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Amaranthus grain nutritional benefits: A review

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Abstract
Amaranth grain is extremely nutritional pseudocereal with a higher amount of proteins when compared to true cereals. It is a reasonably well-balanced food with functional properties that have been shown to provide medicinal benefits. The health benefits credited include decreasing plasma cholesterol levels, exerting an antitumor activity, reducing blood glucose levels and anemia. The current article provides a comprehensive idea of amaranth grain that focuses on recent research reporting its use in the clinical practice and its possible profit to human health.

Keywords: grain amaranth, nutritive value, clinical studies

Introduction
Background
According to FAO Global report on food crises 2017 'The State of *Food* Security and Nutrition in the World, *2017*", worldwide, 108 million people in 2016 had reported to suffer hunger due to crisis level food insecurity and in India 190.7 million persons are malnourished and ranked 100th among 119 countries on global hunger index. Current epidemiological heath scenerio need nutrient enriched foods that are easily availabe world wide and in india. Balanced and effective exploration of sustainable plant resources is an imperative task for ensuring global food security in the future. Humankind has been using more than 10000 edible species; however, today only 150 plant species are commercialized on a significant global scale, 12 of which provide approximately 80% of dietary energy from plants, and over 60% of the global requirement for proteins and calories are met by just 4 species: rice, wheat, maize, and potato [1]. Therefore, valorization of valuable, however, sometimes forgotten, crops has been in the focus of many researchers all over the world during the last several decades.

Amaranth (*Amaranthus* spp.) has been consumed all through the history, including by the Inca, Maya and Aztec civilizations, where it was used as a staple food. Recently, an increased interest in amaranth appeared in the 1980s, when the United States National Academy of Sciences performed research on the grain and described its high nutritional value and agronomic potential [2, 3]. Given the growing recognition of amaranth in countries where its consumption has not been traditional because of the general consumer interest in grains with medicinal properties, literature reviews on amaranth have been published recently focusing on aspects such as the adaptation to traditional cuisines [4], or the nutraceutical properties of this non-conventional grain [5]. At present it is broadly cultivated and consumed throughout India, Nepal, China, Indonesia, Malaysia; whole of Central America, Mexico; Southern and Eastern Africa. However this review is focused on Amaranths seed composition and nutritional value information which may help to many researchers.

Grain amaranth belongs to the order *Caryophyllales*, amaranth family *Amaranthaceae*, sub-family *Amaranthoideae*, genus *Amaranthus*, and according to Sauer [6], into the section *Amaranthus*. The genus *Amaranthus* includes approximately 60 species, most of which are cosmopolitan weeds (*A. retroflexus L.*, *A. hybridus L.*, *A. powellii S. Watt.*, *A. spinosus L.*) and cultivated amaranth species which can be used as food grain, leafy vegetables, forage and ornamentals.

Classification

Kingdom	–	Plantae
Division	–	Magnoliophyta
Class	–	Magnoliopsida
Order	–	Caryophyllales
Family	–	Amaranthaceae
Genus	–	Amaranthus

According to the utilization of cultivated amaranths for human consumption, species can be divided into grain and vegetable amaranths:

Vegetable amaranth: Mostly *Amaranthus* species have edible leaves, and several species (*A. blitum* L.; sin. *A. lividus* L., *A. viridis* L.; sin. *A. gracilis* Desf. and *A. tricolor* L.; sin. *A. gangeticus* L.) are already widely used as potherbs (boiled greens). Their mild spinach-like flavour, high yields, ability to grow in hot weather, and high nutritive value have made them popular vegetable crops, perhaps the most widely eaten vegetables in the humid tropics of Africa and Asia.

Grain amaranth: It belongs to a group of cereal-like grain crops or pseudocereals.
The three principal species considered for grain production include:
Amaranthus hypochondriacus L. (sin. *A. leucocarpus* S. Watts, *A. frumenta ceous*) - prince's feather;
A. cruentus L. sin. *A. paniculatus* L. - bush greens, red amaranth
A. caudatus L. of two subspecies: subsp. *caudatus*; and subsp. *Mantegazzianus* Passerini syn.: *A. edulis* Spagazzini, named love-liebleeding and Inca wheat, respectively.

