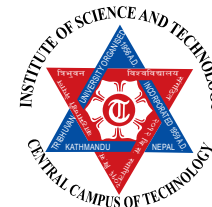




Review Article



Amaranth: A Golden Crop for Future

Geeta Bhattarai^{1*}

¹Central Department of Food Technology, TU, Dharan, Nepal

*Corresponding author: Geeta Bhattarai, Central Department of Food Technology, Dharan, Sunsari, Nepal, E-mail: geetabhattacharai14@gmail.com

Summary:

Amaranth (*Amaranthus*), a member of amaranthaceous group of plants, is classified as a pseudo cereal and grown either as a grain crop or as a leafy vegetable. It is one of the few multi-purpose crops which can supply grains and tasty leafy vegetables. The grain has ability to grow in the dry and semi-dry lands due to its drought tolerant characteristics. It is rich in protein, lysine, carotenoids, dietary fiber, iron, vitamin C, vitamin A, riboflavin, thiamin, folic acid, calcium etc. Amaranth contain substantial amount of bioactive components such as tocopherol (α , β and γ), DPPH (2, 2-diphenyl-1-picrylhydrazyl), anthocyanins, lutein and other phenolic compounds. The fat in amaranth seed is low but composed of essential fatty acids (linoleic and linolenic). Grain amaranth can be used as a flour ingredient for pancakes, bread, muffins, dumplings, crackers, cookies, puddings, porridge, cakes and as a roasted puffed snack. Vegetable types amaranth (also leaves of grain amaranth) are used to make curry, vegetablesalads, steamed salad, boiled soups, stir fried, or baked to taste. The seeds and leaves of amaranth are used as herbal remedies and have nutraceutical value. Because of no gluten content, grain amaranth is valuable carbohydrate source for person having gluten intolerance problem. Seed or leaf of amaranths contains some anti-nutritional factors, such as saponins, tannins, phyticacid, oxalates, protease inhibitors, nitrates and phyto-hemagglutinins. Thermal processing in moist environment, prior to food use inactivates the antinutritional factors. The present paper briefly describes crop introduction, botany, chemical and nutritive composition, functional and bioactive components, antinutritional factors and food uses including new findings on functional properties of grain amaranth.

Keywords: Amarnath, nutritional values, anti-nutritional factors, toxic aspects

Introduction

Rational and effective exploration of sustainable plant resources is an important 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 (FAO, 2005). Therefore, valorization of valuable and forgotten, crops has been in the focus all over the world during the last decades. *Amaranthus* (family *Amaranthaceae*), collectively known as amaranth, is a cosmopolitan genus of annual or short-lived perennial plants, consisting of approximately 60 species, which according to the uses for human consumption can be divided into grain and vegetable amaranths (Mlakar et al, 2010). Amaranth was

important food crop in the Aztec, Mayan, and Incan civilizations; however, its production has declined remarkably, after collapsing of the Central American cultures (Alvarez-Jubete et al, 2010; Bressani, 2003; Schoenlechner et al, 2008). Amaranth is grown either as a grain crop or as a leafy vegetable. It offers important promise for feeding the world's hungry. In the National Academy of Sciences' (1975) study Underexploited Tropical Plants with Promising Economic Value, amaranth was selected from among 36 of the world's most promising crops (Anon, 1984).

Origin, Production and Importance of Grains of Amaranth

Amaranth (*Amaranthus cruentus*), is an ancient Central and South American crop, is currently cultivated in

Africa and Asia.

Seed

Amaranth seed is borne in a utricle, which is classified as dehiscent, semi-dehiscent, or indehiscent type. The colour of the seed in amaranth varies from white, gold, brown and pink to black. Seed is lenticular and relatively small (0.9 to 1.7 mm diameter), with 1000-seed weights from 0.6 to 1 g (Kigel, 1994). Nowadays, one of the goals for amaranth breeding is to increase seed size. Larger seeds would improve seedling vigor, ease of handling and popping (Stallknecht and Schulz-Schaeffer, 1993).

