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Amaranth: A New Millennium Crop of Nutraceutical Values

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The major staple food crops production is not able to fulfill food requirement of the global population due to relatively higher population growth rate in developing countries. The research on these crops for exploring their ultimate yield potential is currently at a plateau level. To replace the existing pressure on these major crops there is an urgent need to explore other alternative crops having the potential to replace and fulfill the available food demand. FAO statistics reveal that there is a high frequency of low birth weight children in the developing countries, which is primarily due to deficiency of micronutrients in the mother's diet. Amaranth, an underutilized crop and a cheap source of proteins, minerals, vitamin A and C, seems to be a future crop which can substantiate this demand due to its tremendous yield potential and nutritional qualities, also recently gained worldwide attention. Recently, current interest in amaranth also resides in the fact that it has a great amount of genetic diversity, phenotypic plasticity, and is extremely adaptable to adverse growing conditions, resists heat and drought, has no major disease problem, and is among the easiest of plants to grow in agriculturally marginal lands. The present review is an effort to gather the available knowledge on various diversified fields of sciences for the future exploitation of the crop.

Keywords *Amaranthus*, nutritive value, medicinal aspect, molecular, breeding

INTRODUCTION

The family Amaranthaceae is generally considered as the "Amaranth family." The word *Amaranthus* is basically derived from the Greek word "Anthos" (Flower) which means everlasting or unwilting. At the present time it is also called a third millennium crop plant. Based on taxonomical studies, the family is divided into two sections (Allen, 1961), namely *Amaranthus* saucer and Blitopsis dumort, with nearly an equal number of species (Thellung, 1914). The section *Amaranthus* is dibasic with x = 16 and 17 and Blitopsis with x = 17 except polyploidy, that is, *A. dubius* (Pal, 1972; Pal and Khoshoo, 1965; Madhusoodanan and Pal, 1981). The genus amaranth is mainly comprised of about 400 species among which few of them are found worldwide. The division of species is based on their utilization method into grain amaranth, vegetable amaranth, ornamental, and weedy amaranth (Sauer, 1967). Grain amaranth has four species, that is, *A. hypocondricus, A. cruentus, A caudatus,* and *A. edulis* associated with three weedy species *A. hybridus, A. powellii,* and *A. quitensis* (Pal and Khoshoo, 1974). The vegetable *Amaranthus* belongs to the section blitopsis (Pal and Khoshoo, 1972; Madhusoodanan and Pal, 1981). Vegetable amaranth has two major species, *A. tricolor* and *A. lividis*. The ornamental species includes *A. tricolor* (Table 1). Amaranth is a fast growing crop and because of its low production cost, it is one of the cheapest dark green vegetable in the tropical market and is often described as the poor man's vegetable. Unlike the other green vegetables, it is cultivated during summer when no other green vegetables are available in the market (Singh and Whitehead, 1996). The amaranth can grow under varied soil and agroclimatic conditions (Katiyar et al., 2000; Shukla and Singh, 2000), and is also resistant to heat and drought with no major disease problems (Robert et al, 2008; Barrio and Anon, 2010). Besides its adaptable nature in various climatic conditions, the amaranth plant also has important nutritional and medicinal properties (Lakshmi and Vimala, 2000). Prakash and Pal (1991); Shukla et al. (2003; 2006) and Prakash et al. (1995) emphasized the use of amaranth as a vegetable and grain crop which can be a cheap alternative rich source of protein and nutrient for poor people in developing countries.

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HISTORY

The historical evidence depicted that *Amaranthus* domestication and cultivation came into use about 8000 years ago in the Mayan civilization of south and Central America. The most

Table 1 List of various species with their local name of Genus Amaranth (cited from Wikipedia)

S.No	Name of Species	Vernacular name
1.	*Amaranthus gangeticus*	elephant head amaranth
2.	*Amaranthus floridanus*	Florida amaranth
3.	*Amaranthus graecizans*	-
4.	*Amaranthus fimbriatus*	fringed amaranth, fringed pigweed
5.	*Amaranthus dubius*	spleen amaranth, khada sag
6.	*Amaranthus deflexus-*	large-fruit amaranth
7.	*Amaranthus cruentus*	purple amaranth, red amaranth, Mexican grain amaranth
8.	*Amaranthus crispus*	crispleaf amaranth
9.	*Amaranthus crassipes*	spreading amaranth
10.	*Amaranthus chlorostachys*	chihuahuan amaranth
11.	*Amaranthus chihuahuensis*	-
12.	*Amaranthus caudatus*	love lies-bleeding, pendant amaranth, tassel flower, quilete
13.	*Amaranthus cannabinus*	tidal-marsh amaranth
14.	*Amaranthus californicus*	California amaranth, California pigweed
15.	*Amaranthus brownii*	Brown's amaranth
16.	*Amaranthus blitum*	purple amaranth
17.	*Amaranthus blitoides*	mat amaranth, prostrate amaranth, prostrate pigweed
18.	*Amaranthus bigelovii*	Bigelow's amaranth
19.	*Amaranthus australis*	southern amaranth
20.	*Amaranthus acanthochiton*	greenstripe
21.	*Amaranthus acutilobius*	sharp-lobe amaranth
22.	*Amaranthus albus*	white pigweed, prostrate pigweed, pigweed amaranth
23.	*Amaranthus arenicola*	sandhill amaranth
24.	*Amaranthus torreyi*	Torrey's amaranth
25.	*Amaranthus thunbergii*	Thunberg's amaranth
26.	*Amaranthus standleyanus*	-
27.	*Amaranthus spinosus*	spiny amaranth, prickly amaranth, thorny amaranth
28.	*Amaranthus scleropoides*	bone-bract amaranth
29.	*Amaranthus rudis*	tall amaranth, common water hemp
30.	*Amaranthus retroflexus*	red-root amaranth, redroot pigweed, common amaranth
31.	*Amaranthus quitensis*	ataco, sangorache
32.	*Amaranthus pumilus*	seaside amaranth
33.	*Amaranthus pringlei*	Pringle's amaranth
34.	*Amaranthus viridis*	slender amaranth, green amaranth
35.	*Amaranthus watsonii*	Watson's amaranth
36.	*Amaranthus wrightii*	Wright's amaranth
37.	*Amaranthus tuberculatus*	rough-fruit amaranth, tall waterhemp
38.	*Amaranthus tricolor*	Joseph's-coat
39.	*Amaranthus lineatus*	Australian amaranth
40.	*Amaranthus leucocarpus*	-
41.	*Amaranthus hypochondriacus*	Prince-of-Wales-feather, princess feather
42.	*Amaranthus hybridus*	smooth amaranth, smooth pigweed, red amaranth
43.	*Amaranthus greggii*	Gregg's amaranth
44.	*Amaranthus powelii*	green amaranth, Powell amaranth, Powell pigweed
45.	*Amaranthus polygonoides*	tropical amaranth
46.	*Amaranthus paniculus*	Reuzen amarant
47.	*Amaranthus palmeri*	Palmer's amaranth, palmer pigweed, careless weed
48.	*Amaranthus obcordatus*	Trans-Pecos amaranth
49.	*Amaranthus muricatus*	African amaranth
50.	*Amaranthus minimus*	-
51.	*Amaranthus mantegazzianus*	Quinoa de Castilla
52.	*Amaranthus lividus*	-

significant historical evidence supports that the amaranths was a staple food, called *huahtli* grown in Mexico during the Aztec civilization (Sauer, 1950a; 1950b; Pal and Khoshoo, 1972; Early, 1977; Haughton, 1978; Lehman, 1994). The Aztecs believed that it had magical properties which gave it strength. Due to this belief *Amaranthus* was used as a grain in religious practices, and was roughly equal to corn. But in the 1500s, the Spanish conquistadors prohibited the growing of *Amaranthus* to suppress the Aztec culture and religion which promoted its adoption and production in the other parts of world. In the present time only a limited amount of grain is being grown in Aztec and used in the production of "alegria" candy after mixing with honey (Early, 1977) and for preparing a tole, a drink (Oke, 1983). Evidence showed that the pale seeded amaranth was also grown in

Germany in the sixteenth century. By the 1700s it had spread throughout Europe and was being used as a herb and ornamental. In the 1800s it was reportedly being grown in the mountain valley of Nepal and parts of east Africa, and later in the nineteenth century it spread to the Himalayas and interior China and eastern Siberia (Sauer, 1977). In Europe it was planted for ornamental purposes and for in Africa for vegetable purposes. Only in the Himalayan region was it eaten and maintained as a minor cereal. During the twentieth century, it had been grown in China, India, Africa, and Europe, as well as in North and South America. Although the U.S. has been the leading producer of grain amaranth which is being used in retail food products, but the largest production area in the last decade is believed to have been in China. The Chinese use amaranth as forage to feed hogs, rather than harvesting it as grain.