Nutritional analysis

Amaranthus is highly nutritious, both the grain amaranth and leaves are utilized for human as well as for animal food [7]. The species vary slightly in their nutritional value and chemical composition. It has been shown that amaranth leaves are excellent sources of protein, with its maximal accumulation in the blossoming phase [8] (17.2–32.6% from dry weight for various samples).
Grain of the amaranth species is of high nutritional value. Grain amaranth has higher protein than other cereal grains and has significantly higher lysine content [9]. It has more protein than maize, and the protein is of an unusually high quality (high in the amino acid lysine, which is the limiting one in cereals like maize, wheat and rice). The protein is also relatively rich in the sulphur-containing amino acids, which are normally limited in the pulse crops. The "protein complement" of grain amaranth is very near to the levels recommended by FAO/WHO [10]. Amaranth grain consists of 6 to 10% of oil, which is higher than most other cereals. Amaranth oil contains approximately 77% polyunsaturated fatty acids which are mostly within the germ [11, 12]. Amaranth oil is predominantly unsaturated oil which is high in linoleic acid (about 50%), which is necessary for human nutrition. Yanez *et al*. [13] recorded that oil extracted from Amaranthus cruentus contained 19% palmitic acid, 3.4% stearic acid, 34% oleic acid and 33% linoleic acid. Docosaenoic acid (C22: 1) was present at the level of 9%. The ratio of saturated to unsaturated fatty acids was approximately 1:3. The lipid fraction is unique due to such high biologically active compounds, such as: squalene (up to 8%), tocopherols (to 2%), phospholipids (to 10%), and phytosterols (to 2%). Detailed studies on amaranth grain oil have been researched further in the last 2–3 decades [14, 15]. The use of cooked or autoclaved amaranth grain for use as chicken feed, gave production results comparable to those from feeding corn/soybean ration [16]. Processed amaranth (*A. hypochondriacus*) grain is a potentially useful energy supplement for broiler diets and can be incorporated at levels up to 400 g per kg without adverse effects [17]. Amaranth also solves the problems of formulating hog feed without using often prohibited animal protein. Zraly *et al*[18]utilized the quality of the amaranth protein, particularly because of the amino acid lysine, to formulate a complete feed ration using both grain and plant biomass to successfully fatten hogs. *A. hybridus* and *A. retroflexus* have been successfully incorporated into feed for calves and sheep as forage, with the results obtained not significantly different from that of alfalfa. Leaves from *A. cruentus* provide balanced forage high in crude protein, low in cellulose and toxic substances [19]. It is recommended as a suitable substitute for conventional forages such as alfalfa as an energy source for growing lambs at levels of up to 50% of diet. Amaranth also has high potential as forage for ruminants.

Table 1: Amino acids content of Amaranthus spp. (USDA 2010).

S.N	Amino acids	Unit Value per 100 g
1	Arginine	1.060 g
2	Alanine	0.799 g
3	Asparticacid	1.261g
4	Tryptophan	0.181 g
5	Threonine	0.558 g
6	Isoleucine	0.582 g
7	Serine	1.148 g
8	Leucine	0.879 g
8	Lysine	0.747 g
9	Methionine	0.226 g
10	Phenylalanine	0.542 g
11	Glycine	1.636 g
12	Proline	0.698 g
13	Tyrosine	0.329 g
14	Valine	0.679 g
15	Histidine	0.389 g
16	Glutamic acid	2.259 g

Table 2: Nutritional content of the Amaranthus spp. (USDA 2010).

Nutrient	Unit	Value per 100 g
Water	G	11.29
Energy	Kcal	371
Energy	kj	1554
Protein	g	13.56
Total lipid(fat)	g	7.02
Ash	g	2.88
Carbohydrate, bydifference	g	65.25
Fiber, totaldietary	g	6.7
Sugars, total	g	1.69
Starch	g	57.27
Calcium, Ca	mg	159
Phosphorus, P	mg	557
Iron, Fe	mg	7.61 2.87
Zinco, Zn	mg	2.87
Magnesium, Mg	mg	248
Zinco, Zn	mg	2.87
Manganese, Mn	mg	3.333
Thiamin	mg	0.116
Riboflavin	mg	mg 0.200
Niacin mg	mg	0.923
Folate,total	µg	82
Vitamin Vitamin C, totalascorbic acid	mg	4.2
E(alpha-tocopherol)	mg	1.19
Vitamin B6	mg	0.591
Fattyacids, totalsaturated	g	1.459
Fattyacids, totalmonounsaturated	g	1.685
Fattyacids, totalpolyunsaturated	g	2.778
Fattyacids,18:3n-3 c,c,c (ALA)	g	0.042
Phytosterols	mg	24
Squalene in amaranth oil[a]	%	2.4to8.00

[a] (Bruni and others, 2001;Rodas andBressani, 2009 ;Sousa and Farf´an,2012)

Health benefits of amaranth grains

The current time world need nutrient enriched grains like amaranths crop, amaranthus is a non-grass "cereal-like" (pseudocereal) dicotyledonous plant of which leaves and grains both are used as astaple food [20]. Amaranth grain obtained from small seeds of Amaranthus family plants are used as an option food source to customary cereal grains such as rice and wheat. The amaranthus seeds are eaten as a cereal by the ancient Mayans and Incas in a similar way like quinoa and chia seeds.

