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GENETIC RESOURCES, VARIETAL AND VALUE-ADDED DEVELOPMENT OF GRAIN AMARANTH IN INDIA: STATUS AND PROSPECTS

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ABSTRACT

Grain amaranth, a minor and underutilized potential crop, has become a life support species due to its potential in extreme environmental situations and threatened habitats, having genetic tolerance to survive under harsh conditions and possessing qualities of nutritional and/or industrial importance for a variety of purposes for the present as well as future needs of mankind. This crop is being promoted globally as a nutritive food crop or potential crop of the future. we firmly believe that this widely distributed, ancient, protein-rich grain amaranth has a potential to augment our food system and demand in future.
Keywords **:** Gluten-free, pseudocereal grain, Ramdana, Rajgira, Value added product, Potential underutilized Crops.

Introduction

A crop of attention these days is grain amaranth, an edible pseudocereal with high vitamin and excellent protein levels. The C4 pathway, which grain amaranth possesses, offers the physiological benefit of a high rate of photosynthesis. It is possible to grow this crop in friendly conditions as well. It is referred to as ramdana ("seed sent by god") in Bihar, Odisha, and Uttar Pradesh, rajgira ("king of seeds") in Gujarati, Chuka in Bengal, Kalaghesa, chumera and ganhar in central India, and Bathu in HP, among other names in various Indian languages. With a high protein, fat, and mineral content and a balanced mix of essential amino acids, grain amaranth has remarkably high nutritional benefits (Saunders and Becker, 1983; Joshi and Rana, 1991). In terms of production and nutritional content, grain amaranths' tiny seeds are comparable to those of maize and other genuine cereals. Because it is a great source of B-carotene and iron, it can help prevent iron and vitamin "A" deficiencies in people. Elevated folic acid content also contributes to elevated blood hemoglobin levels.

Fig. 1 : Cultivation of grain amaranth in Banaskantha district, Gujarat

In both the Old and New Worlds, amaranthus are widely dispersed (Sauer, 1967). This crop is grown as a minor crop throughout the Asia-Pacific region, which includes China, India, Manchuria, Nepal, Bhutan, Afghanistan, Indonesia, Japan, Thailand, and Israel. Grain amaranth is mostly grown in hilly areas of India, although in the late 1990s, cultivation of the crop spread to the Central and Western Plateaus. Due to irregular farming, precise numbers for India's acreage and production are unavailable. Nonetheless, it is estimated that the crop is produced in India throughout 40–50,000 hectares.

Up until then, more than a thousand germplasm accessions have been assessed as part of the Network project's multilocation testing program in India. 32 varieties for both plain and hilly areas have been created and made available thus far from these accessions, Over the past ten years, Gujarat has seen a notable increase in Rajgara area, productivity, and output. Due to water constraint, this crop is replacing wheat and potatoes in some areas, especially in Banaskantha and Kheda districts (Fig. 1). In Gujarat, this crop is grown on around 12,000 hectares of land (Rabi 2019–20). In the districts of Banaskantha, Mehsana, Gandhinagar, Sabarkantha, and Patan in North Gujarat, and Kheda and Anand in Middle Gujarat, it is either grown as a sole crop, taken as a border crop in the fields of lucerne or cumin, or taken as a mixed crop with mustard and vegetables during Rabi Season.

Given its limited use as a food crop, it is doubtful that the area planted to grain amaranth would rise greatly. If this crop is planted in a bigger area, there could be a risk to the price. However, there are new channels for domestic consumption thanks to government policy intervention in social programs like ICDS, midday meals, the Antyodaya program, the sale of wheat floors fortified with amaranth to BPL families at subsidized prices, and the promotion of goods through local farms, tourist destinations, and places of worship, among others. Additionally, attention must be paid to developing grain amaranth through the use of contemporary breeding and biotechnological technologies, as well as IT-based tools to market the crops and their products utilizing the proper value chain at all levels, including producers, consumers, and policy makers.

Materials and Methods

This study's primary goal was to compile data regarding the different features found in the germplasm kept in the genebank. Initially, a list of the germplasm that was made available in NGB was compiled, along with the passport information. The germplasm was then divided into three groups based on how it was intended to be used: vegetable type, grain type, and wild/weedy types. Data on particular characteristics such as early maturity, dwarfism, drought tolerance, non-lodging, pest and disease resistance, high leaf and grain yield, high protein and lysine content, etc. were compiled. The literature study of published sources, including books, catalogues, research papers, yearly reports, and reports on underutilized crops, served as the foundation for the information collection. In order to map the cultivation of grain amaranth and investigate the nutritional analysis in various places from the last 30 years, a review of the literature was done. Using the Google search engine, which aggregated several databases and individual publications from all Indian universities, the first screening of the papers was done. The data that is being given was compiled from a total of fifty sources. In addition, a comprehensive assessment of the literature was conducted to examine the latest advancements in post-harvest technology. We used academic databases and search engines (such Scopus and Google Scholar) to locate English-language papers about post-harvest technologies, the nutritional and biological qualities of grain amaranth, its traditional applications, and the creation of products based on grain amaranth.

Regarding post-harvest technology, there are several aspects to consider: production; post-harvest processes; evolution; innovation; biological and nutritional properties; biological properties; bio-actives; superfood; traditional uses; traditional products; traditional food products; innovation; trends; food trends; future products; new products; and product development of grain-based amaranth-based products. Furthermore, a thorough literature review was carried out to enhance the analysis of grain amaranth waste side stream processing techniques and the possibility of using byproducts in other commercial sectors. Between October 2023 and August 2024, databases and search engines (such Scopus and Google Scholar) were used to look for English-language literature on the subject. These publications covered grain amaranth's use as a new molluscicide, as well as its use as a feedstock and substitute for traditional fuels, making them pertinent to the goal of this work. The two primary search subjects were production and consumption, with four additional relevant subtopics including welfare, nutrition, environment, and market. Finally, a thorough examination of the grain amaranth market was carried out in order to create a qualitative outlook and present market estimates. The information pertaining to this crop is scattered. Sincere efforts have been made in this publication to compile the scattered information covering different aspects of Grain amaranth crop for benefit of the farmers, researcher, students & planners.

Vegetative and reproduction growth of amaranth

Amaranthus is a genus of herbs that is widely used, sometimes referred to as pigweed or amaranth. Pseudocereal plants, amaranths grow quickly and yield valuable amino acids, minerals, and high protein content. Pseudocereals, or amaranths, are classified as such to separate them from actual cereals, which are members of the Gramineae/Poaceae family. Amaranths are members of the Amaranthaceae family. The creamy, pinkish or reddish inflorescence of amaranth plants annual, erect, fast-growing, semi-hard plants with broad leaves produces tiny, spherical seeds with a variety of colors and sheen that are high in proteins and minerals. The plants range in type from branching to unbranched.

The genus "Amaranthus" contains over 75 species. In this genus, two parts are recognized: Blitopsis Dumort (Species with considerable extent of self-pollination) and Amaranthotypus Dumort (Out crossing species). Section Amaranthotypus is where the grain species are classified. While some species in this group are dioecious, the majority of the species have compound inflorescence and are monoecious. Except for the polyploid species Amaranthus dubius, which has 2n = 64, the majority of species have 2n = 32 or 34 (WOI, 1985).