In ancient Greece, the *Amaranthus* was named Chrusanthemon and Elichusos and was also sacred to Ephesian Artemis. They supposed that amaranth had healing property and as a symbol of immorality was used in decoration of gods and tombs. In Greek mythology, *Amaranthus* (a form of Amarantus) was a hunter and king of Euboea island for which it was the eponymous hero. There was a famous temple of Artemis (Amarynthia or Amarysia). It was believed that he was loved by the goddess Artemis and joined her in the hunt. But he insulted Poseidon without any reason due to which the Gods sent a giant wave to wash him into the sea which drowned him. Artemis later turned him into an amaranth-flower, her sacred plant. It was also reported that Pagan tribals used *Amaranthus* in their burial ceremonies.

ORIGIN AND DISTRIBUTION

About 400 species of *Amaranthus* are distributed throughout the world in temperate, subtropical, and tropical climate zones (Suma et al., 2002). A few of them are distributed worldwide (Anon., 1992). About 20 species are found cultivated/wild in India. Among grain types some species are considered as native to south and Central America (Grubben and Van Stolen, 1981) while some other types are native to Europe, Asia, Africa, and Australia (Becker et al., 1981; Teutonico and Knorr, 1985). In its own country of origin, grain *Amaranthus* (*A. caudatus*) is known by various names (Table 2). India has been considered as one of the centers of distribution of amaranth, the other center being tropical America. Dioceous forms are generally absent in India and the old world and found only in the new world.

There is no authenticate/concrete evidence of the origin of *Amaranthus*. According to one view grain amaranth is being cultivated in the old world from time immemorial and probably originated there. The other view stated that it was introduced in India (Malabar Coast) from the new world (Brazil) by early Portuguese traders around 1500 A.D. It is probable that they were independently domesticated by different prehistoric people of North and South America (Anon., 1992). The ornamental type (*A. tricolor)* believed that it originated in India and then introduced to the new world. From species A. *tricolor*, several domestic varieties of ornamental and vegetable types have been developed (An., 1992). The main vegetable type (*A. tricolor*) seems to have originated in south Asia (Grubben and Van Stolen, 1981) and then spread throughout the tropics and temperate areas (Martin and Telek, 1979). *A. tricolor* has been extensively cultivated, primarily in southern China (Martin and Ruberte, 1979).

Table 2 Name of Amaranthus in other languages

S.No.	Name of Countries	Local Name of Amaranthus
1.	China	een choy, yin choy, in-tsai, hsien tsai, xian cai
2.	Japan	hiyuna
3.	India	Chaulai
4.	Indonesia	bayam
5.	Malaysia	bayam
6.	Laos	pak hom
7.	Philippines	kulitis
8.	Sri Lanka	thampala
9.	Thailand	pak khom hat, pak khom suan
10.	Vietnam	yan yang
11.	Peru	anchita, achos, achis,incajataco, coimi and Kiwicha
12.	Bolivia	coimi and millmi
13.	Eucador	Sangoracha, alaco

ARCHEOLOGY

The earliest archaeological record of this pale seeded grain stated that it came into usage as a grain about 4000 years ago in Tehuacan Puebla, Mexico (Pal and Khoshoo, 1974; Sauer, 1979). The oldest seeds found are of a species *A. cruentus*. Some earliest seeds of *A. hypocondriacus* and *A. cruentus* are also found from the old deposits both in caves at Tehuacan and Mexico. Sauer (1979) observed that seeds could be domesticated far away and earlier than those findings indicate. The seeds of *A. hypocondriacus* are also identified in the cache located in a rock shelter in the Ozark mountains of North West Arkhansas. Archaeologists have also recorded the evidence of *Amaranthus* domestication from numerous prehistoric culture sites including Maverick County and the Hinojosa Site near Alice in Jim Wells County, etc. The similarity between Chenopod and amaranth seeds creates confusion for the archaeologist for its clear identification. To solve this problem the seeds are being preserved to make positive identification up to the genus level.

BOTANICAL DISCRIPTION AND AGRONOMICAL PRACTICES

The genus *Amaranthus* generally includes monoecious annuals except some dioceous form (much restricted in distribution and has a branched and bushy appearance). The plant height varies from 0.3 m to 5 m among the various species. Leaves are oblong to elliptical in shape with the color ranging from light to dark green with some expressing red pigment throughout the genus. The inflorescence is very prominent, colorful, and

Table 3 Brief description of habit and plant morphology with basic requirements for its agronomical practices. (Palado and Chang, 2003; Stallknert and Schulz-Schaelfer, 1993)

Plant Description			
Life form	Herb	Category	Vegetables and Grain
Habit	Upright	Branching	Multi branched
Life span	Annual	Plant attributes	Grown on small scale
Ecology			
Crop cycle	Through out year	Soil depth	shallow (4mm)
Temperature requirement	25°C–40°C	Soil texture	Medium, light heavy and organic
Manuring	50 tonnes of wet rotten FYM per ha as basal dose before planting. After preparing trenches, apply N:PzOs:K2O @ 50:50:50 kglha. Another 50 kg of N can be applied at regular intervals as topdressing. Spraying 1% urea immediately after each harvest	Soil fertility	Nutrient rich soil, with potash and nitrogen
		Soil drainage	Well dry spells
		Soil PH	5.0–8.0
		Spacing	15–30 cm in rainy season planting on raised beds
		Light intensity	very bright and clear skies
Climatic zone	Temperate, tropical and sub tropical	Elevation	Sea level to 3500 m
Cultivation			
Abiotic tolerance	Tolerant to high aluminium soils and arid conditions or drought tolerant and poor fertility	Seed rate (Sowing)	1.5–3.0 Kg/ha
Susceptibility (Biotic)	damping-off disease, root rot, and caterpillars, stem borers, and leaf webber attack	Susceptibility (Abiotic)	thrives in 30–35°C and stressful conditions
Plant protection	Avoid use of insecticides or fungicides.		
Useful parts	Whole plant as leafy green vegetables and seed used directly or as flour		

terminal and contains one male flower per glomerule (of nearly 100–250 flowers) in section amaranth while small, generally auxiliary with 10–25% male flowers per glomerule in section Blitopsis. In the dioceous form at least two propagules (male and female) require to disperse together (Khoshoo, NBRI silver Jubilee). The monoceious habit with predominant outcrossing in grain amaranth helped in their domestication (Pal and Khoshoo, 1974). The pollen grains are spherical in shape with poly ontoporate or golf ball like aperture in monoecious form. The pollen grains of dioceous form are poly aperturate in their visible surface. There is no difference between the diameters of aperture of both forms (Franseen et al., 2001). Seeds are small and lenticular averaging 1–1.5 mm in diameter with 1000 seeds weight ranged from 0.6–1.2 g (Jain and Hauptli, 1980; Saunders and Becker, 1984). The color of seeds varies species to species from pale ivory to black (Pal and Khoshoo, 1974; Saunders and Becker, 1984; Irving et al., 1981; NAS, 1975). Seed embryo remain surrounded with the nutritive layer, thin wall perisperm cells being full of starch grains, and the protein bodies are embedded in lipid matrix (Coimbra et al., 1994). The prescribed agronomical practices for better cultivation are presented and shown in Table 3 (Palado and Chang, 2003; Stallknert and Schulz-Schaelfer, 1993).