1. Hypocholesterolemic effect

Several hypotheses have been planned to clarify one of amaranth's most cited abilities, which is the modulation of the serum cholesterol levels.

One of such hypotheses cited the content of unsaturated fatty acids [21, 22]. Concurrently, the amount of total and soluble fiber has also been mentioned [23-25], and possibly that the amino acid profile of its protein [26] may as well be involved in the mechanism. The presence of phytochemicals as tocotrienols [27, 28], phytosterols [26] and tocopherols and squalene [27-31], have undoubtedly been proposed projecting a rather complex set-up, but that also suggests the participation of a set of components of different chemical nature.

Qureshi *et al*. [28], however, studied the effect of supplementing the diet with amaranth for 6 wk on cholesterol biosynthesis in chickens. The total and low-density lipoprotein (LDL) cholesterol values decreased significantly in groups fed with amaranth, but the high-density lipoprotein-C (HDL-c) concentrations remained unchanged. The cholesterol 7 alpha-hydroxylase enzyme activity was 10% to 18% higher in the experimental group compared to the control group, whereas the HMG-CoA reductase activity in the liver was 9% lower. This study suggests that the inhibition of HMG-CoA reductase, which results in lower cholesterol levels, was due to the presence of some potent inhibitors of cholesterol synthesis other than amaranth's tocotrienols and squalene. observed the effect of whole amaranth and oat bran in the blood and liver of 60 male Buffalo rats. The results showed that the amaranth and oat bran were responsible for a significant decrease in the total blood and liver cholesterol levels of rats, and that the oat bran provided a larger decrease compared to amaranth. The intervention products did not show any effect on blood HDL-c levels, but the amaranth caused the triacylglycerol level to decrease in the liver.

Among the diversity of attempts carried out to show the cholesterol lowering power of amaranth, *in vitro* assays and animal models like rats, hamsters, rabbits, and chickens have been used, besides intervention trials in humans. The experiments have tested the different fractions of the grain and used either hypercholesterolemic animals or diets, for the most part. Plate and Areas [25] showed that hypercholesterolemic rabbits fed with an extruded defatted (*A. caudatus*) amaranth flour showed a reduction of LDL- and total cholesterol levels by 50%, whereas amaranth oil was not as efficient as the extruded amaranth. Shin and others [29] made some interesting observations on the effect of amaranth grain, oil and squalene in an experiment in which rats were fed with a semipurified diet containing 1% cholesterol for 4 wk, and amaranth grain or amaranth oil, which were substituted in experimental groups. Both the amaranth grain and the amaranth oil decreased the total blood and liver cholesterol levels and the triacylglycerol concentrations. The fecal cholesterol excretion and bile acid excretion were increased in the amaranth oil group, but only the bile acid excretion was increased in the amaranth group. In another experiment, the rats were fed with a cholesterol diet and salt (control), amaranth squalene or shark squalene for 7 d. The interesting feature of this experiment was that,whereas the amaranth squalene demonstrated a hypolipidemic effect in the blood and liver, an increase in fecal and bile acid cholesterol excretion and inhibition of the HMG-CoA reductase activity, these effects were not observed with the shark squalene. Concerning the effect of the oil fraction and squalene on amaranth's hypolipidemic properties.

Mendonca and others [32] have recorded in their studies that the amaranth protein isolate can also reduce the total and LDL cholesterol levels in hamsters. Although the mechanism involved was not described, an attempt was made to partially explain the mechanism by the lysine/arginine ratio.

2. Antitumor Effect

Diet is considered a risk factor for several chronic diseases, including cancer. In an estimated period of 10 to 30 year, normal cells may be transformed in clinically detectable tumors, and the diet may promote or inhibit the development of the disease [33] Yu and others [34] also investigated the proliferative effects of diets with 2 lectins that can bind a tumor factor (TF-binding lectin): jacalin (*Artocarpus integrifolia*) and amaranth lectin (*A. caudatus*). Increased Thomsen-Friedenreich antigen (TF-antigen, Gal-beta1–3GalNAc alpha) expression is a common characteristic of epithelial malignancy and premalignancy. The results showed that the diets containing the TF-binding lectins may be markers of proliferation of malignant gastro-intestinal epithelial cells and that it may have a role in diagnosing intestinal cancer. Barrio and Anon [35] studied the antitumor properties of the *A. mantegazzianus* isolated protein (MPI) and elucidated the possible mechanism of action. The study was conducted with 4 different tumor cells: MC3T3E1, UMR106, Caco-2, and TC7. MPI showed an antiproliferative effect on the 4 cell lines with different potentials. MPI inhibits cell adhesion and induces apoptosis and necrosis in the malignant cell UMR 106, and the authors concluded that *A. mantegazzianus* grains show an antitumor potential.

