7.4.5. ***Amaranthus hybridus*** L., Sp. Pl., ed. 1, 900 (1753); Boulos, Fl. Egypt 1: 131 (1999).
subsp. ***hybridus***
Syns. *Amaranthus hypochondriacus* L., Sp. Pl., ed. 1, 991(1753); Täckh., Stud. Fl. Egypt, ed. 2, 131 (1974);
Amaranthus chlorostachys Willd., Hist. Amaranth. 34, t. 10, f. 19 (1790); Täckh., Stud. Fl. Egypt, ed. 2, 131 (1974);
Amaranthus patulus Bertel., Comment. It. Neap. 19, t. 2 (1837).
subsp. ***cruentus*** (L.) Thell., Fl. Adv. Montpellier 205 (1912).
Syns. *Amaranthus cruentus* L., Syst. Nat., ed. 10, 2: 1269 (1759); Täckh., Stud. Fl. Egypt, ed. 2, 131 (1974);
Amaranthus paniculatus L., Sp. Pl., ed. 2, 1406 (1763).

Common pigweed, smooth pigweed.

Proximate Composition, Proteins and Amino Acids

The values of proximate, mineral and amino acid compositions and functional properties of leaf protein concentrations of *Amaranthus hybridus* were high in ash, protein and metabolizable energy *viz*. 17.2, 34.8 (g/100 g) and 1.4 MJ respectively. Minerals only slightly high were Na, Ca and P with values of 32.2, 50.2 and 45.7 (mg/100 g). Total amino acid in the plant was 678.1 mg/g crude protein with total essential amino acid of 393.5 mg/g or 58.0%. Threonine was the limiting amino acid with 0.69. The functional properties showed that it has high water and oil absorption capacities with values of 230.0 and 182.9%. While foaming capacity was low, foaming stability was high with a low rate of change (2.0%/min). The protein solubility was moderate with a range of 34.6-42.7% (Adeyeye and Omolayo, 2011).

The mean values of the crude protein of *Amaranthus cruentus* (growing in Cuba) were 22.9, 9.0 and 18.1% for the leaves, stems and whole plant, respectively (Crespo *et al*., 1988). The mineral elements, crude fiber, total N, crude protein, available lysine, total P, Ca, nitrate and oxalic acid levels of *Amaranthus cruentus* are mentioned above (*cf*. 7.4.3). The proximate analysis of the seeds of *Amaranthus cruentus*, *Amaranthus hypochondriacus* and *Amaranthus paniculatus* is shown in Tables 40-42. The nutritional value of green leaves of *Amaranthus cruentus* growing in Nigeria were reported as follows: carbohydrates, 7.0; protein, 4.6; fiber 1.8 (% dry weight), moisture 86% and ascorbic acid 408 mg/100g dry matter. The mineral contents of the same sample were Ca 2.05, K 4.82, Mg 2.53, Na 6.84 and Fe 1.2 mg/100g (Mensah *et al*., 2008).

Ravindran *et al*. (1996) evaluated the feeding and energy utilization values of raw and autoclaved grain amaranth (*Amaranthus hypochondriacus*) in broiler diets. The grain amaranth sample used in the latter study contained (g/kg^{-1}): crude protein, 168; crude fat, 58; crude fiber, 60; ash, 26; Ca, 2.2; total P, 5.6; lysine, 10.1; and methionine, 3.5. The results indicated that processed *Amaranthus hypochondriacus* grain was a potentially useful energy supplement for poultry and could be incorporated in broiler diets at levels of up to 400 g kg^{-1} without adverse effects on the performance (Ravindran *et al*, 1996). The seeds of *Amaranthus hypochondriachus*, growing in Serbia, contained ~ 20% crude protein with ~ 35% proportion of essential amino acids, the lysine content was 5% (5 g/100 protein) (Lepojevic *et al*., 2000).