CHEMICAL COMPOSITION

Starch

Starch is the main component of amaranth grain and used in food preparations (Wu and Corke, 1999). Starch is reported to be 48% in *A. cruentus* and 62% in *A. hypocondriacus* (Becker et al., 1981; Saunders and Becker, 1984). The shape of starch granules varies species to species as small, 1–3 μ in diameter, angular, and polygonal in shape in *A. hypocondriacus* (Lorenz, 1981; Saunders and Becker, 1984; Stone and Lorenz, 1984), spherical as well as angular and polygonal with smooth surface and size varies from 0.75 to 1.5 nm in *A. cruentus* (McMasters et al., 1955; Stone and Lorenz, 1984; Qian and Kuhn, 1999; Hoover et al., 1998), and spherical in small amount with large irregular starch chunks in *A. retroflexus* (Goering, 1967). *A. hypocondriacus* seeds have nonglutinous and glutinous type starch with nearly 100% typical amylopectin (Tomita et al., 1981; Okumo and Sakaguchi, 1981), nonglutinous type in *A. caudatus* (Okumo and Sakaguchi, 1981; 1982), and glutinous types in *A. cruentus* (McMasters et al., 1955). As compared to the starch in corn and wheat, the starch of *A. cruentus* and *A. hypocondriacus* has higher swelling power or absorbance capacity (Resio et al., 1999), lower solubility, greater uptake, lower susceptibility to amylases, and lower amylase content (4.7 to 12.5%) (Qian and Kuhn, 1999; Stone and Lorenz, 1984; Kong et al., 2009) (Table 4).

Table 4 Comparison of grain amaranth with other major cereals (% dry basis) (Pedersen et al., 1987)

Components	Maize	Wheat	Sorghum	Amaranth
Ash	1.2	1.7	1.7	2.5
Protein (N × 6.25)	10.0	13.2	12.6	14.5
Fat	5.2	2.7	4.0	10.2
Sugar	3.2	4.2	2.0	3.1
Starch	72.8	65.7	70.1	62.7
Dietary Fiber	9.3	12.1	8.5	8.8

Fat/Oil

Amaranthus oil is extracted from the seeds of two species, that is, *A. cruentus* and *A. hypocondriacus*, which range between 4.8–8.1% (Gamel et al., 2007; He and Corke, 2003). The hyper oxide stability test showed oil is more soluble than sunflower oil (Gamel et al., 2007). The melting point of amaranth oil is $-27°C$. The oil is medium to light in color, clear and pourable, at low temperature, and highly unsaturated with a delicate agreeable aroma and taste. It contains mainly non-polar lipid compounds especially triglycerides (80.3–82.3%) with a degree of unsaturation and a very low amount (about 9.1–10.2%) of phospholipids (Gamel et al., 2007). Oil is also an excellent source of omega series of fatty acids. The digestibility of oil corresponds approximately to that of cotton but *A. cruentus* oil has low digestibility. The oil also has tocols (1465.15 mg/kg) and squalene (upto 6.8%) as compared to wheat germ oil which has only 0.1–1.7%. Squalene, an oxidation resistant lubricant, is unsaturated open chain fatty acid generally used in the cosmetic and skin care products production industry. *A. cruentus* has 4.0–10.0% squalene (Gamel et al., 2007; Grazdiene, 2007), *A. hypocondriacus* has 6.1%, *A. tricolor* has 5.1% while *A. edulis* has 6.7% (Becker et al., 1981; He and Corke, 2003; He et al., 2002). The oil is composed of myristic acid (upto 0.6%), palmitic acid (upto 18.7%), stearic acid (upto 5.3%), anarchidic acid (upto 1.9%), behenic acid (upto 2.6%), oleic acid (upto 30.5%), linolenic acid (upto 62%), and linoleic acid (upto 40%) (Badami and Patil, 1976; Jahaniaval et al., 2000; He and Corke, 2003; He et al., 2002). It was noticed that there was a positive correlation between squalene yield and oil content and negative between linoleic and either of the two fatty acids, palmitic acid and oleic acid. The ratio of saturated and unsaturated fatty acids decreased with the maturity (He and Corke, 2003). Amaranth oil can raise HDL cholesterol and significantly reduce non-HDL cholesterol which lowers the low density lipoprotein cholesterol by 21–50% (Chaturvedi et al., 2007).

The seeds of the spp. *A. tricolor* yield upto 4.3% oil with 22.2% saturated and 77.8% unsaturated fatty acids (Chidambaram and Iyer, 1941). Among the saturated acids, the content of myristric acid remain upto 24.3%, palmitic acid upto 38.4%, stearic acid upto 32.98%, anarchidic acid upto 2.32%, while in unsaturated acid linoleic acid upto 55.13% and oleic acid upto 44.87%. A growth inhibitory steroid amasterol is reported in the roots which was identified as 24 methylene 20 hydroxy cholesterol-5, 7-en, 3 β-ol (Roy et al., 1982).

Fat, the second important content present in grain amaranth, is higher than cereal. The fat is characterized by a high content of unsaturated fatty acids and major saturated fatty acids. Linoleic acid is a major fatty acid in oil which is more than 50% in the seeds of grain amaranth. The next higher one is oleic acid with more than 20% followed by palmitic acid which is about 20%. The major unsaturated fatty acid in the vegetable amaranth is linoleic acid which is 49% in seeds and 46% in leaves. Among the major saturated fatty acids, 42% linolenic acid remains present in leaves and about 18–25% palmitic acid in leaves, stem, and seeds. (Fernando and Bean, 1984). The degree of unsaturation of fatty acids is over 75%.

The leaves of *A. caudatus* has β-sitosterol (Dixit and Verma, 1971), while the leaves and stem of *A. spinosus* has α-spinasterols and hentricontane (Banerji and Chakravarti, 1973). The roots of A. *spinosus* have ester of octacosanoic acid with α-spinasterols. Massimo et al. (2004) reported β-sitosterols and three major phytosterols that is, μ sitosterols, campesterol, and stigmasterol in *Amaranthus* species K343, RRC1011, K433, and K432.

Proteins

Grain Amaranth has more protein than corn and other major cereal grains (Bejosano and Corke, 1998) (Table 5). Lysine is the principal component which limits amino acid in cereals like maize, wheat, and rice. EAAI value (upto 90.4%) showed that the protein is comparable with egg protein and can be used as a substitute for a meal (Pisarikova et al., 2005). The protein is relatively high in sulphur containing amino acid (4.4%) (Senft, 1980), which is normally present in the pulses crops. The protein component of amaranth is quite close to the level recommended by the FAO/WHO for a balanced diet in humans. The protein in grain amaranth ranges from 14.5% to 15.1% (Rodas and Bressani, 2009) and in leaf upto 14.3 g/kg with an average of 12.4 g/kg (Shukla et al., 2003; 2006; Prakash and Pal, 1991). The protein content in amaranth leaf is also higher than spinach, another leafy vegetable (Table 6). The lysine in protein ranges from 40–50 g/kg. The amino acid composition revealed that *Amaranthus* is a rich source of important amino acids, namely, alnine, valine, leucine, arginine, phenylalanine, pralines, methionines, α aminobutyric acid, tryptophan, isoleucine, and serine which suggests that amaranth is a pseudo cereal which can be used as a substitute to nutrient cereal (Pedersen et al., 1987; Gorinstein et al., 2002; Jaiswal et al., 1984; Misra et al., 1983;

Table 5 Comparison of grain amaranthus with other grains (per 100 gms) (USDA and National Research Council)

Grain Type	Amaranth	Corn	Rye	Buckwheat	Rice	Milk(human)
Protein%	14.5%	9%	13%	12%	7%	3.5%
Lysine%	0.85%	0.25%	0.40%	0.58%	0.35%	0.49%
Carbohydrate	63 g	74 g	73 g	72 g	71 g	5 g
Calcium	162 mg	20 mg	38 mg	33 mg	41 mg	118 mg
Iron	10.0 mg	1.8 mg	2.6 mg	2.8 mg	3.3 mg	Traces
Phosphorus	455 mg	256 mg	376 mg	282 mg	372 mg	93 mg

Table 6 Nutrients comparison of vegetable amaranth with spinach and other leafy vegetables (per 100 g)

Components	Amaranth	Spinach	Basella	Chard
Protein	3.5 g	3.2 g	1.8 g	2.4 g
Ascorbic acid	80 mg	51 mg	102 mg	32 mg
Fiber	1.3 g	0.6 g	0.7 g	0.8 g
Carotenoids	6,100 IU	8,100 IU	8,000 IU	6,500 IU
Fat	0.5 g	0.3 g	0.3 g	0.3 g
Carbohydrate	6.5 g	4.3 g	3.4 g	4.6 g
Calcium	267 mg	93 mg	109 mg	88 mg
Iron	3.9 mg	3.1 mg	1.2 mg	3.2 mg
Potassium	411 mg	470 mg	—	550 mg

1985; Mukut and Andhiwal, 1976; Vasi and Kalintha, 1980; Ramachandran and Phanasalkar, 1956; Jaun et al., 2007; Pisarikova et al., 2005) (Table 7). Juan et al. (2007) illustrated that the wild species have more equilibrate amino acids which can be introgressed in a cultivated species through hybridization.