Approximately 20 types of amaranth are found in the wild or as valuable grain. Plant heights range from 30 cm to 400 cm, contingent upon the species, growing medium, and surrounding conditions. The species can be separated into grain and vegetable amaranths based on the use of farmed amaranths for human use

Grain Amaranth: *A. hypochondriacus, A. cruentus*, and *A. caudatus* are the three primary species that are taken into consideration for grain production.

A. hypochondriacus (L.): Due to its superior nutritional makeup, this grain can be ground, roasted, and eaten similarly to maize, which is a common grain in Indian homes for breadmaking (Mlakar *et al*., 2009). Other natural sources of squalene, which is primarily present in marine sharks and has a significant positive impact on cancer (Rao and Newmark 1998) and lowers blood cholesterol (Smith 2000), have been proposed for the grain of A. hypochonriacus (He *et al*., 2002).

A. cruentus: The protein of the *A. cruentus* species contains methionine and cysteine, two sulfur-containing amino acids that can be employed to create complementary meals and snacks (Escudero *et al*., 2004; Schmidt 1977; Martinez-Nunez *et al*., 2019).

A. caudatus L. subsp.caudatus; A. Grown at high elevations, edulis Spagazzini, also known as Inca wheat and love-lie bleeding, is generally susceptible to most diseases and has a late maturation period.

Vegetable Grain Amaranth: A number of Amaranthus species are already commonly used as potherbs (cooked greens), including *A. blitum* L., *A. lividus* L., *A. viridis* L., and *A. gracilis* Desf. Additionally, *A. tricolor* L. and *A. gangeticus* L.

Dual purpose Amaranth (vegetable and fodder): A. hybridus is a species of annual herbaceous flowering plant that goes by several names, including smooth amaranth, red amaranth, green amaranth, thin amaranth, and smooth pigweed. This widespread weed species can be found in North America, as well as in portions of Mexico, Central America, and northern South America, as well as in fields, gardens, waste areas, roadside vegetation, riverbanks, and other open, disturbed environments.

Wild Amaranth: A. spinosus, sometimes referred to as the spiny amaranth, is a tropical American natural plant also known as spiny pigweed, prickly amaranth, or thorny amaranth. In Asia, it can be a significant weed in rice farming.

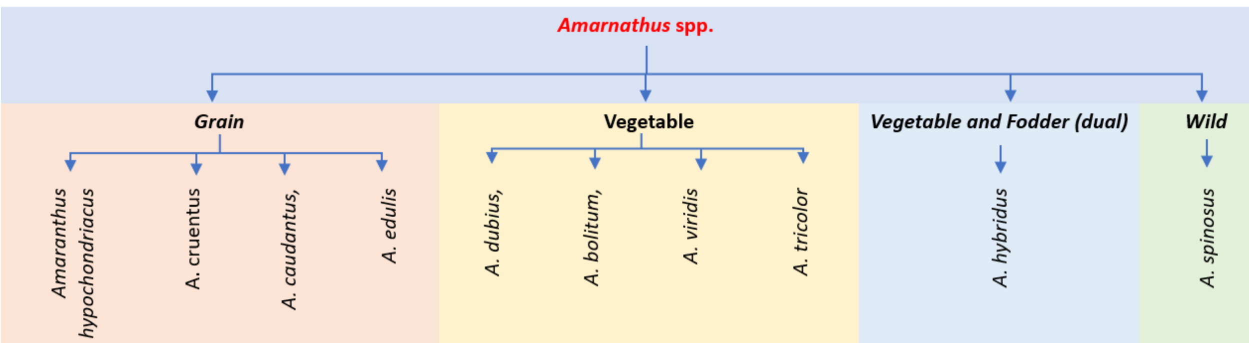

Fig. 2: Different Amaranth species

Genetic resources in Amaranth at Global and National Level

Amaranth germplasm is found all over the world, particularly in the USA, India, and Peru. While they are grown for a healthy diet in the USA, they are a traditional meal that lost its identity with the introduction of new world grains like wheat and rice to nations like Peru, Bolivia, India, and Mexico (Brenner *et al*., 2013). 3,300 accessions of A. hypochondriacus from 40 different nations are housed in a conservatory within the USA germplasm collection (Trucco *et al*., 2011).

A total of 5657 A. hypochondriacus accessions are held by the National Botanical Research Institute, Lucknow (2576 accessions) (Mathews 2001) and National Bureau of Plant Genetic Resources (3081 accessions) in India (Das 2016). The Univ. Nacional San AntonioAbad del Cusco (UNSAAC/CICA) in Peru is home to 740 specimens of A. caudatus (Kalinowski, 1992). A study conducted by Kachiguma *et al*. (2015) on 20 wild accessions of Amaranthus L. shows that these accessions are richer in vitamins, minerals, and nutrients than domesticated accessions from other agro-ecological zones.

Genetic heterogeneity was found in amaranth species accessions that were evaluated using simple sequence repeat markers (Suresh *et al*., 2014). This indicates the range of possibilities for future breeding projects aimed at creating a rich germplasm pool of amaranth crop. Based on the diversity found in the examined accessions for crop improvement, genotypes were categorized into 10 clusters that can be chosen as parents for the hybridization program (Prashantha and Nagaraja, 2011). For 14 features of grain amaranth (*A. hypochondriacus* L.), 98 genotypes were examined in order to investigate the connection between genetic divergence and eco-geographical location. Nevertheless, among clustering patterns, no noteworthy outcomes were found (Pandey and Singh, 2011).

In a hybridization program, these clusters could be utilized to identify transgressive segregants from the population created to boost production and good parents with the highest variability. Phenotypic analysis of amaranth genotypes based on biomass production and related traits laid the groundwork for trait-focused breeding efforts (Baturaygil *et al*., 2021). Chaney *et al*. (2016) used simple sequence repeats to study the entire chloroplast genome sequences of many amaranth species. When researching phylogeny from a variety of genetic variation, SNPs and indels have proven to be excellent genetic resources. 37 accessions from Nigeria were analyzed from three amaranth grain species, and following examination, clusters were created (Olusanya, 2018). This led to the conclusion that there is a significant amount of genetic variety available to increase yield metrics through breeding.

In order to improve high-yielding cultivars based on origin and preferred production location, 229 genotypes from 20 Amaranthus species were assessed for genotype diversity (Wu *et al*., 2000). Thirteen genotypes of various species of A. hypochondriacus and A. tricolor were grouped into two major clusters to differentiate between ornamental and edible (Erum, 2012). Thirty-two Amaranthus species were evaluated for sixteen traits for the morphological characterization of genetic resources for breeding purposes (Gerrano *et al*., 2017). According to Hricova *et al*. (2016), two specific mutant lines created by subjecting A. cruentus L. to gamma radiation were assessed, and the treated plants had noticeably greater seed weight and yield than the untreated plants.