Table 40. Proximate analysis, phenolic content, and pepsin-trypsin nitrogen digestibility of some *Amaranthus* LPC*

	Species	Crude protein† (N x 6.25)	Ether extract†	Crude fiber†	Ash†	Nitrogen-free extract†	Pepsin-trypsin N digestibility (%)	Ethanol-extractable phenolics‡	Pepsin-trypsin-released phenolics‡
1.	*Amaranthus anclancalius*	22.4	5.2	8.0	27.6	36.8	34	145	145
2.	*Amaranthus ascendens*	22.5	6.5	7.3	27.9	35.8	43	140	145
3.	*Amaranthus cruentus* HH1	16.6	5.0	8.8	26.9	42.7	42	75	170
4.	*Amaranthus cruentus* HH2	18.1	5.0	5.8	25.5	45.6	45	55	170
5.	*Amaranthus cruentus* HH3	16.6	4.0	7.4	24.8	47.2	45	100	110
6.	*Amaranthus flavus*	18.4	5.4	8.3	32.1	35.8	37	160	175
7.	*Amaranthus gangeticus*	21.6	5.6	8.4	28.3	36.1	28	190	150
8.	*Amaranthus hypochondriacus*	20.6	5.3	8.1	26.3	39.7	45	135	160
9.	*Amaranthus mantegazzianus*	23.4	5.8	8.1	25.2	37.5	44	85	150
10.	*Amaranthus* Taiwan 3§	23.6	6.2	4.6	23.9	41.7	31	205	150
11.	*Amaranthus* Taiwan 12§	22.9	5.4	5.4	24.7	41.6	32	110	135

† Dry weight basis.
‡ Milligrams of chlorogenic acid equivalents per gram of N.
§ Seed obtained from Taiwan; species not identified.
* Cheeke *et al.* (1981).

Table 41. Proximate analyses of wheat and *Amaranthus hypochondriacus**

		Flours		Starches	
		Wheat	*Amaranthus hypochondriacus*	Wheat	*Amaranthus hypochondriacus*
Moisture	%	10.5	8.2	-	-
Ash	%	0.44	2.97	-	-
Fat	%	0.75	5.8	0.54	1.1
Protein	%	11.4	13.9	0.35	0.49

* As is basis Protein = N × 5.70. Lorenz and Collins (1981)

Table 42. Oxalate and phytic acid contents in the seeds of some *Amaranthus* species*

Sample	Oxalate g kg^{-1}	Phytic acid[a] g kg^{-1}
Amaranthus paniculatus	6.09+2.38	5.9+0.9
Amaranthus polygamous	9.13+7.93	6.2+0.1
Amaranthus gracilis	8.88+6.12	4.3+0.3
Amaranthus spinosus	9.96+0.030	5.3+0.6
Amaranthus tenuifolious	8.76+0.028	5.8+0.3

[a]Expressed as myoinositol hexaphosphate.
* Singhal and Kulkarni (1988)

The nutritive value of the seeds of *Amaranthus paniculatus* was reported as follows: moisture, 9-11; crude protein, 14.5-16.0; carbohydrartes, 66.8; crude fiber, 2; and ash, 3.6%. The ash contained 6% Ca and 18% P. Feeding experiments revealed a high level of protein deficiency comparable to casein (Subramanian and Srinivasan, 1951). When the protein was supplied by unfamiliar cereals (including *Amaranthus paniculatus*) and rice, *Amaranthus paniculatus*, was found inferior (*N*-balanced method) (Kundaji and Rao, 1954).

The proximate composition of *Amaranthus hybridus* seeds is: moisture 9.07±0.84, crude protein 17.19±1.47, crude fat 10.57±0.05, and ash 4.86±0.08 (Kimbonguila *et al*., 2010). The leaves of *Amaranthus hybridus* contain low protein content (1.07%) (Omale and Ugwu, 2011). The proximate composition of the seeds of *Amaranthus hybridus* and *Amaranthus hypochondriacus* as reported in literature is crude protein 13.8-21.5, 15.0-16.6; crude fat 5.6-8.1, 6.1-7.3; carbohydrates 63.1-70.0, 67.9 and ash 3.0-3.8, 3.3-3.4% respectively (Mlakar *et al*., 2009). There are several other reports on the proximate composition and nutritional value of *Amaranthus cruentus* (Lyon and Becker, 1987; Babor *et al*., 1994; Tapia-Blacdo *et al*., 2010; Aguilar *et al*., 2011; Menegassi *et al*., 2011) and *Amaranthus hybridus* (Lyimo *et al*., 2003; Ibrahim *et al*., 2011; Tideman-Andersen *et al*., 2011; Gbate and Mann, 2012).