Minerals

A large number of necessary minerals have been reported in *Amaranthus*. The vegetable amaranth leaves (*A. tricolor*) have potassium from 6.4 to 6.7 g/kg with an average of 3.7 ± 0.26 g/kg, calcium 0.73 to 1.9 g/kg with a mean 1.7 ± 0.04 g/kg, magnesium from 2.8 to 3.0 g/kg with an average of 2.9 ± 0.01 g/kg, zinc 434.7 to 1230 mg/kg with an average of 791.7 ± 28.98 mg/kg, iron 783–2306 mg/kg with mean 1233.8 ± 50.02 mg/kg, manganese 66.7–155 mg/kg with an average 108.1 ± 3.82 mg/kg, and nickel 321.3 to 89.3 mg/kg with an average of 222.6 ± 9.51 mg/kg (Shukla et al., 2006).

Table 7 Comparison for amino acids content (g/16 g N) of Grain amaranth with other major cereals. (Pedersen et al., 1987)

Components	Maize	Wheat	Sorghum	Amaranth
Alanine	7.85	3.53	9.22	3.52
Arginine	4.31	4.47	3.64	8.65
Aspartic acid	7.00	4.93	6.48	7.32
Cystine	2.29	2.43	1.91	2.12
Glutamic acid	18.87	30.39	21.01	15.78
Glycine	3.64	3.90	2.93	6.67
Histidine	2.95	2.27	1.97	2.38
Isoleucine	3.46	3.54 c	4.05	3.41
Leucine	12.42	6.73	13.67	5.15 ∼
Lysine	2.96*a*	2.75°	2.03*a*	5.19
Methionine	1.99	1.60	1.84	2.17
Phenyalanine	4.40	4.37	4.85	3.66
Proline	9.03	9.56	7.69	3.92
serine	4.69	4.40	4.20	5.90
Theonine	3.28 c	2.56 b	2.71 b	3.31 b
Tryptophan	0.70 b	1.33	1.06	1.31
Tyrosine	3.35	2.51	3.80	3.33
Valine	4.91	4.46	5.50	4.04 b

a = First limiting amino acid.
b = Second limiting amino acid.
c = Third limiting amino acid.

In grain types, minerals are twice as high as the cereals and about 66% of these minerals remain present in bran and germ fractions (Saunders and Becker, 1984). Bran and germ layers have high ash than the perisperm. The grains also have high content of calcium, magnesium, iron, potassium, and zinc (Table 7).

Vitamins

Amaranthus has necessary daily required vitamins upto a nutrient significant level and can be an excellent source for reducing vitamin deficiency (Graebner et al., 2003). In the leaves of *A. tricolor,* vitamin A (carotenoids) ranged from 0.83 ± 0.02 mg/kg and Ascorbic acid (vitamin C) ranged from 112.33 ± 5 mg/kg (Shukla et al., 2006). Amaranth has more riboflavin (vitamin B_2) and vitamin C than cereal and is also a good source of vitamin E that has anti-oxidative property. An organic compound called quercetin and Vitamin K is also reported in *A. blitum* (Ganju and Puri, 1959) (Table 7).

Fiber

Fiber is also a naturally occurring constituent of *Amaranthus*. In the leaves of vegetable amaranth fiber ranged between 6.95–9.65% with an average 8.39 ± 0.1% (Shukla et al., 2006). In grain amaranth fiber is slightly lower than wheat which occurs in bran instead of perisperm layer. The fiber content ranged from 19.5–27.9%, 35.1–49.3% and 33–44% in *A cruentus, A. hypocondriacus,* and *A. caudatus* respectively (Pedersen et al., 1990) .

Instead of these primary nutritionally important compounds some other secondary metabolites that derived from metabolic and synthetic pathways in amaranth also play an important role in the human diet besides performing some special functions in the plants. The descriptions of such important secondary metabolites are discussed as follows.

Phytic Acids

The phosphorus present in the amaranth plant is produced through the presence of phytic acid. The phytic acid ranges between 0.3 to 0.6% in *Amaranthus* which is equally distributed in the seeds. It is decreased by abrasive elehulling or extraction with water. The phytic acid has a property to lower the cholesterol level in human system.

Saponins

Saponins are found in small quantities in some of the *Amaranthus* species. In seeds of *A. cruentus,* it varied from 0.09–0.1% of dry weight. Such a low quantity of saponins

Table 8 Comparison of minerals and vitamins of grain amaranth with wheat (per 100 gm).

Minerals	Grain Amaranth*	Wheat (Anglani, 1998)	Vitamins	Grain amaranth*	Wheat (Anglani, 1998)
Phosphorus	455 mg	158 mg	Ascorbic acid	4.20 mg	Infinite
Potassium	290 mg	101 mg	Riboflavin	0.23 mg	181 mg
Calcium	175 mg	528 mg	Folacin	49 mcg	129 mcg
Magnesium	266 mg	266 mg	Niacin	1.45 mg	
Iron	17.4 mg	238 mg			
Zinc	3.7 mg	120 mg			
Copper	0.77 mg				

*www.eap.mcgill.ca/CPAT_1.htm. Nov. 2008.

is not hazardous for consumers. The saponins present in roots of *A. spinosus* are β-D-glucopyranosyl (1→4)-β-D-glucopyranosyl(1→4)-β-D-glucuronopyranosyl(1→3)-oleanolic acid (Banerji and Chakravarti, 1973; Banerji, 1980), β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl(1→2)-β-D-glucopyranosyl(1→3)-α-spinasterol and β-D-glucopyranosyl (1→4)-β-D-glucopyranosyl (1→3)-α-spinasterol (Banerji, 1980). Junkuszew et al. (1998) reported four new saponins, namely, 3-beta-(O-glucopyranosyl) ester, 3-beta-O-(alpha-L-rhamnopyranosyl (1–>3)-beta-glucuronopyranosyl)-2 beta, 3 beta, 23-trihydroxyolean-12-en-28-oic acid 28-O-(beta-D-glucopyranosyl) ester, 3 beta-O-(beta- glucopyranosyl)-2 beta, 3 beta-dihydroxy-30 norolean-12,20(29)-diene-23,28-dioic acid 28-O-(beta-D- glucopyranosyl) ester together with known chondrillasterol (5 alpha- stigmasta-7,22-dien-3 beta-ol) and its 3-O- glucopyranoside.

Pigments and Chlorophyll

The beautiful color of leaves in ornamental amaranth is due to the presence of betacyanin pigments which belongs to betaline group. In amaranth betacyanin compounds are identified as amaranthin and iso amaranthin (Dixit et al., 1991; Stintzing et al., 2004; Repo-Carrasco-Valencia et al., 2010). The compound is O-(β –D glucopyranosuluronic acid)-5-O-β-D glucopyranosides of betadine and iso betadine respectively. The amaranthin is an intermediate compound involved in the conversion of nitrogen compounds in the cell (Gins et al., 2002). In the leaves of vegetable amaranth, chlorophyll a ranges between 490 $\pm$ 71.13 to 655.74 $\pm$ 109.18 and chlorophyll b ranges between 406.27 $\pm$ 65.81 to 554.92 $\pm$ 103.02 mg/kg (Shukla et al., 2003; Ivete et al., 2004). The immense biosynthesis of amaranthine, tyrosine, and phenylalanine caused a decrease in the contents of lignin, protein, and cellulose in leaves (Gins et al., 2002).

Oxalates and Nitrates

Besides immense nutritional properties amaranth has two anti-nutritional compounds, oxalates and nitrates, which ranged from 5.1–19.2 g/kg in vegetable type and 3–16.5 g/kg in grain types and from 0.8–0.80% mg/kg in vegetable and grain types (Prakash and Pal, 1991; Gelinas and Seguin, 2007). The two anti-nutritional compounds have the property to inhibit the absorption of calcium and zinc which latterly causes the development of kidney stones (Siener et al., 2006; Radek and Savage, 2008). The antinutritional compounds can easily be removed by boiling of seeds or leaves for 5 minutes before using it for edible purposes.