Table 1: Status of germplasm holdings of potential crops in the National Gene Bank in India

S. No.	Category	Species
1	**Grain type**	*Amaranthus hypocondriacus* (3200), *Amaranthus caudatus* (213), *Amaranthus caudatus* var. *albiflorus* (1), *Amaranthus caudatus var. atropurpurea* (1), *Amaranthus cordatus* (3), *Amaranthus cruentus* (184), *Amaranthus edulis* (1),
2	**Vegetable type**	*Amaranthus tricolor* (474), *Amaranthus gangeticus* (26), *Amaranthus viridis* (71), *Amaranthus tricolor* spp. *Tristis* (1),
3	**Dual Type (Vegetable)**	*Amaranthus hybridus* (87),
4	**Wild and weedy relative**	*Amaranthus spinosus* (48),

In India, about 32 species can be found in the wild or under cultivation. For long-term preservation, 5914 amaranth germplasm accessions are housed at the National Gene Bank (NGB) (Raiger *et al*., 2022). Furthermore, at the Tissue Culture and Cryopreservation Unit (TCCU), located in New Delhi, 57 accessions are cryopreserved. Among them, 32 different species *viz*. *Amaranthus albus* (4), *Amaranthus amora* (6), *Amaranthus blitum* (32), *Amaranthus caudatum* (10), *Amaranthus crispus* (1), *Amaranthus dubius* (84), *Amaranthus fimbriatus* (2), *Amaranthus flavus* (1), *Amaranthus graecizans* (32), *Amaranthus leucocorpus* (2), *Amaranthus mangostanus* (7), *Amaranthus oleraceus* (23), *Amaranthus palmeri* (3), *Amaranthus paniculatus* (17), *Amaranthus polygonoides* (4), *Amaranthus powellii* (3), *Amaranthus retroflexus* (9), *Amaranthus* sp. (1356), *Amaranthus tristis* (8), Among them 504 accessions are vegetable type amaranths. These genetic materials are available to amaranth breeders for utilization in their breeding programs.

Nutritional and Biological Properties of Grain amaranth

Because of its superior nutritional qualities and C4 metabolism, amaranth is therefore a perfect crop for surviving and growing in a climate change-affected environment. Due to the high-quality protein found in amaranth seeds, the "AMA-1" gene has been extracted from this crop and is now being incorporated into other significant food crops, such as rice and potatoes (Dua *et al.,* 2009). It has been determined that the potato product with the increased yield and protein content is safe. Tests for toxicity and other negative effects have been successfully completed by the product. In terms of human nutrition, the leaves are very beneficial and high in protein.

According to Bhagmal (1994), this crop has a remarkably high nutritional value due to its high protein, fat, and mineral content as well as its balanced composition of key amino acids (Tables 1 and 2). In terms of productivity and nutritional value, grain amaranth's tiny seeds compare favorably to those of maize and other genuine cereals. It can aid in preventing iron and vitamin "A" deficiency because it is a great source of both iron and beta-carotene. increased levels of folic acid are also associated with increased levels of hemoglobin in the blood in humans. The gluten-free grains serve as a beneficial dietary supplement for those with celiac disease.

Table 2 : Nutritional makeup of different cereals, including amaranth.

Nutrients (%)	Amaranth	Millet	Sorghum	Rice	Wheat	Maize
Moisture	11.29	8.67	12.4	N.D.	N.D.	10.21
Protein	13.56	11.02	10.62	6.67	10.91	9.42
Lipid	7.2	4.2	3.46	2.22	1.82	4.74
Ash	2.88	3.25	N.D.	N.D.	N.D.	N.D.
Carbohydrate	65.25	72.85	72.09	75.56	80	74.26
Fiber	6.7	8.5	6.7	2.2	2.2	N.D.
Energy (kcal/100g)	371	375	329	356	364	365
Mineral (mg/100 g)						
Iron	7.61	3.01	3.30	1.11	3.27	2.17
Zinc	287	1.68	1.67	N.D.	2.73	2.21
Magnesium	248	114	165	N.D.	109	127
Manganese	3.3	1.6	N.D.	N.D.	N.D.	N.D.
Potassium	508	198	363	202	400	287
Calcium	159	8.0	13	4	36	7
Amino acids (g/100 g protein)						
Lysine	5.0	0.5	2.08	3.8	2.8	2.9
Methionine	4.0	1.0	1.61	2.3	1.5	3.4
Cysteine	4.0	0.8	1.67	1.4	2.2	3.4
Isoleucine	3.0	5.1	4.22	3.8	3.3	4.1
Leucine	4.7	14.1	13.98	3.2	6.7	13.0

N.D: not determined, Source: Gebhardt *et al.* (2008). Awadelkareem *et al.* (2015), Kamara, *et al.* (2009); (b) Bagdi *et al.,* 2011; (c) Saldivar (2003); (d) Devi *et al.* (2011).

Despite being ancient crops with great nutritional and medicinal significance, amaranthus species are not yet completely utilized to their full potential. Local populations in several parts of Africa use a variety of underutilized potential green vegetables with African origins for therapeutic purposes (Kwenin, Wolli, and Dzomeku 2011). The nutrients and bioactive substances that these vegetables contain play a major role in their capacity to support health (Cornejo *et al.,* 2019). Due to its high nutritional content, amaranthus is utilized for animal feed and food in both its grains and leaves (Mustafa, Seguin, and Gelinas 2011). The plant has a higher protein and mineral content than typical cereals including millet, sorghum, rice, wheat, and maize (Mustafa, Seguin, and Gelinas 2011).

It also contains unsaturated fatty acids and necessary amino acids in a balanced amount. Lysine, a limiting amino acid that is absent from many other grains, is abundant in its protein (Amare *et al.,* 2015). Additionally, compared to legumes, the protein is relatively high in sulfur-containing amino acids. Because of its balanced amino acid composition, amaranth protein is said to be extremely close to FAO/WHO recommended amounts (O'Brien and Price 2008; Murya and Pratibha 2018). One of the most promising crops for feeding the world's population is amaranth, according to Mekonnen *et al.* (2018).

Amaranthus species are thought to be a storehouse of vital vitamins, including vitamin C, B6, folic acid, and carotene, among other green leafy vegetables and grains (Musa *et al.,* 2011).

The nutritional profiles of amaranth and various cereal grains are displayed in Table 2. The nutritional and chemical makeup of the various species differs slightly, according to chemical examination (Kadoshnikov *et al.,* 2005). Depending on the species, the dry weight percentage of protein in leaves can range from 17.2 to 32.6% (Murya and Pratibha 2018) and Ohsawa (2013) examined the protein content of amaranth leaves grown as a weed, vegetable, and cereal; the weed amaranth leaves had the highest protein content.

This bolsters the argument that edible wild plants might be more nutrient-dense (Guil, Rodriguez-Garcia, and Torija, 1997), therefore more research is required to determine how best to use and incorporate these plants into a diet for food and nutritional security. Apart from its nutritive value, amaranth grain has health-promoting bioactive components (Karamac *et al.,* 2019). The potential of amaranth species seems huge and promising, which makes it crucial to explore them for industrial and health uses. Research has indicated that consuming amaranth on a daily basis may help reduce cholesterol and benefit those with hypertension and cardiovascular disease (Karama *et al.,* 2019; Olaniyi 2007; Kolawole and Sarah 2009). Amaranthus caudatus extract has been proven in several published studies on health benefits using animal models to lower cholesterol (Chavez-Jauregui, Silva and Areas 2000), improve liver function (Kim *et al.,* 2006; Kim, Kim and Shin 2006), and prevent cancer (Bario et Anon 2010).

The bioactive chemicals found in amaranth are what give it its health benefits. The phenolic acids protocatechuic acid, hydroxybenzoic acid, caffeic acid, and ferulic acid, as well as rutin, nicotiflorin, and isoquercetin, are among the bioactive substances found in amaranth grain. Research has shown that nictoflorin helps preserve memory functions, quercetin inhibits oxidation, and rutin slows down the aging process (Alvarez *et al.,* 2010). Globally, there is growing popularity for the idea that eating grains and vegetables might help keep one's heart healthy (Lillioja *et al.,* 2013). Consumption of amaranth species has been shown to improve health in rural people in Zimbabwe (Tagwira *et al.,* 2006).