One of the most pronounced difficulties in commercial amaranth production is mechanical harvesting. The plants do not dry down uniformly and sufficiently at maturity to permit harvest. Harvesting should be done as soon as possible to reduce wind damage and grain shattering (Weber, 1987) and cereal harvesters may successfully be used (Majewski et al, 1994). Amaranth grain yield depends on environment, weather conditions, species, genotype, and production techniques, and varies in a wide range from 500 to 2,000 kg grain per ha. With appropriate varieties and production techniques yields of 1,500 to 3,000 kg grain per ha can be expected (Williams and Brenner, 1995). According to Jamriska (1990) and Kaul et al, (1996) grain yields in Europe ranged between 2,000 in 3,800 kg per hectare.

Physical Composition

Amaranth seeds are very small; 1,000-3,000 seeds per gram are common. Amaranth germ and bran constitute 26 percent of the seed. When the whole grain is milled, its protein, vitamins, fat, and minerals are concentrated significantly in the bran/germ fraction. Amaranth germ contains 30 percent protein. It also contains about 20

percent oil. The bran is high in fiber, protein, vitamins, and minerals (Anon, 1984)

Chemical Composition and Nutritive Value

Average chemical composition of *amaranth* grain is shown in Table 4, amino acid content is in Table 2. Amaranth has a protein content as high as 16 percent, which is higher than commercial varieties of other cereals. The charts (Table 2) show the contents of essential amino acid of grain amaranth is superior in comparison with the more common commercial grains. The balance of amino acids in amaranth protein is closer to the optimum balance required in the human diet. As noted already, the average protein and lysine content in amaranth is high as compared with that found among the most common cereals (Figure 1 and 2). Thus, amaranth's importance is that its essential amino acids complement those of corn, rice, and wheat. For example, corn protein is low in both tryptophan and lysine, whereas amaranth has high levels of both (Anon, 1984). Prakash and Pal (1991) reported that amaranth greens are high in protein (14 to 43 g kg⁻¹ in fresh matter), lysine (40 to 56 g kg⁻¹) and caroteneids (60 to 200 mg kg⁻¹). Amaranth contains the oxalates and nitrates, and their concentration in fresh matter varied from 4.1 to 9.2 g kg⁻¹ and from 3 to 16.5 g kg⁻¹, respectively (Williams and Brenner, 1995). The amaranth leaves, after eating provide protein, high dietary fiber, high iron, low fats and very high vitamin C, Vitamin A, Folic acid and calcium (Funke and Olumakaiye, 2011). The minerals, vitamins and bioactive components found in amaranth seed is given in Table 1 and 3 respectively. Amaranths are sometimes recommended by doctors for people with low red blood cell count because vitamin C promotes iron absorption from the small intestine (Anon, 2007).

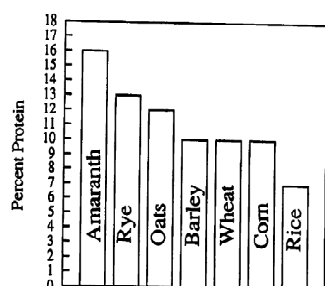


Figure 1. Protein Content of Amaranth as Compared to other Grains
SOURCE: National Academy Press, 1983

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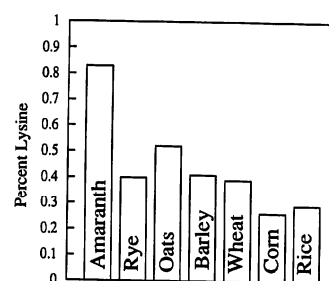


Figure 2. Percent Lysine in Amaranth as Compared to other Grains
SOURCE: National Academy Press, 1983