USES

As Food

Amaranthus is an important nutritional crop. It is rare plant whose leaves are eaten as vegetable while seeds are eaten as cereal (Oke, 1983; Saunders and Becker, 1984; Kauffman and Hass, 1983). The spp. *A. caudatus*, *A. hypocondriacus,* and *A. cruentus* used for grain purposes has tremendous potential to increase the food production of a country. In the cultivated region of amaranth, people use amaranth as vegetable and also as cereal in the bakery, cookies, biscuits, candies, pancakes, pasta, and noodles formation, etc. In Peru and Bolvia, *Amaranthus* seeds are used as grain (Sumar, 1983) while in Mexico the seeds of *A. hypocondriacus* used as grain. From popped seeds they make candies and molasses (Early, 1977). In Peru the seeds are popped and use as flour or bound with syrup to make bells (Sumar, 1983). Seeds are mostly used to make laddoos in India (Vietmeyer, 1978) and sometimes it is taken with rice after boiling with rice (Oke, 1983). In the Himalayan region, the seed flour is used to make chapattis while in Nepal the seed flour is used as satto. In the United States, the seeds are used to make crackers, cookies, and as cereal and also in the preparation of baked products. Most commercial product is the "breakfast amaranth." A traditional use of amaranth in Mexico and other countries is to mix popped amaranth with honey to make a type of snack bar or snack cake. Sometimes the whole seeds are used in a type of porridge or as a condiment or other foods.

The amaranth is being grown for vegetable purposes throughout the tropics and Eastern Asia (Feine et al., 1979). Amaranth leaves taste the same as spinach. For preparation of a recipe it is recommended to boil leaves for five minutes to remove the effect of antinutritional compounds. The cooked mass is eaten separately or with other food (Martin and Telek, 1979). Some tribal groups like Yuma, Mojava, and Cocopa cook the green amaranth, rolled them into a ball, and dried and stored them for winter. The Tarahumara tribe utilizes the leafy vegetable of species *A. retroflexus* especially along with other leafy small annuals. They collect the leaves during the growth cycle when the nutrient remains at the peak in plants. In Nigeria, the leaves are mixed with condiments for the preparation of soup (Oke, 1983). In Indonesia and Malaysia, it is commonly called bayam and is used as a vegetable. In China the leaves and stems are used as a frying vegetable. In the African region, the leaves are called callaloo and used in the soup known as pepperpot soup. In Jamaica, it is eaten routinely at breakfast and dinner. In India, the green leaves are used directly or with other vegetables, especially potato. However, in some parts of India, grains are used with pulses. In the Chattishgarh region, lal Bhaji is a popular vegetable and its young stems and leaves are used as vegetable.

As Dye

For the last 20 years, there has been an increasing trend towards the replacement of synthetic dyes by natural pigments. For this purpose the whole plant of amaranth can be used in preparing yellow and green dyes (Grae, 1974). The red pigment present in the plant (part not specify) is used as a colorant in foods and medicines (Cai et al., 2005; Cai and Corke, 1999). In America, the roots are used to produce a dye which fades very slightly and achieves a light yellow color with alum mordant, tan with chrome, light olive with copper, light gold with tin, gray with iron, and ivory with no mordant. In Bolivia and northwestern Argentina, people used red dye of *Amaranthus* leaves to color alcoholic beverages while in Mexico and southwestern United States it is used for coloring maize dough (Sauer, 1950a) and for coloring foods and beverages in Ecuador (Jain and Hauptli, 1980).

In Craft

Due to the bright red color of flowers with everlasting property, they are used in craft in some parts of world.

In Myth and Poetry

Amaranth or Amarant, is a name chiefly used in poetry as a simile to express the feeling of unfading immorality. Aesop's fables (sixth century BC) compares the rose to Amaranth to show the difference in fleeting and everlasting beauty. John Milton in "Paradise Lost (1667)" and Samuel Taylor Coleridge in "Work without Hope (1825)" also referred to Amaranth.

MEDICINAL IMPORTANCE

Classical Uses

Amaranthus being an under-utilized crop also has tremendous medicinal properties. Various species of *Amaranthus* have been used in the past for the manufacturing of medicines worldwide; however, efforts still continue. In the Ayurvedic medicine system of India, the classical text of different species of amaranth are known by different names. In Sanskrit *A. spinosus* is known as *Tanduliya, Meghnath, Cander, Tandulitabeej, Vishagna,* etc. Ayurveda describes the plant as diuretic, useful in cough and cold, in urinary and throat troubles, for gastric problems and vata (Bhandari, C., 1938). The easily digestible leaves are used in cough and cold, in swelling, and as an antidote to treat poison (Bhandari, C., 1938). *A. blitum* is known as Marisa, Vaspaka, etc., in Sanskrit and is recommended as a remedy for vata, cough and cold, and in excessive bile secretion. The species *A. caudatus* is known as *Rajadri, Rajagiri*, etc., and used as Pittanashka, Rucikara and also in the treatment of goiter, urinary troubles, and raktasodhaka. *A. tricolor* is known as Ramasitalika and used in Raktatisara and raktapradara (Chopra et al., 1955). Mishra (1878) describes the use of the whole plant as a cooling agent for urinary troubles and as a lotion for external use, in relieving pain during pregnancy, and for skin diseases. Its roots along with amla and bark of Ashok and Daru Haldi are used in leucorrhea.

In the Unani system of medicine, amaranth is a useful medicinal plant. The system considers the juice of the root as a remedy for gastric problems, treating the poison of scorpion, in leucorrhea and menorrhea. The leaves are used in urinary troubles, especially in removing kidney stones. The plant is also used to remove skin problems (Bhandari, C., 1938). A drug "Tukhme Ispisth" used in the system for centuries has been identified as the seeds of *A. retroflexus.* According to the book "Talif Sharif," the plants of amaranth were used as a remedy in cough and cold, gastric problems, blood purification, snake bite, and to stop blood secretion from the uterus (Bhandari, C., 1938). Another important species of amaranth is *A. caudatus* which is also discussed in the Indian Ayurvedic system. The whole plant is considered as a diet for health maintenance, in blood purification, in goiter, and as a lotion (Mishra, 1978; Yoganarasimthan, 2000).

Ethanobotanical/Folk Uses

In India the leaves of *A. caudatus* are used as tea to get relief from pulmonary problems and piles and also used in the purification of blood, stragury in scrofula, and as a diuretic (Gupta et al. 2004). The tribals of Ghana used amaranth both medicinally and as a lotion. The Senegal tribes used boiled amaranth roots with honey as a laxative (Anon., 1992; Kumar et al., 2004; Nadkarni, 1954). Seeds of amaranth are used in hypertension, cardiovascular diseases, reducing blood pressure, and for lowering cholesterol. In the Chattisgarh region, the traditional people used lal bhaji for treating both internal and external diseases. They also used amaranth for gynecological troubles, anemic patients, dysmenorrhea, and epistaxix (Naksir). Bilaspur regional/traditional healers use lal bhaji in reducing extra fat from the body and also as a promising herb for the patient engaged in the obesity management program. The traditional healers of Kondagaon region suggest that young ones wash their face with a decoction of lalbhaji for removing pimples. The traditional healers of Sarguja region use the fresh leaf juice in the treatment of earache.

In east Africa, the leaf known as *Mchicha* is prescribed by doctors to people experiencing a low red blood cell count. In South Africa the leaf of *A. caudatus* is used as an abortifacient and in pulmonary condition (Anon., 1992). The foliage of Native American Amaranth (*A. caudatus*) is used to reduce hemorrhea, diarrhea, and to treat ulcerated wounds. The dried flowers are used as tea and in contraception and excessive menses. The boiled leaves are used in swellings and in stomach upset (Michael, 2002). In China the native amaranth roots are used to alleviate cold, as a diuretic, and to check bleeding. The Chinese people eat amaranth during summer, believing that it can reduce internal heat and dampness. They also use amaranth to treat diarrhea, ulcer, inflammation, throat and mouth problems, diabetes, and allergic reactions (Bi Fong et al., 2005). They recommend tepid stem and leaves for washing of any affected areas, simmered leaves with Cuttle fish for treating jaundice, and with honey for treating dysentery. They also suggested that amaranth leaves be used for bee stings.