The communities said that eating amaranth grain improved their own health and that their children's health had significantly improved, with improvements in appetite, mouth sore healing, and decreased obesity among the latter two. Additionally, it was shown that nursing moms who consumed amaranth grains produced more milk; this finding was seen as a benefit for the security of food and nutrition (Tagwira *et al.,* 2006). Vegetable amaranth has been advised for patients with constipation, fever, bleeding, anemia, or kidney issues in certain parts of Benin, as well as for infants and nursing mothers (Akubugwo *et al.,* 2007). In Senegal, newborns are given boiling roots and honey as a laxative. In Ghana, people bathe their painful limbs with the water from the soaked plants.

A. cruentus is used to drive out tapeworms in Ethiopia. The ashes from the stems are applied to wounds in Sudan. The heated leaves were utilized as a tumor treatment in Gabon (Grubben 2004). Both A. caudatus and A. tricolor are used as an internal diuretic and as an exterior inflammatory remedy (Agong 2006; Kim *et al.,* 2006; Kim and Shin 2006; Martirosyan *et al.,* 2007). It has been demonstrated that amaranthus grains can be used in place of wheat and other grains when creating meals for people with celiac disease. For patients suffering from celiac disease, an autoimmune small intestinal ailment linked to a lifelong intolerance to gluten proteins, a gluten-free diet is the only therapeutic option now available (Mart_ānez-Villaluenga *et al.,* 2020). The primary proteins found in amaranth are albumins and globulins; prolamins, which are harmful proteins for those with celiac disease, are extremely uncommon.

Antinutrient composition of amaranth grain

Amaranth has been shown to contain phytates, saponins, tannins, oxalates, protease inhibitors, and nitrates, among other antinutrients. Particularly concerning are the effects of phytates and oxalates on nutrient inhibition in amaranth grains. Small levels of saponin are present in amaranth grains; Dobos (1992) showed that the average concentration of saponin in different amaranth species was 0.09%. While nitrates are concentrated in the grains and leaves of amaranth, protease inhibitors (chymotrypsin and trypsin) are also present in amaranth, but in smaller concentrations than in other cereals. In plants, these antinutritive substances have a shielding effect. For instance, phosphorus in plants is stored in phytotic acid. On the other hand, they prevent nutrients from being absorbed by humans. Since phytotate cannot be digested by humans, it cannot be used as a source of phosphate or inositol. Instead, it binds to proteins to form complexes that restrict its availability. Furthermore, it has been shown that phytate and oxalate impede the digestion of starch. Mineral components including iron and zinc can form complexes with saponins; oxalate binds to calcium, reducing its absorption (Cuadrado *et al.*, 2019). A variety of processing techniques have been employed to reduce amaranth's antinutrient content. Grain husk contains a significant amount of tannins. The majority of the tannins are eliminated by removing the husk, but the phytic acid is left behind. Because phytic acid is uniformly distributed throughout the grain, it cannot be lowered by water extraction or by grinding away the outer layers of the grain. The effects of five processing techniques (defatting, blanching, sprouting, fermentation, and autoclaving) on the protein digestibility and antinutrient composition of grains of *Amaranthus viridis* were studied by Babatunde and Gbadamosi (2017). In comparison to fermentation, which increased protein digestibility by 76%, sprouting at 30°C for 72 hours was found to have the greatest impact on protein digestibility, with an 82% increase. The amount of tannin and oxalate was more effectively reduced by heat treatments such autoclaving and blanching. Njoki (2015) looked into the effects of wet heating techniques (cooking amaranth flour at a water : flour ratio of 6:1) and dry heating techniques (roasting at 160°C for 10 minutes and popping at 190°C for 15 seconds) on significant characteristics of Amaranthus albus grains. Protein digestibility rose by 24% and 15%, respectively, when flour and whole grains were cooked; protein digestibility fell when proteins were roasted.

Fig. 4: Laddoo prepared by AICRN on Potential Crops, UAS, Bengaluru

Compared to roasting and popping, cooking had a greater impact on reducing the levels of tannin, phytate, and oxalate. For amaranth grains, Kanensi *et al.* (2011) optimized the soaking and germination times. Based on the reduction of antinutrient content and dry matter loss, five hours of soaking time and twenty-four hours of germination time were determined to be the ideal processing timings. It is true that using amaranth grains for food security can be difficult due to their antinutrient content, however this content can be reduced with the right processing techniques.

Table-3: Uses of Amaranth

S. no.	Uses	Details	Reference
1.	Amaranth is used as vegetable	Vegetables to help lower cholesterol and manage weight. : Leafy vegetables promote reparation of energy loss due to oxidative stress, and they have the potential to alleviate hunger and malnutrition as well as other forms of metabolic imbalance ravaging the world	Muhali Olaide Jimoh *et al,* 2022
2.	The grains are prepared in a variety of ways	Sweet balls (laddoo), lysine-rich infant food, bread, biscuits, flakes, cakes, pastries, crackers, and ice cream. Its flour use as chappatis, and formanted alcoholic beverages	Joshi and Rana (1991)
3.	Agro-industrial uses	Cosmetics, natural colors, and polymers. Use as a preservative. Amaranth oil, which contains 'squalene', a cosmetic component and skin penetrator and lubricant for computer discs. Highest in amaranth plants. Cosmetics and personal hygiene items can incorporate plant-based squalene oil. Due to its strong antioxidant content, amaranth squalene protects the skin from oxidative damage produced by free radicals. The skin's renewal of its protective layer and promotes skin regeneration.	Sanchez-Marroquin (1983); (Alvarez *et al*., 2010; Venskutonis and Kraujalis 2013); (Ofitserov 2001); (Huang *et al*., 2009)
4.	Medicinal use	To treat measles and snake bites, foot and mouth illness in animals, Kidney stones. Treatment of cardiovascular disorders. Treat chest congestion	Baraniak, Justyna and Małgorzata Kania-Dobrowolska (2022).
5.	Creation of functional drinks	The most popular functional food long shelf life beverages. Sales of functional beverages 105.5 billion dollars worldwide.	Corbo *et al*., 2014; Pandal 2017
6.	The possibility using amaranth grain to feed chickens	Babak. contribute to enhanced flock health and higher yields of high-quality poultry products without negatively impacting performance	(Hosseintabar-Ghasemabad by the end of 2024)
7.	Amaranth usage in animal feed	Amaranth leaves and grains are utilized as silage crops or fodder for a variety of animals, including pigs, chickens, cattle, and rabbits, in many different nations. Good quality silage., because of its high protein content, low oxalate and nitrate content, and excellent fodder yields.	Peiretti 2018; Seguin *et al.* (2013); Ayodele (2009); Alegbejo (2014); (Ahuja *et al*., 1991)
8.	Use as an ornamental plant	In gardens and parks	Park *et al.* (2020)

Varietal Development of Grain amaranth in India

Since the program's start, over 1000 germplasm accessions have been assessed at multiple locations as part of the All India Coordinated Research Network on Potential Crops (previously Under Utilized Crops), which conducts research on grain amaranth. Out of these additions, 32 varieties have been selected, developed, and released for the plains and hills, and have been announced at the national and regional levels for this crop by the State Variety Release Committee (S) and the Central Sub-Committee on Crop Standards, Notification and Release of Varieties for Agricultural Crops.

