaranth oil is that it is highly resistant to oxidation.[34]

Status of Amaranth as a Food or Food Ingredients

The seeds, oil, and leaves of this plant are used as food. Amaranth seeds were consumed as early as the time of the Incan, Mayan, and Aztec Empires. According to the EU Novel Food Catalogue, in the case of Amaranthus caudatus, Amaranthus cruentus, Amaranthus hypocondriacus as food, only the use of grains from the plant is known in the EU. This product was present on the market as a food or food ingredient and was consumed to a significant degree before 15 May 1997, when the first regulation on novel food came into force. Thus, its access to the market is not subject to the Novel Food Regulation (EU) 2015/2283. However, other specific legislation may restrict the placing of this product as a food or food ingredient on the market in some Member States.

Biological and Pharmacological Activity

This plant has many valuable health benefits. Amaranth has been used as an astringent. This effect probably originates from the content of saponins, protoalkaloids, and betacyans.[35] According to PDR for Herbal Medicines, amaranth has been used for the treatment of diarrhea, ulcers, and in cases of pharyngitis. There are also reports on the use of the plant in excessive menstruation, skin problems such as acne and eczema, and as a mouthwash for sore mouths.[36] Saponins, protoalkaloids, and betacyans are responsible for the pharmacological activity of amaranth.

There are reports in the scientific literature regarding the beneficial activity of amaranth on the cardiovascular and nervous systems, hypoglycemic effect, antimicrobial activity, antioxidant activity. Amaranth is widely used in the pharmaceutical industry to produce medicinal products against atherosclerosis, stomach ulcers, tuberculosis, as well as antiseptic, antifungal, and anti-inflammatory preparations. According to Khare 2004, the seeds of Amaranthus hypochondriacus L. in Unani medicine are considered as a spermatogenetic drug

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and tonic. A decoction is used in heavy menstrual bleeding, flowers are treated as remedium for diarrhea, dysentery, cough, and hemorrhages. Amaranthus polygamus Willd. is used as a spasmolytic, emmenagogue, galactagogue factor. Amaranthus spinosus Linn. is taken to reduce heavy menstrual bleeding and in cases of excessive vaginal discharge, also as a diuretic medium.

The whole plants of Amaranthus blitum Linn., Amaranthus gangeticus Linn., Amaranthus mangostanus Linn., and Amaranthus tricolor Linn. are considered as astringent, diuretic, demulcent, and cooling.[37] Amaranthus tricolor Linn. is placed and described in the Ayurvedic Pharmacopoeia of India. Amaranth seed oil exhibits hypolipemic, anti-atherosclerotic, hypotensive, and antioxidant activity. Therefore, its consumption may lead to inhibition or delay in the development of diet-related diseases of civilization.

Table 1. Multifunctionality of *Amaranthus* in Food, Medicine and Biotechnology

Domain	Applications	Key Compounds
Food / Nutrition	Grain used as gluten-free pseudocereal Leaves consumed as vegetable (rich in vitamins, minerals, protein)	High in protein (lysine), fiber, iron, calcium, folate, B-vitamins
Medicinal Uses	Traditionally used for diarrhea, cough, dysentery, excessive menstrual bleeding Tonic, diuretic, astringent properties	Saponins, betacyanins, flavonoids, peptides, phenolic compounds
Pharmacological Effects	Antioxidant, anti-inflammatory, antimicrobial, hypolipemic, hypotensive, antidiabetic, spermatogenic, anticancer potential	Bioactive peptides, amaranth oil (squalene), phenolic acids
Biotechnology / Industrial	Source of functional ingredients & nutraceuticals - Natural food coloring dyes (betalains) Cosmetic and supplement formulations	Betalain pigments, oils, proteins, squalene
Agriculture / Feed	Plant residue used as high-protein animal fodder - Drought-resistant crop for sustainable agriculture	High biomass yield, adaptable to poor soils

Amaranthus is an exceptional genus that demonstrates remarkable multifunctionality across food, medicinal and biotechnological sectors. Nutritionally, amaranth grain is considered a gluten-free ancient pseudocereal with high-quality protein rich in lysine, dietary fiber, minerals (such as iron, calcium, and magnesium) and essential vitamins. Its tender leaves are consumed as leafy vegetables in many Asian and African countries, providing a rich source of micronutrients and antioxidants.

Medicinally, various Amaranthus species have been traditionally used to treat ailments like diarrhea, dysentery, cough, and excessive menstrual bleeding due to their astringent, anti-inflammatory and diuretic properties. Modern phytochemical investigations reveal that amaranth contains bioactive molecules such as saponins, betacyanins, phenolic compounds and bioactive peptides, which exhibit significant antioxidant, hypolipidemic, antimicrobial, antihypertensive, antidiabetic, and potential anticancer effects. From a biotechnological perspective, amaranth oil is rich in squalene and polyunsaturated fatty acids, making it valuable in nutraceutical and cosmetic formulations.

Journal of Advancement in Pharmacognosy
Volume 5 Issue 2, 2025
ISSN: 2582-8401

Table 2. Bioactive compounds of AMRANTH and their functional and nutraceutical properties.

Amaranths' Components	Contents	Benefits	References
Polyphenols & Phenolic Acid	168 to 329 mg/kg	High antioxidant activity	38
Squalene	620mg/kg	Nutraceutical effects	39-41
Starch		High swelling power or absorbance capacity, low solubility, greater uptake, lower susceptibility to amylases.	42
Saponins	0.10%	Low levels make it completely safe for human consumption	43
Fibers	4.20%	Reduce cholesterol & promote gut health.	44

Future Challenges of Amaranthus Utilization

Although Amaranthus presents enormous potential as a multipurpose crop, several challenges still limit its large-scale utilization and commercialization. Public awareness about its nutritional and medicinal value remains low, and in many regions, it is still regarded as a neglected or minor crop. Standard large-scale cultivation systems and post-harvest processing technologies for amaranth grain, oil, and pigments are not yet fully developed, hampering industrial use. In addition, the presence of antinutritional factors such as oxalates and phytates can interfere with mineral absorption, and effective processing strategies are needed to reduce these without compromising its nutrient content. Another major limitation is its comparatively low grain yield, which requires genetic improvement programs to develop high-yielding, disease-resistant cultivars. Moreover, regulatory guidelines and clinical studies on safety and dosage for medicinal or nutraceutical applications are still insufficient, delaying formal approval of amaranth-based products. Issues related to storage and shelf-life, especially due to the oxidation of unsaturated oil and betalain pigments, also restrict commercial applications. Finally, the existing market and value chain for amaranth products are poorly organized in many developing countries, requiring government support and industrial investment to promote cultivation, processing, and marketing. Addressing these challenges through focused research and policy support will be crucial for the full-scale exploitation of Amaranthus in food, medicine, and biotechnology sectors.

CONCLUSION

Amaranthus represents a highly valuable multipurpose crop spanning across nutrition, medicine, and biotechnology. Its use as a protein-rich grain and leafy vegetable can effectively combat nutrient deficiencies and serve as a gluten-free dietary option. The presence of diverse phytochemicals contributes to its wide range of therapeutic properties, making it a promising natural source for future drug development and nutraceuticals. Its industrial value is evident through its application in natural dye production, squalene-rich oil, and functional formulations. However, challenges such as limited public awareness, low agricultural yield, antinutritional factors, and absence of standardized processing must be addressed. With strategic research, breeding, and technology support, Amaranthus could become an important crop for sustainable development. The plant offers tremendous scope not only for improving health and nutrition but also for supporting eco-friendly industrial applications.

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Volume 5 Issue 2, 2025
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