In Nepal, the juice of amaranth root is used to treat fever, urinary trouble, diarrhea menorrhagia, gonorrhea, eczema, colic lactogogue, and dysentery and its combination with the juice of *Dichrophela integra* and *Rubus elliptices* in stomach disorders. Boiled roots and leaves are given to children as laxative and emollient and as poultice in abscesses, in burns, and snake bite (Ministry of Forest (Nepal), 1970).

In Swaziland and South Africa, the ash of the plant is used either alone or mixed with an equal quantity of powdered tobacco for making snuff (Edward, 1978).

Another species, *A. blitum* of *Amaranthus*, is also used medically. It is a cooling, stomachic, emollient and slightly astringent, useful in biliousness, hemorrhea, and diathesis. It is also used in the preparation of tonic and remediation of round worm (Anon., 1992; Jain and Defillips, 1991). In the Garhwal region, the leaf of *A. hybridus* is used for diarrhea and leucorrhea and the root in gonorrohea, colic, and eczema (Rajwar, 1983). The whole plant of *A. hybridus* subsp. *cruentus* (Linn.) is an astringent (Jain and Defillips, 1991) used in piles to purify blood, as a diuretic, and an antiscorbutic (Anon., 1992). The plant of subsp. *A. hybridus* is used as a detergent and astringent, for menorrhagia, diarrhea, dysentery, ulcerated condition of throat and mouth, leucorrhea, and for washing of ulcers and sores, etc. (Anon., 1992). Another important species, *A. spinosus*, has been used for a long time as an important medicinal plant. The whole plant is recommended as an enmenagogue and galactagogue. The plant is used as a refrigent, diuretic, purgative (Sebasttian and Bhandari, 1984), as a laxative in vomiting (Jain and Defillips, 1991), enemas in stomach troubles, against inflammation, in uterine bleeding, as an antidote to snake bite, in wounds, as wormicidal, for reduction of excessive bleeding during menstruation, in skin diseases, and cough and cold (Anon., 1992; Suresh et al., 1995; Bhatnagar et al., 1973; Srivastava et al., 1866; Raj and Patel, 1978; Joshi et al., 1980; Banerjee and Banerjee, 1986; Basak, 1997; Kumar and Goel, 1998; Sudhakar and Chetty, 1998; Jain and Defillips, 1991; Yoganarasimthan, 2000; Ministry of Forest (Nepal), 1970; Vaidyaratnam, 1993; Lindley, 1981; Prajapati et al., 2003). The roots are thermogenic and hemostatic and useful in vitiated condition of Kalpa, menorrhea, hemoptysis, hematemensis, leucorrhea, and anti-diarrheal (Sebasttian and Bhandari, 1984; Mohanty et al., 1996), an emollient (Singh et al., 1998), an anti-spasmodic (Bhatnagar et al., 1973), and in ear diseases (Reddy et al., 1989). The plant is also considered as sudorific and febrifuge and recommended for eruptive fevers (Yoganarasimthan, 2000). The decoction of the plant improves digestion, treats kidney problems, and is used as mouthwash for toothache. The decoction with palm nut soap is used to arrest miscarriage (Bakshi et al., 1992).

Siddha used the plant in its entirety for treating snake bite, amenorrhoea, leucorrhoea, and abscesses. Roots are used in uterine diseases and burning sensation (Yoganarasimthan, 2000). The Lodha tribes use smoke of the root as a hallucinogen and eat root paste; however, this can cause insanity (Bakshi et al., 1992). The tribes of Medinipur tie a piece (2 cm) of root in black thread on left arm of a pregnant lady to cure piles (Bakshi et al., 1992). In Ivory Coast the plant is used for treating leprosy (Anon., 1992).

The species *A. tricolor* is also used medically. The plant is used as an astringent and diuretic, in menorrhea, diarrhea, dysentery, cuts and wounds, cough and bronchitis, paralysis in cattle, and as a poultice to wash wounds (Tripathi et al., 1996; Kapoor and Kapoor, 1980; Srivastava et al., 1980; Singh and Dhar, 1993; Singh et al., 1998; Jain and Defillips, 1991). The leaves are used in jaundice, intestinal and urinary discharges, menorrhea, fever, blood disorder, piles, and strangury scrogfula (Borthakur and Goswami, 1995; Gupta et al., 2004; Sankarnarayanan, 1988; Tripathi et al., 1996; Yoganarasimthan, 2000). The roots are used in gonorrhea, eczema, and as a demulcent. Its decoction is used for stricture, piles, and diarrhea. The roots and seeds are also used to cure leucorrhea and impotency (Chopra et al., 1956; Anon., 1992; Prajapati et al., 2003; Bakshi et al., 1992). In present times the poultice is used in ulcerated throat, toothache, and as an astringent and cooling agent (Bakshi et al., 1992).

Other species, *A. viridis*, has anthelmintic properties and is also used as a laxative. It is used in inflammation (Tripathi et al., 1996; Kakrani and Saluja, 1994) in snake bite, and scorpion stings (Jain and Defillips, 1991). The roots of the plant are recommended in eczema and against ring worm (Siddiqui et al., 1989). Traditionally, Lodha tribes used root paste on burns (Bakshi et al., 1992). In Brazil the plant is used as a diuretic and galactagogue. The leaves are used as a poultice in inflammation, boils, and abscesses (Anon., 1992). The species *A. oleracea* is used for emollients, cooling stomach, hemorrhea, diathesis, and biliousness (Jain and Defillips, 1991). The species *A. polygonam* is used as a demulcent, aphrodisiac, and in impotency. The decoction of the roots and leaves are used to treat leucorrhea, menorrhea, and diarrhea. The leaves are used as a poultice in inflammation, painful body parts, and abscesses. The roots are recommended for colic gonorrhea and eczema.

BIOLOGICAL EFFECTS

Though *Amaranthus* species can be used for different beneficial purposes but some weedy species have negative as well as allergic effects. Suma et al. (2002) studied the allelophatic effect of weedy amaranths viz. *A. retroflexus*, *A. spinosus*, and *A. viridis*. They reported that these species inhibit crop growth and characterizes allelochemicals from *A. spinosus*. The pollen of *A. spinosus* causes pollen allergic diseases and pollen of *A. viridis* are found to be associated with skin diseases. Petroleum ether extract of aerial parts of *A. tricolor* showed antibacterial activity against gram positive bacteria *Staphylococcus aurens*, *Staph albus*, and *Streptococcus viridians* (Sharma and Mukat, 1991). The seeds of *A. blitum* growing in dung revealed in vitro antibacterial activity against *Pseudomonas cichorii* and *Xanthomonas campestris* and *A. viridis* seed inhibits bacteria *Bacillus subtilis* and *E. coli* MLS-16 (Bagchi et al., 1997; 1999). The extract of leaves of *A. viridis* showed strong nematocidal activity against second larvae of *Meloidogyne incognita* in vitro at various concentrations (Nandal and Bhatti, 1983; Siddiqui and Alam, 1997). Amoli et al. (2009) determined the total toxicity of *Amaranthus retroflexus* L. The plant extract has been tested for bioactivity in *Artemia salina* and cytotoxicity against bovine kidney for cells. The bovine kidney cells were exposed to various concentrations of the plant extracts (100 ppm-0.1 ppm). After treating with 100 and 0.1 ppm for 24 h, the viability of the cells were reduced by about 49% and 35%, respectively, in MTT viability assay. The study confirmed that *Amaranthus retroflexus* has a cytotoxic effect and more specifically to renal cells.