Table 4: Released/notified varieties at the national/regional level in Grain amaranth by the Central Sub-Committee on Crop Standards Notification and Release of Varieties (1982-2024)

S. No.	Varieties	Year	Av. yield (q/ha)	Protein (%)	Oil (%)	Lysine (g/100g Protein)	Recommended areas in India	Notification no. & date
1	Annapurna	1984	22.50	12.20	7.53	5.40	Mid and high Himalayan	S.O. 258 (E) 14.05.1986
2	GA-1	1991	19.50	13.23	8.20	4.83	Gujarat, Maharashtra	S.O. 527(E) 16.08.1991
3	Suvarna	1992	16.00	12.57	7.61	5.23	Karnataka, Orissa, Gujarat	
4	PRA-1	1997	14.50	13.10	11.60	4.80	Uttaranchal hills	
5	PRA-2	2001	14.50	15.00	6.94	4.90	N-W Himalayan region except J&K	S.O.92(E) 02.02.2001
6	GA-2	2002	15.50	13.70	7.31	4.50	Gujarat state	S.O.937(E) 04.09.2002
7	PRA-3	2003	16.50	13.60	6.36	5.60	N-W Himalayan region except J&K	
8	BGA-2	2006	13.26	13.57	7.54	4.87	Karnataka, Orissa and Tamil Nadu	S.O. 599(E) 25.04.2006
9	Durga	2006	21.00	14.10	7.38	4.80	N-W hill (HP, Uttaranchal and J&K)	S.O. 599(E) 25.04.2006
10	VL Chua 44	2006	13.20	11.80	6.30	4.70	Mid and higher hills of Uttaranchal	S.O. 599(E) 25.04.2006
11	GA-3	2008	12.58	12.43	7.20	5.60	States of Gujarat and Jharkhand	S.O. 2458(E) 16.10.2008
12	RMA- 4	2008	13.90	12.38	7.20	5.80	Rajasthan, Jharkhand and Orissa	S.O. 449 (E) 11.02.2009
13	RMA-7	2010	14.66	12.34	7.24	5.80	Raj., Gujarat, Orissa, Maharashtra, Haryana, Delhi	S.O. 632 (E) 25.3.2011
14	KBGA-1	2012	15.00	12.10	7.20	5.20	Karnataka	S.O. 2805 (E) 25.08.2017
15	Phule kartiki	2012	15.00	13.80	9.30	5.20	Maharashtra	S.O. 2125 (E) 10.09.2012
16	Prachi	2015	11.60	15.30	6.60	5.40	Odisha state	
17	Ruchi	2015	11.90	12.30	6.80	5.40	Odisha state	
18	Chhattisgarh Rajgira-1	2017	14.00	11.70	6.50	5.50	Chhattisgarh	S.O. 3220(E) 05.09.2019
19	KBGA-4	2017	21.00	12.30	6.80	5.60	Karnataka	S.O. 3482 (E) 07.10.2020
20	Suvadra	2018	17.50	11.40	7.10	5.28	Odisha, Chhattisgarh, Jharkhand, Maharashtra and Gujarat	S.O. 3482 (E) 07.10.2020
21	GA-4	2020	16.45	12.40	7.20	5.00	Karnataka State	S.O.500 (E) 02-02-2021
22	GA-5	2020	19.02	11.85	7.71	5.98	Gujarat, Raj., Maharashtra and Jharkhand	S.O.500 (E) 02-02-2021
23	GA-6	2020	18.50	11.52	7.80	8.58	Gujarat	S.O.500 (E) 02-02-2021
24	VL Chua-110	2020	13.00	14.27	8.64	6.43	Uttarakhand Hills	S.O.500 (E) 02-02-2021
25	KBAG-15	2021	20.00	12.30	8.71	6.44	Karnataka	S.O. 1056(E) 06.03.2023

26	GA7	2024	15.81	12.56	8.19	2.93	South zone (Karnataka)	SO 4388(E) 08.10.2024
27	Him Gauri	2024	16.71	13.39	8.10	7.18	North Hill Zone (HP and UK)	SO 4388(E) 08.10.2024
28	Jodhpur Rajgira 1	2024	14.01	11.83	7.84	5.17	Raj., Gujarat; UP; Odisha; Chhattisgarh	SO 4388(E) 08.10.2024
29	Jodhpur Rajgira 2	2024	14.05	12.60	8.33	4.72	Raj., Gujarat; UP; Odisha; Chhattisgarh	SO 4388(E) 08.10.2024
30	VL Chua 140	2024	16.86	14.38	8.66	5.50	Himachal Pradesh and Uttarakhand	SO 4388(E) 08.10.2024
31	GA8	2024	14.55	12.21	8.09	5.03	Raj., Gujarat, Maharashtra, UP; Jharkhand, Odisha, Chhattisgarh	SO 4388(E) 08.10.2024
32	GA9	2024	14.12	12.51	7.89	4.69	Raj., Gujarat, Maharashtra, UP; Jharkhand, Odisha, Chhattisgarh	SO 4388(E) 08.10.2024