The trace elements of *Amaranthus hybridus*, growing in India, was: Zn, 27.52; Mn, 112.50; Cu, 14.44 ppm and Fe, 251.0 mg/100 g (Desai *et al*., 1984). The seeds of *Amaranthus hypochondriacus* contain relatively high content of Ca (0.4%), Mg (0.67%) and K (1.15%) (Lepojevic *et al*., 2000). The latter species has been early reported to contain ascorbic acid 23.22 mg % and dehydroascorbic acid 11.85 mg % (Giral and Alvarez, 1943).

Amaranthus hybridus has been reported as a rich source of Na, K and Ca (Gbate and Mann, 2012). The macro and micro mineral content in the ash (6.0%) of *Amaranthus*

hybridus leaves are: Ca, 83.37; Cd, 0.50; Fe, 2.84; K, 134.44; Mg, 9.73; Na, 3.00; Ni, 2.88; Pb, 2.54 and Zn, 5.45 ppm (Omale and Ugwu, 2011).

The phytochemical characteristics of *Amaranthus cruentus* leaves are as follows: ascorbic acid (0.48-0.55%); about 1 % of flavonoids (mainly rutin) and 3-5% of tannins. The polysaccharide complex is presented mostly by pectins (23-27%). The amount of lignins is insignificant (3-4%). The content of water soluble amino acids is not high and comes to 1.6 mg/g. Leaves of amaranth contain potassium (2.0-2.6%), calcium (1.8-2.0%) and magnesium (about 0.6%) in a significant amount, and also phytosterols (0.26-0.54%) and a-linolenic acid (about 0.4%) (Faustova and Kosman, 2009). The nutritional quality (dry material, crude protein, Ca, Mg, P, crude fibrt, oxalic acid and nitrates) of *Amaranthus cruentus* L. cv. Don Guien were determined in stems and leaves from the plantlet to the beginning of florescence. The results were significant, except those of of dry material, Ca and nitrates. The best time for use as a vegetable would be 40 to 45 days after sowing, and as fodder at the initiation of flowering (De Troiani *et al*., 1993).

Nitrate levels of vegetable of three *Amaranthus* accessions studied by Mnkeni *et al*. (2007) agree with those reported by Mziray *et al*. (2001) in *Amaranthus hybridus*.

Average total oxalate and nitrate contents of *Amaranthus cruentus* (*Amaranthus caudatus*) are 8.86 and 0.67% (Schmidt *et al*., 1971).

Amaranthus hybridus, growing in Nigeria, contained relatively high nitrate-nitrite content, which may contribute to the induction of metahemoglobin (Okiei and Adamson, 1979). The nitrate content of *Amaranthus cruentus* was reported low (Bertoni *et al*., 1984b). *Amaranthus chlorostachys* Willd. is used by the African in South Africa as a green food (Watt and Breyer-Brandwijk, 1962).

Alcohol soluble proteins from seeds of four *Amaranthus* species (*Amaranthus cruentus, Amaranthus flavus, Amaranthus caudatus* and *Amaranthus hypochondriacus*) contain 80-85 % polypeptides of 10-14 KDa and 7% of 20 KDa polypeptides, the rest being minor fractions (Gorinstein, 1991a). The average values of albumins and globulins, alcohol-soluble proteins A1 and A2 and glutelins G2 and G3 in the seeds of these species were 61.3, 1.4 and 24.1 respectively. The main protein subunits have molecular masses of 10 - 45 KDa. Albumins, globulins and glutelin G3 have much higher lysine contents than the alcohol-soluble and glutelin G2 protein fractions. Globulins were only intermediate in comparative contents of methionine and cysteine (Gorinstein, 1991b). Of the four varieties of *Amarathus hypochondriacus*, cultivated in Mexico, Tulyehualco and DGETA had higher seed yield of 1475 and 1422 kg ha^{-1}, respectively comparable to corn and soybeen production in agricultural areas. Gabriela variety had the highest protein content of 17.3 %, but all varieties had an adequate balance of essential amino acids (Barba de la Rosa *et al*., 2009).