3. Effect on liver function

Besides the effects cited on the blood glucose levels, the work of Kim and other [36, 37] also reported that feeding rats with either the whole grain or its oil resulted in an improvement (decrease) in the animals' AST (aspartate aminotransferase) and ALT (alanine aminotransferase) enzymes, which are liver function markers. Moreover, there was a reduction in TBARS levels (thiobarbituric acid reactive substances, lipid peroxidation and oxidative stress indexes) in the liver cytosol. Considering that the fecal excretion of cholesterol, triacylglycerols, and bile acids of the diabetic animals that consumed amaranth grain and amaranth oil was likewise substantially increased, it is understood that the actions of this grain on the general metabolism can be rather extensive.

4. Antioxidant activity

Antioxidant activity has been reported in several of the various fractions of amaranth. The *in vitro* antioxidant activity of amaranth grain species, *A. caudatus* and *A. paniculatus*, in a model system of β-carotene/linoleic acid was reported by Klimczak and others [38]. These authors estimated the content of phenolic compounds by the Folin–Ciocalteu method as being 39.17 mg/100 g in *A. caudatus* and 56.22 mg/100 g in *A. Paniculatus.*The biological antioxidant properties, and the amount of oil, squalene and phenolic compounds have also been determined in two *A. caudatus* grain varieties (Oscar

Blanco and Victor Red) by Conforti and others [39]. The antioxidant activity was evaluated using a lipid peroxidation assay, The varieties showed different squalene amounts; however, the antioxidant activity did not show significant statistical differences. Nevertheless, amethanolic extract of both varieties displayed antidiabetic activity, showing 50.5% for *A. caudatus* var. Oscar Blanco and 28% for *A. caudatus* var. Victor Red at a concentration of 25 mg/ml. The phenolic and flavonoid compositions of two *A. cruentus* cultivars were determined by Pasko and others [40]. Later, the same group investigated the antioxidant capacity, the amount of phenolic compounds and the content of anthocyanins in *A. cruentus* grains and sprouts. These authors found that at 4 d of germination the seeds significantly increased, not only in the total contents of phenolics and anthocyanins, but also in their antioxidant capacity, as measured by ferric reducing ability of plasma (FRAP), antioxidant capacity by 2,2'- azino-bis(3 ethylbenzothiozoline-6-sulphonic acid (ABTS) and Diphenylpicrylhydrazyl. From these results the authors concluded that although the grains contained a considerable amounts of phenolic compounds, and that the sprouts became a significant source of the flavonoid rutin, thus contributing to the substantially greater levels of antioxidant activity of the sprouts [41]. Pasko and others [42] further evaluated the effect of amaranth grains on oxidative stress in the plasma, heart, kidney, and pancreas of rats. Fructose was administered to induce oxidative stress, which was manifested through an increase of malondialdehyde and a decrease of enzyme antioxidant capacity in the plasma and selected tissues. The ingestion of amaranth grains (310 and 155 g/kg of diet) restored the activity of a number of enzymes and influenced the oxidative stress through the decrease of malondialdehyde, the increase of ferric ion reduction capacity in the plasma (FRAP) and the activity of antioxidant enzymes (erythrocyte superoxide dismutase-eSOD, catalase-CAT, and glutathione peroxidase-GPx1). The results showed that amaranth grains may have a moderate, dose-dependent protective effect against the changes promoted by the fructose-induced oxidative stress in rats through the reduction of lipid peroxidation and increased antioxidant capacity of the tissues.

Conclusion

Although the great majority of the research about the beneficial functions and actions of amaranth has been conducted in experimental animal models, there are compounds in the grain with potentially beneficial medicinal properties present in the various fractions. Because one of the basic principles of functional foods is the functionality of bioactive substances through multiple metabolic paths, the beneficial health effects of amaranth are likely due to the joint presence of all of them, as found in the whole grain. Future research should be directed to epidemiologic studies and towards consolidating the mechanisms of action, especially in the human body. Results of studies out- lined in this review provide an in-depth analysis of health effects of extracts from different bioparts and with reference to major bioactive ingredients of Amaranthus spp.

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