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regions such as Mexico, Central and South America, Africa, south Asia, and part of China (Valencia-Chamorro, 2004). This plant is constantly studied by food scientists due to its high nutritional value, mainly for its protein content (Schoenlechner et al, 2008) and levels of essential amino acids (Valencia-Chamorro, 2004). The oils obtained from amaranth is also important because it contain oleic (18:1 n-9), linoleic (18:2 n-6) and α -linolenic fatty acids (18:3 n-3) (Ryan, 2007; Schoenlechner et al, 2008). According to Perini (2010), linoleic and α linolenic fatty acids are strictly essential, because they are not produced by human body and must be provided by an adequate diet. The ingestion of 18:1 n-9 instead of saturated fatty acids helps to reduce the low density lipoprotein levels in blood and, the chance of cardiovascular diseases will reduced (Elmadfa and Kornsteiner, 2009). The lipid fraction of this pseudo-cereals cited above also contains compounds with antioxidant capacities, such as tocopherols, which act as scavengers of lipid peroxidation radicals (Leon-Camacho et al, 2001; Ryan, 2007). Part of this activity may be due to polyphenolic compounds, comprised of several classes of flavonoids and anthocyanins, as well as other phenolic constituents widely distributed at varying levels in plant based foods (Lobo, 2009). These polyphenolic compounds work as free radical terminators and metal ion chelators. However, even with all of the nutritional benefits granted by lipids, proteins and antioxidant molecules, native varieties of amaranth is rejected by many human consumers. This happens because it has a little bitter taste, which is associated with the presence of saponins. The compound saponins is water-soluble and thermo labile with a prominent toxicity in high doses when administered in vivo. (Kuljanabhagavad, 2008). Raw amaranth is known to be rich in micronutrients particularly iron and vitamin C. Amaranth is one of the most commonly consumed green leafy vegetable in Nigeria. There are about six species in cultivation and they protect against several disorders such as defective vision, respiratory infections, recurrent colds, retarded growth, functional sterility, bleeding tendencies, leucorrhoea, and premature ageing (Bakhru, 2007). It is always available, affordable and accessible. Amaranth can conveniently accompany with any types of meals. It is eaten at any time of the day as a garnish in breakfast, lunch and dinner. According to World Health Organization, in developing countries, every second pregnant woman and about 40% of preschool children are estimated to be anaemic. In many developing countries, iron deficiency is aggravated by worm infections, malaria and other infectious diseases like tuberculosis. Anemia also contributes to 20% of all maternal deaths. Iron content of foods is the most important constituent of forming hemoglobin. In this context, amaranth leaves are

rich in iron. An Australian investigator in 1973 and the book "Unexploited Plants with Promising Economic Value" helped to raise interest in grain amaranth cultivation and food uses (Berghoefer and Schoenlechner, 2002).

Botany

Grain amaranth belongs to the order *Caryophyllales*, the amaranth family *Amaranthaceae*, sub-family *Amaranthoideae*, to the genus *Amaranthus*, and according to Sauer (1967), into the section *Amaranthus*. The genus *Amaranthus* includes approximately 60 species, most of which are cosmopolitan weeds. According to the utilization of cultivated amaranths for human consumption, species can be divided into grain and vegetable amaranths. Grain amaranth belongs to a group of cereal-like grain crops or pseudocereals.

Roots

Root morphology, growth, development and root distribution in the soil, as well as its responses to availability of nutrients and water, have been barely investigated in amaranths. In amaranth, the root system develops rapidly, reaching nearly its maximum extent (2.4 m depth and 1.8 m spread) after only 10 weeks of growth. This fast development of the root system may contribute to the competitive ability of grain amaranths to absorb the nutrients (Kigel, 1994).

Stem

The stem measures from 0.5 to 3.5 m in height and is simple or branched, depending on species, genotype and growth conditions. One of the main breeding objectives of grain amaranth is to reduce plant height to less than 1.5 m, and select genotypes with a less degree of branching (Kaufman, 1992).

Leaves

Leaves are of various shapes: elliptic, rhombic, ovate, lanceolate or rhombate-ovate, with acute, obtuse or acuminate leaf tips, of green, red or silver colour. Because of anthocyanin (amaranthine) coloration, entirely red plants and plants with reddish or silver spots on the leaves are found (Williams and Brenner, 1995). Most *Amaranthus* species have edible leaves are known as vegetable amaranths; i.e., *A. blitum* L., *A. viridis* L. and *A. tricolor* L. 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

Table 1. Minerals content in amaranth (mg/100 g)

Minerals	Content(mg/100 g)
Fe	29.35
Cu	1.25
Mn	4.07
Na	4.14
Ca	283.14
Mg	425.21
K	770.15
P	55.59

Source: (Palombini et al, 2013).