Globulins are some of the most abundant storage proteins of amaranth grain. They contain two fractions distinguishable according to their different solubilty: the salt-soluble 7S and 11S-globulins and globulin-p which is soluble in mild-alkali, low-ionic-strength solutions. In this concern, Quiroga *et al*. (2009) investigated the structural characteristics responsible for the different physicochemical properties of these globulins in *Amaranthus hypochondriacus*. They studied certain conformational parameters of the purified aggregates (AMGp) and individual molecules (IMGp) of globulin-p and of the partially purified globulin (ppGb) and compared the AMGp polypeptide sequences with the sequence of the 11S-globulin propolypeptide. The results indicated that the AMGp aggregates are responsible for the different solubilty of globulin-p. Subtle conformational differences as determined by fluorescence spectroscopy and urea sensitivity were found between the molecules studied: the AMGp showed some surface differences from the IMGp and the ppGb, and the AMGp also had a lower affinity for the hydrophobic fluorescent probe 1,8-aniline-naphthalene-sulfonate

as well as a higher ionic charge than the ppGb and the IMGp, characteristics that might cause their lower solubility In addition, the authors demonstrated differences between the AMGp polypeptide sequences and that reported for amaranth 11S-globulin. These differences suggest that the globulin-p and 11S-globulin are two 11S-globulin isoforms comprised of polypeptides coming from different legumin-gene subfamilies (Quiroga *et al*., 2009). Whole flour of *Amaranthus hypochondriacus* from Slovakia had a high content of proteins (17.7 % on dry basid). The lipid content of the grains was rather high (7.32 % on dry basis). The acidity of flour increased relatively little during 6 week of storage. The quantity of fiber (4.91%) on dry basis was comparable with more varieties of amaranth. Amaranth had a relatively high content of Ca, Mg, P, K and Fe. The quantity of thiamine corresponded to the average values of other amaranths. Riboflavin was ≤ fold the amounts reported in the literature (Dodok *et al*., 1994).

The study of the characteristics of 48 *Amaranthus hypochondriacus* and 11 *Amaranthus caudatus* (plants, grains and flours), showed that the latter species had a higher protein content, fat content and tendency for retrogradation, and lower α-amylase activity as compared to *Amaranthus hypochondriacus* lines (Kaur *et al*., 2010). The 7S-globulin fraction or vicilin of *Amaranthus hypochondriacus* had a sedimentation coefficient of 8.6 ± 0.6 S and was composed of main subunits of 66, 52, 38 and 16 kDa. Amaranth vicilin may be classified into vicilin group that includes pea, broad bean and sesame vicilins, among others (Quiroga *et al*., 2010). The study of bioactive peptides in *Amaranthus hypochondriacus* seeds showed an average concentration of 11.1 μg lunasin equivelant/g total extracted protein in four genotypes of mature amaranth seeds. Glutelin fraction had the highest lunasin concentration (3.0 μg/g). Lunasin was also identified in albumin, prolamin and globulin amaranth fractions and even in popped amaranth seeds (Silva-Sanchez *et al*., 2008).

Uzo and Okorie (1983) reported that grain yields of *Amaranthus hybridus* were comparable to those of major grain and cereal crops in West Africa. *Amaranthus hybridus* grain is suggested as a cheap high-protein grain supplement to both humans and poultry. A yield of 6 ton/ha was attained. Crude protein content of 17.2 % and lysine value of 6.3 g/16 g were recorded. Accordingly, it has great nutritional value (Uzo and Okorie, 1983). The crude fiber content of *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus mantegazzianus* was 2.89-3.60% (Bertoni *et al*., 1984b). Analysis of *Amaranthus hybridus* seeds showed that they contain a high amount of protein (13.1%) of high biological value. The protein efficiency ratio (2.3) is comparable to that of casein (2.5); the biological value, digestibility, and net protein utilization were also comparable. The tannin content (0.15%) seems to be sufficiently low to have non significant effect on the nutritional value (Osuntogun and Oke, 1983). The high tryptophan, lysine, and nicotinic acid content of *Amaranthus hybridus* made it a good supplement to maize meal; since it raised the protein score of maize from 43 to 67 and the net dietary protein value from 2.2 to 3.7% (Lewis *et al*., 1971). The amino acid composition of the leaves protein was not affected by the age of the plant (Fafunso and Bassir, 1975). Jaiswal *et al*. (1984) reported that the seeds are rich in the essential amino acids. Methionine was found as a free amino acid.