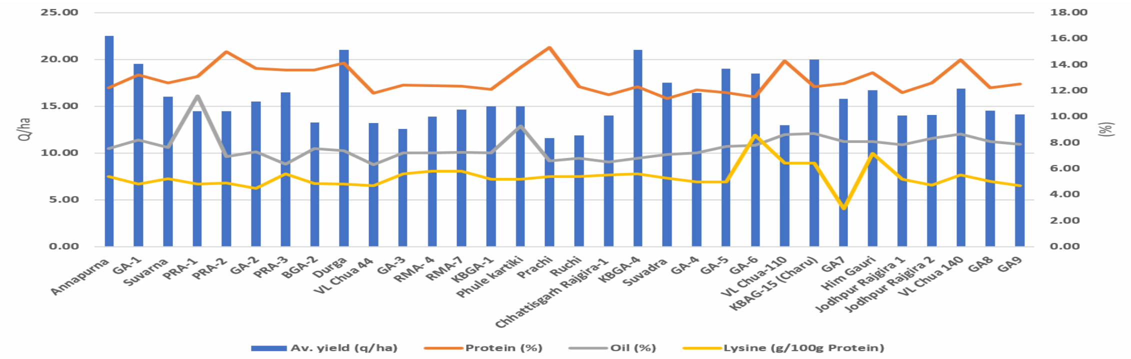

Fig. 3: Nutritional profiles of released cultivar of grain amaranth in India

Fig. 5: VL Chua 110: for rainfed organic ecology of Uttarakhand Hill

Fig. 6: Suvadra: Medium maturity and high yielding

Fig. 7: GA5: Field resistant to major diseases and pests

Fig. 8: Suvarna: Early maturing

Amaranth production and the requirement for a seed management system

The Amaranthaceae family includes amaranthus. According to Petruzzello (2016), it is a herbaceous annual or short-lived perennial plant. Many communities, both rural and urban, highly value this vegetable crop due to its large output (Chelang'a, Obare, and Kimenju 2013). Compared to traditional cereal crops, amaranth is a highly adaptable crop that can withstand heat, drought, and pests. It also grows more readily in unfavorable conditions. Because of its short growth cycle and ability to withstand a wide range of environmental conditions, amaranth has the potential to be a "golden" vegetable with significant commercial value (Hoidal *et al.,* 2020). As a vegetable for the home garden, it can be grown all year round. Although amaranth can cope with unfavourable conditions and can adapt to a variety of soil types, it thrives best in fertile, well-drained and loose soils with high organic matter content (Stetter, Vidal-Villarejo and Schmid 2020). Amaranth is usually grown in mixed crops. Intercropping amaranth with field bean, rice bean, ragi, peanut and pigeon pea has proven to be profitable. Simply mixing seeds of different crops and broadcasts may not give the desired results (Fig. 9). However, to maximise the benefits of intercropping and to facilitate separate harvesting of each crop, crops should be sown in different rows and in an appropriate row ratio. In hills, intercropping field bean and amaranth at a 2:1 ratio and applying the fertilizers recommended only for field bean (N:P:K @ 20 : 40:20 kg/ha) resulted in the highest B:C ratio (2.57). There are no reports of serious pest and diseases problems in this crop. However, leaf head canker, white rust, fungal attack, mycoplasma and viral diseases can affect this crop. Among the pests, aphids, caterpillars, leafhoppers, blister beetles, flea beetles, mealybugs, stem weevils and stem borers have been reported as pests for this crop. Use of disease-resistant varieties, spraying of fungicides (Dithane Z-78 against late blight, Karathane against white rust and Bavistin against damping-off) @ 0.1%, use of Lindane 10% @25 kg/ha dust against caterpillars, beetles and bugs, Phorate 10 G @3.5 kg/ha against stem weevils and borers and Malathion for aphid control are recommended. The average productivity of grain amaranth is estimated at about 16 q/ha. Yields of up to 40 q/ha have been achieved in the mountainous regions and 25 q/ha in the plains.

Fig. 9: Prominent intercropping system in Gujarat (Grain amaranth+ gram 1:1)

The largest producers of amaranth are Mexico, Russia, China, India, Nepal, Argentina, Peru and Kenya. However, data on the global production of amaranth is scarce and FAOSTAT does not publish production records (Rosentrater and Evers 2018). Amaranth grown for seed production requires a different type of management than amaranth grown for grain. Since amaranth is a self-pollinating plant, it is highly prone to cross-pollination, resulting in the production of hybrid seeds that may not be desirable. Sometimes corn strips are planted between the amaranth lines to prevent cross-pollination and keep the seed pure (Manikandan and Srimathi 2014). A seed production field should be free of weedy amaranth varieties, which can produce weed hybrid seeds with lower yields. This is a major challenge for amaranth seed systems. Smallholder farmers operating in the informal seed sector obtain seed from their harvest or collect and buy it from neighbors, village markets or traders on market day. Training farmers in seed production strategies and linking farmers with seed companies and research institutions to routinely renew the seed stock can help improve the quality of seed in the informal sector. Moreover, the formal sector is less interested in seed multiplication for self-pollinating crops. They can be encouraged to produce and sell basic seeds to trained community growers who produce and sell them to farmers in their communities (Oyekale 2014). Seed viability is critical in the production of amaranth. If amaranth is to be an alternative to food crops such as rice, millet, wheat and sorghum in sub-Saharan Africa, good seed management must be at the centre of efforts. A good seed management system involves the development of high-yielding seeds and an efficient system for making them available to farmers. To achieve this, there must be linkages between researchers, extension workers, government agencies, farmer groups and the private sector. It is therefore necessary to develop a seed platform for specific crops such as amaranth that integrates both commercial and community-based seed supply systems. The system will ensure that the production and marketing of quality seed is not compromised.

Post-harvest procedures for amaranth

The practice of efficient post-harvest management is very important for maintaining the entire value chain of any crop. India experienced a range of 4.65 to 5.99 percent of total crop losses. The percentage of loss incurred during storage was 0.75 to 1.21 percent, but the percentage of loss incurred during farm operations was 3.90–4.78%. According to Vishwakarma *et al.* (2020), a delay in harvesting, poor threshing and winnowing techniques, and unsuitable storing methods contributed significantly to the total losses. Post-harvest losses of cereals in sub-Saharan Africa are estimated at 5 to 13 % (FAO 2011; Tibagonzeka *et al.,* 2018). Like any other grain, amaranth must be treated after harvest to ensure that the grain remains viable, retains its nutritional content and has a high market value. While the pre-harvest procedures for amaranth seed production differ from those of cereal production, post-harvest management is similar for seeds and cereals. Post-harvest management of cereals generally includes harvesting, drying in the field, threshing and cleaning, further drying, storage and processing.

In order to minimize grain losses, these few processes need to be conducted with the meticulous attention to detail that they deserve (Manikandan and Srimathi 2014). Crop harvesting in underdeveloped nations is primarily done by hand with instruments like sickles, knives, and cutters. Yet, employing combined harvesters is recommended in industrialized nations (Parfitt, Barthel, and Macnaughton 2010; Hodges, Buzby, and Bennett 2011). The timing and technique of harvesting play a significant role in determining the losses that occur during the process. Early harvesting at a high moisture content raises the expense of drying the crop, increasing the risk of mold formation if the crop is not dried thoroughly. This also leads to a high percentage of broken grains and low milling yields (Khan 2010). The majority of amaranth cultivars grow quickly, and they can be harvested six to eight weeks after seeding.

Following harvesting, drying is essential to preserving crop quality, minimizing storage losses, and cutting down on transportation expenses (Abass *et al.,* 2014). Drying can be done mechanically with dryers or naturally with the sun or shade. The conventional and cost-effective method for drying the harvested crop is natural drying, often known as sun drying. Most crops have a safe moisture level of less than 12% when stored for an extended period of time (Kitinoja 2013). Grain that is left out to dry in the sun is vulnerable to contamination from stones, dust, animal feces, and other foreign objects, as well as bird and insect consumption.

Farmers distribute the grains on mats, which are plastic sheets, which lowers contamination and simplifies grain gathering. Nonetheless, mechanical drying overcomes a few of the drawbacks of sun-dried air drying. Convection solar tent dryers are an alternative to open sun drying, which has several drawbacks. Freshly collected *Amaranthus cruentus* grains with an average moisture content of 64% were dried to a stable moisture content of 7% on a dry basis after seven days in an experimental (Ronoh *et al.,* 2010) using a solar tent dryer.

The experiment involved two temperature and humidity ranges: 22.6 to 30.4 ^{o}C and 25 to 52% for the ambient temperature and 31.2 to 54.7 ^{o}C and 22 to 34% for the internal temperature of the solar drier, respectively. After drying, threshing and cleaning can be completed manually or mechanically. While washing involves separating entire grains from broken grains and other foreign objects like stones, sand, and chaff, threshing involves separating the grain from the panicles.

According to Abedin *et al.* (2012), the majority of grains in developing nations are kept in traditional home containers including metal bins, clay pots, and bags for future planting season use and self-consumption. After cleaning and drying, the best way to store grain is in heavy-duty paper bags or wooden storage boxes until needed. To prevent infection, it's critical to store thoroughly dried seeds in a tight container.

After drying, amaranth seed must have a moisture level of no more than 12% to be successfully preserved; any higher percentage could encourage the growth of mold and lower quality (Uganda National Bureau of Standards, 2011). According to Tibagonzeka *et al.* (2018), it's crucial to store grain in containers elevated on pallets to facilitate heat exchange.