Table 2. Essential amino acids in seeds of amaranths and some other crops (g 100 g-1 of protein)

Protein source	Trp	Met/ Cys	Thr	Isl	Val	Lys	Phe/ Tyr	Leu	LAA	EAA ^B
FAO/WHO (1973)	1.0	3.5	4.0	4.0	5.0	5.5	6.0	7.0	--	--
Amaranth	1.3	4.4	2.9	3.0	3.6	5.0	6.4	4.7	67	87
Barley	1.2	3.2	3.2	4.7	3.2	8.2	6.5	6.5	83	97
Buck wheat	1.4	3.7	3.9	3.8	5.2	5.9	5.8	5.8	83	97
Maize	0.6	3.2	4.0	4.6	5.1	5.1	1.9	10.6	35	86
Oat	1.2	3.4	3.1	4.8	5.6	3.4	8.4	7.0	62	92
Rice	1.0	3.0	3.7	4.5	6.7	3.8	9.1	8.2	69	94
Soya	1.4	3.1	3.9	5.4	5.3	6.3	8.1	7.7	89	98
Wheat	1.2	3.5	2.7	4.1	4.3	2.6	8.1	6.3	47	86

Sources: (Senft, 1979)

a= relative value of limited amino acid according to FAO/WHO requirements

b= relative value of essential amino acids according to FAO/WHO requirements

Sources: (Ayorinde et al, 1989; Becker et al, 1981; R. Bressani et al, 1993; Dodok et al, 1994; Gorinstein and Moshe, 1991; Leon-Camacho et al, 2001; Lyon and Becker, 1987; Marcone and Yada, 1998; Pedersen et al, 1987; Prakash and Pal, 1991; Sanches-M et al, 1986; Singhal and Kulkarni, 1988; Zheleznov et al, 1997)

Table 3. Tocopherol, total phenolics and Vitamins content of amaranth

Components	Contents
α-tocophero(mg/100 g)	1.15
β+γtocopherol(mg/100g)	1.35
DPPH(IC ₅₀)µg/mL	638.67
Total Phenolic Content (mg GAE/100 g).	62.90
Source; (Palombini <i>et al</i> , 2013)	
Riboflavin	0.19 to 0.23mg /100 g
Ascorbic acid	4.5 mg /100 g
Niacin	1.17 to 1.45 mg /100 g
Thiamine	0.07 to 0.1 mg /100 g

Source: (Becker *et al*, 1981)

Proximate Composition of *Amaranthus* Seeds

rate of 30 to 40 % and 18 %, respectively (Schnetzler and Breene 1994). Tosi et al. (2001) reported 14.2 % of dietary fibre in the *A. cruentus* flour (8.1 % soluble, 6.1 % insoluble). With different milling, sifting and pneumatic

On the average pale-seeded *Amaranthus* contain 8 % of dietary fibre and black coloured 16 % with soluble fibre

classification procedures used, authors achieved fractions 70.8 %. The proximate composition of different of flour with increased share of dietary fiber from 32.1 to *Amaranthus* seeds is given in Table 4.

Table 4. Proximate Composition of different *Amaranthus* Seeds^a

<i>Amaranthus</i>	Nitrogen (%)	Crude (%) Protein ^b	Fat (%)	Fiber (%)	Ash%
<i>A. cruentus</i> , ^{c,d}	3.05	17.8	7.9	4.4	3.3
<i>A. cruentus</i> x <i>hypochondriacus</i> ^d	2.97	17.4	8.0	4.3	3.0
<i>A. edulis</i> ^d (<i>A. caudatus</i>)	2.70	15.8	8.1	3.2	3.2
<i>A. hypochondriacus</i> . ^{e,f}	2.67	15.6	6.1	5.0	3.3

^a=Dry basis (original moisture contents, 6-11%)

^b= N x 5.85

^c=Average of two *A. cruentus* samples

^d=Becker et al, 1981)

^e= PR Cheeke and Bronson, 1980

^f=Average of four *A. hypochondriacus* samples

Bioactive Components and Medicinal Properties of Amaranth

Amaranth is ranked as one of the top five vegetables in antioxidant capacities, (Walter, 2001). The health benefits of amaranths have always been recognized in homoeopathic and Ayurvedic medicines. Both the seeds and leaves of amaranth are used as herbal remedies and have nutraceutical value. Amaranth protein contains a low proportion of prolamins which makes it a safe ingredient for people with celiac disease and recent studies have shown that amaranth peptides displayed antihypertensive and anti-inflammatory activity (Kirtikar and Basu, 1987). Some studies using amaranth flour and protein isolates reported the occurrence of peptides with biological activities such as anti-hypertensive, anti-oxidant, anti thrombotic, anti-proliferative among others activity (Kirtikar and Basu, 1987). It contains ample amount of bioactive components, such as tocopherols, L-ascorbic acid, betacarotene, polyphenol, anthocyanins and lutein (Walter, 2001). It has been used as an antipyretic to reduce labour pain in Indian traditional medicine. The bioactive component in amaranth acts as diuretic, haemorrhage and hepatoprotective agent (Kirtikar and Basu, 1987). Amaranths have also been used to treat bladder distress, piles, toothache, blood disorders and dysentery (Madhav et al, 2008).