MOLECULAR APPROACHES

A lot of molecular work has been carried out by various workers on Amaranth to study the basic structure of different molecules and genes responsible for various important proteins, starch and other compounds present in it. Raina and Dutta (1992) isolated a well-balanced albumin protein (35Kda) with four isoforms from the seeds of *A. hypocondriacus*. Chakraborty et al. (2000) expressed a non-allergic seed albumin AmA1 with a well balanced amino acid composition encoded from a single gene of *A. hypocondricus* using granule bound starch synthatase enzyme (GBSS) and cauliflower mosaic virus 35S promoter to express in potato to increase the nutritive value of potato. Marcone et al. (1994) purified other major albumin fraction (i.e., albumin 1) of *A. hypocondriacus* having a molecular mass of 133400d. The secondary, tertiary, and quaternary structure of storage globulin protein were also studied through electron microscope which showed that it had some overall structure as a dicot plant (Marcone et al., 1994). Similarly, RomeroZepeda et al. (1996) isolated IIs amaranth seed globulin with molecular weight 389 kda from *A. hypocondricus* and termed it Amaranthin. Dela Rosa (1996) extracted a globulin protein of molecular weight 398 kda from amaranth seeds and purified it by gel filtration and ultracentrifuge. The deduced amino acid sequence confirmed that protein synthesized was similar to other IIs like protein and also had the same ancestral gene compared to the dicot and the monocot species. Castellani et al. (1999) studied the role of disulphide bands on the structure stability of amaranth globule protein and noticed that its polymerization was high (51+/-1mu mol/g) and similar to soybean IIs globulin content. Ramirez-Medeles et al. (2003) also isolated and purified nsLTP protein with molecular mass of 9747.29 Da from the seeds of *A. hypocondriacus* by gel filtration and reverse phase HPLC. The protein had a alpha helical structure typical to other plants nsLTP1 and had 40 to 57% sequences identical to other plants. Lozanov et al. (1997) reported total synthesis of a-amylase inhibitor, a 32 residue long peptide with 3 disulphide bridges from the seeds of *Amaranthus*. Aphalo et al. (2004) studied the surface characteristic and assess the homology of globulin protein, the polymerized 11s amaranth globulin with other storage proteins which showed that globulin P unitary molecules with aggregates had a similar reactive surface. Chen et al. (2004) separated ribosome inactivating protein (molecular weight 29kda) from the seeds of *Amaranthus mangostanus,* a kind of vegetable which had an isoelectric point greater than 9. This protein can be used for medicinal purposes which can be applied in the preparation of antitumor, antiviral, and anti HIV drug formation. For the first time Petruccelli et al. (2007) studied the role of short sequence conserved among 7S and 11S proteins in vacuolor sorting and interaction among proteins of different classes in *A. hypocondriacus*. Legaria et al. (1998) isolated a genome clone (a hybadh 4) and a clone (a hybadh A), both encoded for betaine aldehyde dehydrogenase from *A. hypocondriacus*. Molina et al. (2008) reported that the seeds of *Amaranthus* also contain non-processed 11 s precursors which are constituent of albumin 2.

Two antimicrobial polypeptides were isolated from *A. caudatus* seeds (Ac AMP 1 and Ac-AMP 2) and had a molecular mass of 3025 and 3181da with PI values 9 and 10 (Broekaert et al., 1992). The amino acid sequence was identical in both polypeptides except the latter had one additional residue at the carboxyl terminus. The sequences had high homology to other chitin binding protein. They could inhibit the growth of different plant pathogen fungi at much low doses and other known fungal chitin binding proteins. They also show activity to gram positive bacteria. Rodriguez (1993) purified a 69 amino acids protein with high catene and valine, arginine, glutamic acid and lack in methionine protein protinase inhibitor of molecular weight 7400 having an isoelectric point 7.5 from a seed extract of *A. hypocondriacus*. It had the tendency to inhibit the activity of larvae of insect Prostephanus truncates. Another major trypsin inhibitor (AMTI) which is of 69 amino acid protein had the homology with members of the potato I inhibitor family, which were isolated and sequenced by Valdes-Rodriguez in 1999. He cloned and expressed 394 bp cDNA sequences with an open reading frame corresponding to a polypeptide of 76 amino acids residues and encoded these in various vegetative tissues of amaranth plant during seed development and imbibitions. Further, Rodriguez et al. (2007) encoded and characterized Cysteine proteases inhibitor (Al CPI) which had a polypeptide of 247 amino acids including a putative n-terminal signal peptide. The sequence also had G and PW conserved as motifs, to conserve LARFAV sequence for phytocystatins, and the relative site QWAG. The sequence (ALCPI) showed a significant homology to other plant cystatins. Its expression analyses indicated that it expressed in mature seeds and decreased during germination which described that single cystatin protein could have a regulatory role in germination. Similarly, Tamir et al. (1996) isolated a 8 kd trypsin chromatrypsin inhibitor proteins from seeds of *A. hypocondriacus* through affinity chromatography on trypsin sepharose and by HPLC. The protein was stable at neutral and alkaline pH and was relatively thermostable. Pribylova et al. (2006) tried to develop an easy and cheap PCR method for detection of an antimicrobial peptide from *Amaranthus* for transformation of proteins. Again, Pribylova et al. (2008) used the primer to amplify the gene AMP2 in *A. caudatus*. He noticed that the same genes were present in other seven species of Amaranth, namely *A. albus*, *A. cruentus*, *A. hybridus*, *A. hypocondriacus*, *A. retroflexus,* and *A. tricolor* and observed that all sequences were identical except for two polymorphisms and this polymorphism was present outside the region encoding the chitin binding peptide domain, thus not affecting the proper functioning of the antimicrobial peptide.

Boinski et al. (1993) studied the post-transcription control of cell type specific gene expression in bundle sheath and mesophyll chloroplast of *A. hypocondriacus* and demonstrated that the rubisco LSU polypeptide was present only in chloroplast preparation of bundle sheath cells and Pyruvate orthophosphate dikinase (PPDK). A nuclear encoded chloroplastic enzyme was only found in a mesophyll chloroplast preparation. Brery et al. (1997) studied photosynthetic gene expression in developing the leaves of a NAD-ME type C4 dicot in amaranth and showed that the C4 gene independently regulated by a different multiple control mechanism instead of environmental and metabolic signals. Ptushenko et al. (2002) tried to study the interaction of Amaranthin protein to ETC of chloroplasts at the PS level. They found that the protein affect ETC near PS I and had no significant inhibitory effect on the light dependent formation of the transmembrane PH gradient at the same time. Long et al. (1994) purified mitochondrial NAD dependent malic enzyme made up of 2 subunits, 65 and 60 kd designated α and β, respectively, to catalyze the decarboxylation of 4 carbon malate in bundle sheath cells releasing CO_2 for the calvin cycle. The Zummogold electromicroscopy using α subunit antiserum demonstrated that the protein was localized specifically in mitochondrial matrix bundle sheath cells and had similarity with the other plants, animals, and bacterial malic enzyme. Barrio and Anon (2010) isolated protein from the seeds of *Amaranthus mantegazzianus* that exhibit potential of antitumor properties using four different tumor-derived and in vitro-transformed cell lines with different morphology and tumorigenicity (MC3T3E1, UMR106, Caco-2, and TC7). The MPI showed an antiproliferative effect on four cell lines with different potencies. The MPI produced morphological changes and caused a rearrangement of the cytoskeleton in UMR106 cell line.

Praznik et al. (1999) for the first time studied the molecular background of technological properties, for example, gelatinization, stability to mechanical stress, resistance to stability in continuous freeze cycle of selected starch of maize, amaranth, *C. quinoa*, etc. and correlated these properties with molecular features such as branching characteristic in terms of iodine complexing potential molar mass occupied glucan volume, packing density of glucan oils, and theological properties.

Bello Pezec (1998) studied the macromolecular feature of starch with the help of high performance size exclusion chromatography (HPSEC), static light scattering (SCS), and dynamic light scattering (DLS) techniques for characterization of amaranth starch and showed the sphere and the globular structure of starch. Bunzel et al. (2005) studied the association of non-starch polysaccharides and ferulic acid in dietary fiber of grain amaranth (*A. caudatus*). They reported that through the ferulocylated oligosaccharides ferulic acid was predominately bounded to pectin arabians and galactins in amaranth insoluble fiber. The compound 50 transferoloyl L arabinofuranose was isolated in pure form from pectic arabinans but also from arabinoxylans. Park et al. (2009) isolated and characterized a full-length cDNA clone encoding granule-bound starch synthase I (GBSSI = Waxy gene) from grain amaranth (*Amaranthus cruentus L.*) perisperm. Segregation of amylose content in F_2 population suggested that the amylose content of *A. cruentus* is controlled by a single gene. cDNA clone of this gene is 2076 bp in length and contains an open reading frame of 1821 bp corresponding to a polypeptide of 606 amino acids residues, including a transit peptide of 77 amino acids. Sarkar et al. (2009) isolated a water-soluble polysaccharide (PS-I), from the aqueous extract of the stems of *Amaranthus tricolor Linn. (Amaranthus gangeticus L.),* was found to consist of L-arabinose, methyl-D-galacturonate, D-galactose, and 3-O-Ac-L-rhamnose in a molar ratio of nearly 1:1:1:1. Kong et al. (2009) determined the fine structure of amylopectin from grain amaranth. *Amaranthus* amylopectin was hydrolyzed with alpha-amylase, and single clusters and a group of clusters (domain) were isolated by methanol precipitation and showed that the domain fraction contained approximately 2.2 clusters, and single clusters composed of approximately 13 chains. The phi,beta-limit dextrins of the clusters were further hydrolyzed with alpha-amylase to characterize their building block composition. The average DP of the branched blocks was approximately 11 and contained on an average of approximately 2.5 chains. Their average chain length, internal chain length, and degree of branching were approximately 4.3, 2.8, and 14, respectively.