Possibility of local and international markets for amaranth grains

In Europe, there is a growing market niche for pseudo cereals, with an annual growth in demand. On the other hand, information about the amount of output and the relationship between the importing and producing nations' markets is lacking. According to the Confederation of British Industry (CBI Product Factsheet 2014), developing nations supplied almost 6,000 tonnes of specialty grains, the majority of which were amaranth seeds. That survey states that Germany is the primary amaranth seed consumer market.

But in other wealthy nations like the UK, the Netherlands, Sweden, Belgium, and France, this item is gaining popularity. Mainly used as a health food, amaranth can be purchased in 500 g tiny containers (raw, popped, or milled) or as an ingredient in healthy snacks, bakery goods, and morning cereals (CBI Product Factsheet 2014). Due to low standards, low demand, and a restricted supply of commodities, amaranth crop markets in Africa are small and underdeveloped. Due to their weak connections to major purchasers, smallholder farmers grow grain amaranth, which reduces their potential for sales.

Leaders in the African business and other significant players can establish robust market connections with European nations and furnish readily obtainable data on regions with elevated demand. This will encourage the creation of income and lessen poverty. Several prominent nations that cultivate and possess a market share of grain amaranth are Mexico, Russia, China, India, Peru, and Kenya. (2012) Ainebyona *et al.* The growth of food processing industries and the use of organic ingredients in medical cosmetics are expected to propel the grain amaranth market. In India, one of the largest marketplaces in Gujarat for buying and selling amaranth grain is the Palanpur APMC market in the Banaskantha district. From there, the grain is exported throughout the nation. Approximately fifteen thousand tons of grains are received at the Palanpur grain market each year. There are a few intermediaries who purchase grains from farmers and sell them to food businesses outside of the state, but the majority of farmers dispose of their produce in the APMC markets in Palanpur (Raiger *et al.,* 2022).

Development of food products using amaranth

According to some, grain amaranth is a "super" grain-producing plant with excellent prospects and significant commercial potential for new product development, especially in the food industries' baking sector. Unlike wheat, it is gluten-free, making it an excellent raw material substitution for the creation of gluten-free goods. Amaranth grain can be processed using certain methods to increase its nutritional value and suitability for human consumption. In a family, amaranth grains can be cooked and consumed as porridge (Mugalavai 2013).

It can also be malted to make beer. Amaranth grain has been shown to be capable of being popped or roasted in order to produce flour. This flour can then be combined with other food ingredients or used alone to create a variety of goods, including morning cereal, biscuits, pasta, crackers, pancakes, and muffins (Emire and Arega 2012). To make thin porridge, unpopped grain can be mashed and combined with fish flour or flour from other cereals including millet, sorghum, and maize (O'Brien and Price 2008; Janet 2015). If amaranth grain is given the proper care throughout the manufacturing and storage processes, it can significantly improve nutrition and food security as well as serve as a raw and intermediate material for enterprises looking to expand their scope of work and create jobs.

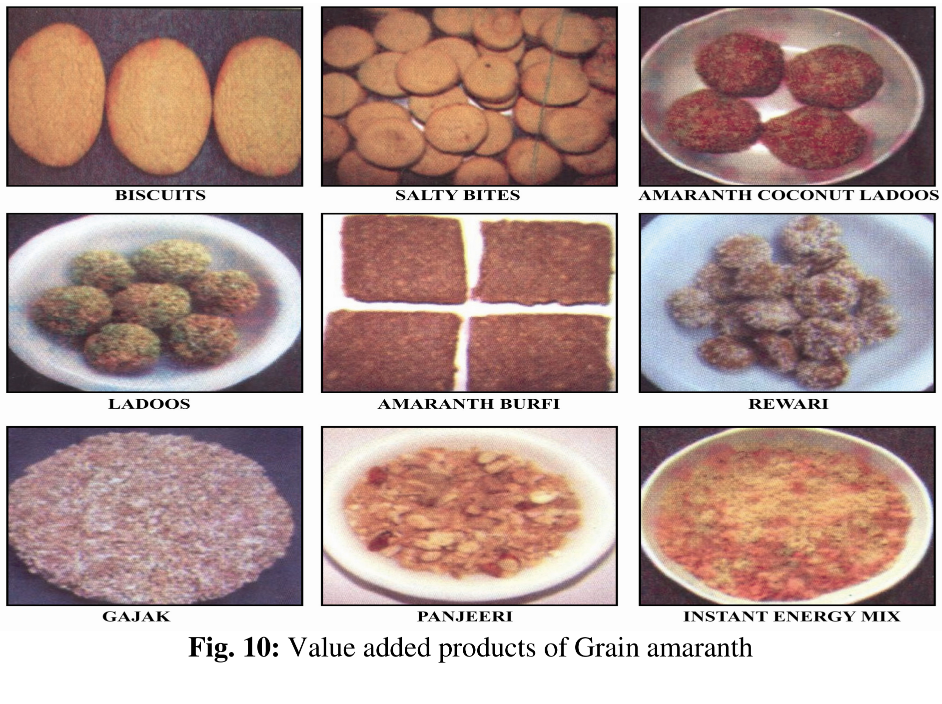

Fig. 10: Value added products of Grain amaranth

A few number of plant species now dominate the world's nutritional security landscape. Amaranth is one of these grains that has a strong commercial potential, particularly in terms of its nutritional and therapeutic qualities. In majority of India's tribal areas, this crop is traditionally employed in various meal dishes as a staple diet. These crops provide enormous potential for development of high-nutrient value value added products and for use as supplements. Product competitiveness for location-specific conventional value-added products would arise from the usage of this crop (Fig. 10).

Like amaranth, or Rajgira, it is also typically rolled and popped. It can be used in a variety of recipes, such as granola bars, cakes, chikki, chapati, panjiri, malt/beverages, barfi, laddu, upama, and ready-to-eat breakfast cereals. The Department of Food Science, Nutrition and Technology, College of Home Science, CSK Himachal Pradesh Krishi Visvavidyalaya, Palampur; University of Agriculture, Gandhi Krishi Vigyana Kendra (GKVK), Bangalore; Orissa University of Agriculture and Technology, Bhubaneshwar; and Indira Gandhi Krishi Vishvidyalaya, Raipur, Chhattisgarh, India, developed and standardized recipes for a variety of value-added products made from grain amaranth. Given the importance of amaranth as a grain, there is opportunity to stimulate entrepreneurship in a variety of food items at the household and cottage industry levels.

Amaranthus as a possible nutritional supplement for athletes' diets

Amaranthus is regarded as a superfood with significant nutritional benefits. It is a functional food that is made up of bioactive substances that are essential for sports nutrition, such as antioxidants, proteins, fat, carbohydrates, fibers, minerals, and vitamins; additionally, it contains secondary metabolites, tocopherols, sterols, squalene, trace elements, polyphenols, peptides, and polyunsaturated fatty acids. Interestingly, it contains a lot of amino acids, particularly branched-chain amino acids (BCAAs), which are a natural way to raise nitric oxide levels, which helps athletes with their stamina, endurance, strength, and circulation. It has been discovered to enhance muscle repair, aerobic ability, and improved body composition.