The cholesterol- lowering effects in amaranth may be due to unsaturated fatty acids. Being a good source of magnesium which is effective to relax blood vessels and prevent constriction and rebound dilation. It also helps to fight against migraines. Cooking had no deleterious effect on total bioactive component except for the reduction of anthocyanins content. Home cooking increases the antioxidant activities and the contents of a carotenoids, especially by steaming. Both simmering and blanching

increased the betacarotene and lutein in the cooked amaranth (Han and Xu, 2014). The health benefits of amaranths had been recognized in homoeopathic and Ayurvedic medicines. Both the seeds and leaves of amaranth are used as herbal remedies and have nutraceutical value.

Processing

Amaranth is cleaned with screens, by winnowing, with a fan or other blowing device. After harvesting, it is important to further dry the crop to ensure it won't spoil during storage. It can be left on trays in the hot sun or placed near an indoor heat source. Amaranth has no hulls to remove unlike beans or true grains; Amaranth is relatively a small sized grain (Coimbra and Salema, 1994). Nutrients are concentrated in bran and germ fractions of the grain. The amaranth grain can be toasted, popped, extruded or milled into flour and can therefore be consumed as such or included in other cereal products such as bread, cakes, muffins, pancakes, cookies, dumplings, crepes, noodles and crackers.

Food Uses of Amaranth

Vegetable amaranths are widely consumed as leafy vegetables in India including South-east Asian countries. In Africa, north and South America grain amaranths are widely consumed by making different products. Amaranth seed oil has been reported to contain large amount (7-8% and 11%) of squalene which is often used in cosmetics and medicine, where olive oil contains only 1% of squalene. Amaranth oil is also a rich source of tocotrienols which is very effective to lower the LDL cholesterol (Becker et al, 2003; Plate and Areas, 2002). Amaranth grain may be processed in various ways, like grains can be popped, flaked, extruded and ground into flour. Popped amaranth

can be enjoyed on its own or can be served with milk or soymilk and fruit for a healthy breakfast. Amaranth can be used as a substitute in porridge, stirred into soups. Amaranth grains can be cooked whole in a pot, rice cooker or pressure cooker to prepare breakfast porridge or savory 'polenta'. The grain flour or flaked grains are combined with wheat or other flours to make cereals, cookies, bread and other baked goods. As per general recommendation, amaranth grain flour should contribute only 10-20% of the mixed flour blended with wheat flour. It has been shown that amaranth grain flour blended up to 50-75% of the mixed flour, it will still retain functional properties as well as flavor.

Amaranth grain can also be used for beer production (as ingredient for *ogi*—traditional product of lactic fermentation of cereal porridges in Africa). It can serve as a starchy material in spirit production. Amaranth grain could be a suitable high protein material for maize supplement in nixtamalization or lime cooking, the process which is used for tortilla production. Grain amaranth can be ground and used as a flour ingredient in different mixtures for cakes, pancakes, bread, muffins, dumplings, crackers, cookies, puddings, etc. (Bejosano and Corke, 1998; Berghoefer and Schoenlenchner, 2002; Early, 1990). Vegetable types (also leaves of grain types) are usually picked fresh, used as greens in salads or blanched, steamed, boiled, stir fried, or baked to taste.

Vegetable amaranth has been rated higher in minerals, such as calcium, iron, phosphorous (Igbokwe et al, 1988; Makus and Davis, 1984) and carotenoids (Martirosyan et al, 2004) than most vegetables. It was determined that *Amaranthus paniculatus* and *Amaranthus cruentus* are good sources of flavanoids, especially for rutin, which are mostly produced in the stage of blossoming (Martirosyan et al, 2003). Usage of amaranth as livestock feed indicated relatively high protein qualities (Kadoshnikov et al, 2001; Sanchez, 1990; Sleugha et al, 2001).