To study the genetic diversity based on molecular markers among the *Amaranthus* several efforts had been made. Sun et al. (1999) used a low cost DNA probe obtained by isolation of various classes of repetitive DNA sequences, including satellite, mini satellite, rDNA, retro transposones like sequences, and other unidentical novel repetitive sequences to study genetic diversity among 24 cultivated and wild species of *Amaranthus*. DNA fingerprinting by repetitive DNA probes revealed a different level of polymorphism in Amaranth genome. Wetzel et al. (1999) used the PCR based molecule identification system to distinguish the weedy species of genus Amaranth. Lee et al. (2008) isolated 12 polymorphic microsatellite markers from 20 accessions of *A. hypocondriacus* and reported 92 alleles with average alleles 7.7 per locus with heterozygosity value ranged from 0.0 to 0.95. The results demonstrated that it has wide applicability of markers for the study of intra and inter specific genetic diversity as well as evolutionary relationships among cultivated and wild amaranth. Mallory et al. (2008) developed microsatellite enriched libraries by sequencing 1457 clones in grain amaranth and reported that 179 microsatellites were polymorphic across accessions of three grain amaranth. In polymorphic satellites a total of 731 alleles were reported with an average of 4 alleles per locus which suggested that 3 cultivated species were evolved from different *A. hybridus* ancestors.

BREEDING APPROACHES

Amaranthus is a rich and cheap source of daily required nutrients as already mentioned previously. In recent years it is gaining importance as an alternative crop to other important cereals. To meet out increasing global demand and simultaneously to decrease pressure on major cereal crops, the development of high yielding varieties rich in nutrients are very important. In this direction various studies and breeding efforts have been initiated worldwide, especially in India. In the development of a high yielding variety, the presence of genetic diversity among available germplasm lines plays a major role (Shukla et al., 2010). The extent of genetic diversity among different lines of three species of grain *Amaranthus* and among 66 strains of vegetable amaranth have been explored by Gupta and Gudu (1991), Shukla et al. (2002), and Pandey (2009), respectively. Transue et al. (1994); Chan and Sun (1997), Ranade et al. (1997), Xu and Sun (2001), Stefunova and Bezo (2003), and Costea et al. (2006) studied genetic diversity among different *Amaranthus* germplasm based on RAPD or AFLP markers or isozymes. Overall study showed that *A. hypocondriacus* and *A. caudatus* were more genetically similar than *A. cruentus*, putative origin of *A. dubious* was from *A. hybridus* and *A. spinosus*, *A. caudatus*, and *A. tricolor* were however, intermediate. *A. hybridus* and *A. dubious* were more similar. Ray and Roy (2007) for the first time made phylogenetic relationships among the members of amaranthaceae and chenopodiaceae. For improvement of cultivars not only the knowledge of genetic diversity is important but also knowledge of magnitude of variation in the available germplasms, interdependence of quantitative characters with yield, extent of environmental influence on these factors, heritability, but genetic advance of various contributing traits are also required. Keeping this in mind various workers made their efforts in this direction as well. Imeri et al. (1987), George et al. (1989), and Shukla and Singh (2003) studied the genetic variability and correlation among the different varieties of grain amaranth. Similarly, Reddy and Varalakshmi (1994), Shukla and Singh (2000), and Shukla et al. (2004; 2005; 2006; 2006) studied genetic variability among the available accessions and also studied different genetic parameters for different traits over different cuttings in vegetable *Amaranthus* and suggested that the enhancement of their foliage yield and its quality traits could be achieved through selection of plant types based on all of its component traits. Similarly, Prakash and Pal (1991); Shukla et al. (2000; 2002; 2004), Shukla and Singh (2000), and Bhargava et al. (2004) studied the correlation among foliage yield and its contributing traits in vegetable amaranth over different cuttings. However, Katiyar et al. (2000), Reddy and Varalakshmi (1994), and Shukla and Singh (2001; 2003) studied the correlation over different traits. Katiyar et al. (2000) and Mathe-Gaspar (2001) isolated lines of grain amaranth suitable in sodic soil and tolerant to drought. They reported that grain amaranths due to drought tolerance ability, can be suitable and economically feasible commercial crop for wastelands. Mathe-Gaspar (2001) characterized the important phenological traits of *Amaranthus* cultivation. Similarly, Escudero et al. (1999) in *A. muricatus*, Lakshmi and Vimala (2000) in *A. gangeticus* and Shukla et al. (2003; 2006) in *A. tricolor* made their efforts to study the nutritional and mineral components. Previously, Rangarajan et al. (1998) also evaluated the grain and leafy amaranth for iron and found that amaranth has relatively much iron than other leafy vegetable. Sharma et al. (2001) studied the stability of grain amaranth genotypes over different years and noted significant genotype x environment interactions for all the traits. Similarly, Varalakshmi (2003) and Shukla and Singh (2003) studied the stability for economic traits in vegetable amaranth. Lehmann et al. (1991) and Reddy and Varalakshmi (1998) studied the combining ability and heterosis in amaranthus. Wu et al. (2000) evaluated the *Amaranthus* collection of China and concluded that many species were sensitive to day length. Cultivated species had high grain yield but were more sensitive to diseases. Jamriska (1993) and Henderson et al. (2000) studied row spacing, plant population, and cultivar effects on grain and found that yield depends upon weather conditions and narrow row spacing produced average higher yields than the stands with wider row spacing. Teutonico and Knorr (1984) studied the antinutritional components of *A. tricolor* through tissue culture. Later on, Bennici et al. (1992; 1997) also made tissue culture studies in different lines of grain *Amaranthus* species. They suggested that genotype, growth regulator dose, type, and physiological stage of explants were important factors for *Amaranthus* in in vitro regeneration. Law-Ogbomo and Ajayi (2009) determined the influence of planting density and poultry manure application on the growth and yield of *Amaranthus cruentus* (Linnaeus) and reported that the combination of 62,500 plants per hectare and application of poultry manure of 12 t/ha, provided the highest yield (15.74 t/ha). Khandaker et al. (2010) evaluated biomass yield and accumulation of betacyanin, chlorophyll, total polyphenol, and antioxidant activity in *Amaranthus tricolor* L. under five shades made up of white, blue, green, yellow, and black polythene and a control. They reported that blue polythene has the potential to increase the yield with health beneficiary bioactive compounds betacyanins, polyphenol, and antioxidant activity during the low temperature regime in the spring season.

FUTURE PROSPECTS

The overview of available literature showed that *Amaranthus* possesses versatility in its nature and uses. The presence of genetic diversity among lines/species of both grain and vegetable types opened the path for breeders for its improvement and development of nutritionally rich varieties by applying conventional breeding approaches. The presence of a large amount of different amino acids in seed embryo provides the way for the development of specific nutritionally rich varieties (Tomoskozi et al., 2009). The species which have drought tolerance and capability to grow in sodic soil can be explored for wastelands cultivation. Amaranth seed oil contains non-polar lipids with a high degree of unsaturation still needed to be identified followed by the establishment of accurate oil refining processes. At the present time the development of varieties with low/nil oxalate and nitrate components is required which needs extensive research. Teutonico and Knorr (1984) obtained reduction in oxalate and nitrate through tissue culture techniques, thereby opening the possibilities for the development of such varieties by tissue culture. Demko (1997) noticed the use of *Amaranthus retroflexus* as a new alternative of renewable energy resources and found that it reached 75 to 90% of the calorific power of wood. So, the efforts should be made to explore other species also for the purpose of renewable resources. Based on available information on medicinal uses of *Amaranthus* for pharmaceutical industries, researchers should focus on separation and characterization of compounds having medicinal properties. Thus, *Amaranthus* can be a future crop for diversified purposes and can solve the problem of malnutrition, especially for developing countries.

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