Table 5: Amaranthus as a possible nutritional supplement for athletes' diets

S. No.	Performance	References
1.	Gluten free diet	Woomer *et al.,* 2021; de la Barca *et al.,* 2010; Rai *et al.,* 2018; Niro *et al.,* 2019; Caerio *et al.,* 2022
2.	Fiber-rich, improves digestion	Repo-Carrasco- Valencia *et al.,* 2009; Baraniak *et al.,* 2022
3.	Prebiotic and Hemoglobin increase effect	Orsango *et al.,* 2020; Gullon *et al.,* 2016
4.	Vegetarian and vegan diets	Balakrishnan 2022; Schoenfeld *et al.,* 2020; Rogerson 2017
5.	Strengthen bones	Baraniak *et al.,* 2022; Martinez *et al.,* 2020
6.	Protein rich instant beverage	Manassero *et al.,* 2020; Arcila *et al.,* 2006
7.	Anti-inflammatory, boots immune system	Martinez-Lopez, a., *et al.,* 2020; Tang *et al.,* 2017
8.	Hypocholesterolemic and helps in weight loss	Prince *et al.,* 2021; Shahbaz *et al.,* 2022; Morales *et al.,* 2021; Wu *et al.,* 2019; Moszak *et al.,* 2020
9.	Improves aerobic capacity and metabolism	Liubertas *et al.,* 2020; Yelisyeyeva *et al.,* 2012; Yelisyeyeva *et al.,* 2009
10.	Muscle growth	Antonio *et al.,* 2019; Bull *et al.,* 2022; Lopez *et al.,* 2019; Malik *et al.,* 2022
11.	Endurance, Stamina and multiple health benefits	Espino-Gonzalez *et al.,* 2018; Olawoye *et al.,* 2021
12.	Pre-workout nitric oxide supplement	Subramanian *et al.,* 2016; Liubertas *et al.,* 2020
13.	Protein-rich, high nutritive value	Torregrosa Garcia *et al.,* 2019; Malik *et al.,* 2022; Pareek *et al.,* 2021
14.	Rich in BCAAs and antioxidants	Martinez-Lopez, A., *et al.,* 2020; Kim *et al.,* 2006; Tang *et al.,* 2017
15.	Vitamin B, C, E, K1, Calcium, Manganese	Rastogi *et al.,* 2013; Martinez-Lopez, A., *et al.,* 2020; Niro *et al.,* 2019
16.	Improves heart and Eye health	Chmelik *et al.,* 2019; Martirosyan *et al.,* 2007; Suri *et al.,* 2017; Haskell *et al.,* 2005

Framework for creating a grain-amaranth value chain that will ensure the security of food and nutrition

Among the hundreds of underutilized species grown throughout Africa, amaranth has unquestionably been designated as a priority crop for value chain improvement (Njoroge *et al.,* 2014). Despite its advantages, it is intimidated by the numerous limitations all along its valve chain. The aforementioned limitations pertain to the production, handling, and distribution of grain amaranth and its derivatives (Emokaro, Ekunwe, and Osifo 2007). Lack of access to high-quality seeds, inadequate understanding of optimal agronomic procedures, and inadequate farmer organization resulting in inadequate connections with research and extension agencies pose significant challenges to the cultivation of grain amaranth.

This is in addition to the agricultural difficulties that developing nations now face, which include restricted access to land, high labor costs, a lack of irrigation systems, a shortage of fertilizer, and inadequate transportation. Poor market channels, a lack of funding, and the framework for activities and players required to enhance the grain-amaranth value chain for an improved food and nutrition security system are all shown in Figure 1 (Chemining'wa *et al.,* 2016). Grain amaranth has significant losses after harvest, as well as a deficiency in processing and storage facilities and technological expertise.

Because so few people are aware of the nutritional and therapeutic benefits of amaranth, the grain's marketing has not completely changed. Due to their lack of awareness of the advantages, consumers who are meant to generate demand have little to no preference for grain amaranth and its byproducts. Even in the event that demand exists, it will be hindered by inconsistent supply and subpar goods. The same is true for decision-makers who, lacking sufficient knowledge about this significant crop's potential, fail to adequately assess the growth of its value chain (Chemining'wa *et al.,* 2016).

But in order for grain amaranth to realize its full potential for ensuring food and nutrition security, the appropriate policies and regulations need to be in place to remove the obstacles. Six recommendations were given for the improvement of the amaranth value chain during the national innovation platform workshop that was held in Zimbabwe, Kenya, and Benin. The stand points presented at the end of the workshop included creating market access and consumer demand, bolstering the input (seeds, fertilizers, and agrochemicals) system, advancing planting and value-adding technology, properly organizing farmers and establishing connections with extensionists and other researchers, interacting with policy makers through lobbying and advocacy, and raising money from the public and private sectors (Hall *et al.,* 2014).

To increase grain amaranth production, processing, and consumption in Africa, a value chain development strategy is required. The goal of this strategy is to strengthen the connections between major and small players. A suggested structure for the development of the grain amaranth value chain is shown in Figure 1. The current status of the amaranth value chain, which is mostly restricted to small-scale production and extremely poor utilization, is identified by the proposed framework. It highlights the crucial role that research plays along the value chain and connects it to the players and initiatives that are required to advance grain amaranth.

Partnerships and alliances between academics, farmers, and the public and private sectors are welcome. In spite of the fact that scientists have long studied and supported underutilized crops, a concentrated and well-coordinated effort is desperately needed to improve the amaranth value chain.

It is necessary to gather the varied germplasm that exists in India, then choose and breed high-quality, adaptable species. Technological advancements ought to go hand in hand with this to lessen production and processing limits. Strategic planning that integrates manufacturing, processing, and marketing must be developed through research projects. Research results must support industrial applications, as demonstrated by the addition of amaranth grain to consumer-acceptable food products. The majority of cutting-edge research and development on industrial applications of underutilized crops is carried out, and is encouraged by, policies in industrialized nations. In emerging nations, this ought to be promoted, but the pace of growth needs to be flexible to accommodate local conditions.

A value chain development strategy will support and promote partnerships with the private sector, which will help smallholders by giving them access to a more stable market for goods and output (Devaux *et al.,* 2018). It's becoming essential for grain amaranth stakeholders to establish a network. Coordination of efforts and the exchange of information and resources should be the network's main objectives. You could use an innovation platform for this. These are multi-stakeholder platforms that promote commercial and technical connections. More importantly, researchers should concentrate on applying newly acquired information and technological capabilities to fortify actors and alter processes rather than just creating new knowledge and tools.

The private sector should be involved to influence their willingness to process and market grain amaranth products; policy discussions should aim to raise awareness and generate support; donors should be partnered with for financial support while searching internally for additional funding sources; and farmers should be involved in the entire process.

Summary

A staple of the Indian diet, amaranth is hailed as a "superfood" for its well-balanced amino acid profile and high protein content. When it comes to nutritious content, amaranth outperforms a lot of other crops, like rice, corn, and wheat. Furthermore, the amount of lysine is double that of rice and three times that of maize. This crop has received a lot of praise for its gluten-free qualities in addition to its good agronomic qualities. In addition to helping people who are vegan or have a gluten sensitivity, it also has the ability to deliver high-quality proteins and antibacterial properties to packaged foods.

Even with all these advantages, this crop is still not widely grown in India or anywhere else in the world. It is possible to significantly raise the yield of grain amaranth on both hills and plains by implementing the upgraded varieties and agro-techniques mentioned above. It would not only improve the financial situation of the farmers living in the plains and hills, but it will also increase the amount of nutrient-dense food available to prevent human malnutrition.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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