Chopped plants have been used as forage for livestock (O'Brien and Price, 2008). In Mexico, the popped amaranth confection, 'alegría' is a popular favorite among locals and tourists. The flour or flaked forms are combined with wheat or other flours to make bread, cereals, cookies and other baked goods. Coarsely ground amaranth is used to make a tasty and nutritious porridge cooked by itself or mixed with other grains and pseudo cereals such as oats and wheat.

Several studies have shown that amaranth seed or oil may be of benefit for those with hypertension and cardiovascular disease; regular consumption reduces

blood pressure and cholesterol levels, while improving antioxidant status and some immune parameters (Czerwinski et al, 2004; Gonor et al, 2006; Martirosyan et al, 2007).

Amaranth grain can also be germinated for sprouts and malted for fermentation and beer production (traditional beer *chicha* in Peru). It can serve as a starchy material in spirit production. From the grain or from green material protein concentrates can be produced. Amaranth grain, mostly rolled or popped can be used in muesli and in granola bars. Vegetable types (also leaves of grain types) are usually picked fresh, used as greens in salads or blanched, steamed, boiled, stir fried, or baked to taste. Cooked greens can be used as a side dish, in soups, as an ingredient in baby food, casserole, lasagna (a dish of Italian origin), pasta, pie, soufflé, etc.

Antinutritional Factors and Toxic Aspects of Amaranth

Seed or leaves of amaranths contain some antinutritional factors which can have a nutritional impact or can limit their food application. The anti-nutritional factors are phenolics, saponins, tannins, phytic acid, oxalates, protease inhibitors, nitrates, polyphenols and phyto-hemagglutinins, (Berghoefer and Schoenlenchner, 2002; Lehman, 1992; Souci et al, 1994). Of these, oxalates and nitrates are of more concern when amaranth grain is used in foraging applications. Thermal processing of amaranth in moist environment, prior to its preparation in food and human consumption may reduce the adverse effects of amaranth's antinutritional and toxic factors.

Nitrate Accumulation & Poisoning:

Plants absorb nitrates from the soil and convert them into more complex forms of nitrogen, such as proteins. Amaranth is one of the plants that accumulate nitrates especially when soil fertility is very high (generally the result of adding nitrogen fertilizer), and when something slows the process of photosynthesis, such as herbicide, drought, or frost. Nitrates are accumulated mainly in the plant tissues and not in the seeds (O'Brien and Price, 2008). Nitrites bind to the hemoglobin in blood, robbing it of the ability to carry oxygen. Since hemoglobin's function is to carry oxygen, the net effect is oxygen starvation. Hence the symptoms of nitrite poisoning include shortness of breath and reduced immunity to disease, and, in extreme cases, may lead to death from suffocation (O'Brien and Price, 2008). Nitrates also combine with some proteins to make nitrosamines, which may cause cancer.

Scientists in Australia fed raw amaranth grain to poultry. As a result the chickens went into convulsions and died (P. R. Cheeke et al, 1980). These antinutritional components can be removed by boiling the vegetable part of plant in water or by steaming.

Conclusions

Due to some unique properties and versatile usage, grain amaranth has gained increased attention since 1970s. This re-discovered crop has some nutritional, medicinal and agricultural advantages. From agricultural view, this crop has ability to grow successfully in adverse environmental conditions such as high irradiance, temperature and drought. Grain amaranth has been tested by many authorities as a gluten-free foodstuff suitable for incorporation into the diet for celiac disease patients. Lack of gluten is favorable for the consumers who have the gluten intolerance problem. Regarding the nutritional and medicinal point of view, amaranth (grain and vegetable) has enormous benefits when used as human food or animal feed. Product made by Amaranth is health beneficial for

such consumer. Wide range of product can be made from this grain. It is easy to cultivate because of its drought tolerance capacity. The limiting factors of Amaranth's flour uses in composite flour for bread production is its harsh pungent flavor and bitter aftertaste. However, consumer's food acceptance not only depends on sensory, but also on non-sensory factors, such as health benefit, price and convenience of preparation, ease of cultivations. To raise its production and uses, information should be provided to farmers along with consumers. Amaranth's products must be introduced on the market. Because of above stated properties, grain amaranths can be considered as the golden crop for future generation.

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