The amino acid analysis (Table 43) of a sample of *Amaranthus hypochondriacus* compared favourably in terms of essential amino acid composition to that of soybean meal, particularly with respect to lysine, and sulphur-containing amino acids and was very similar in amino acid composition of alfalfa leaf protein concentrate (LPC). The LPC samples from *Amaranthus* species were much lower in protein and higher in ash (Table 40) (Cheeke *et al*., 1981). However, high ash content may be characteristic of *Amaranthus*, since in the studies of Cheeke and Carlsson (1978) *Amaranthus* whole-plant grown elsewhere was found to have a high ash content.

Table 43. Amino acid composition of LPC prepared from *Amaranthus hypochondriacus* (g amino acid /16g N) compared to that of soybean meal and alfalfa LPC*

Amino acids	g Amino acid /16g N		
	Amaranthus hypochondriacus LPC	Alfalfa LPC†	Soybean meal‡
1. Lysine	6.6	5.9	6.5
2. Threonine	5.0	5.1	1.3
3. Proline	4.6	4.9	6.3
4. Cysteine	1.2	1.2	1.5
5. Methionine	2.4	2.3	1.3
6. Valine	6.9	6.3	5.3
7. Isolecucine	5.8	5.6	5.3
8. Leucine	9.3	9.3	8.2
9. Phenylalanine	6.0	5.9	5.3
10. Tyrosine	4.2	4.8	3.3
11. Histidine	2.4	2.3	2.7
12. Arginine	5.8	6.5	7.3
13. Aspartic acid	9.9	10.0	14.0
14. Serine	5.3	4.3	5.6
15. Glutamic acid	10.6	11.4	20.0
16. Glycine	5.4	5.5	5.2
17. Alanine	6.0	6.3	5.3

† Kuzmicky and Kohler (1977); ‡ International feed reference number 5 04 604.
* Cheeke *et al*. (1981).

Pandey and Purohit (1979) analysed the seeds of 3 morphological variants of *Amaranthus paniculatus*, 2 of *Amaranthus tricolor*, and 2 wild species (*Amaranthus spinosus* and *Amaranthus viridis*) for germinability, total protein, and multiple forms of protein. They found that wild species exhibited poor germeability and lower protein contents in comparison to cultivated types. Bhatia (2003) reported that *Amaranthus paniculatus* has high content of β-carotene (about 15 mg/100 g), viamin C and folate. Seeds of thirteen amaranth (*Amaranthus cruentus* and *Amaranthus hypochondiacus*) accessions were surveyed for their composition of tocols (Lehmann *et al*., 1994). The most common tocols found were α-tocopherol (2.97 to 15.65 mg/kg seed), β-tocotrienol (5.92 to 11.47 mg/kg seed) and γ-tocotrienol (0.95 to 8.69 mg/kg seed), while some of *Amaranthus cruentus* accessions contained δ-tocotrienol (0.01 to 0.42 mg/kg seed). Unlike many cereal grains, *Amaranthus* species have significant amounts of both β- and γ-tocotrienols, however, β-tocopherol was not detected in any of the amaranths studied by Lehmann *et al*., 1994). Lutein content ranged from 53 to 143 μg/g and 58 to 171 μg/g in fresh and cooked leafy vegetables (including

Amaranthus cruentus). β-Carotene contents in the same samples were found to range from 45 to 119 μg/g in fresh samples and from 40 to 159 μg/g in cooked samples (Bélanger *et al*., 2010). The presence of *cis*-isomer of β-carotene (Van der Pol *et al*., 1988), lutein and β-carotene (Belanger *et al*., 2010) in *Amaranthus cruentus* was reported.

The protein of *Amaranthus hypochandriacus* (yellow seeds) and *Amaranthus anclancalius* (black seeds) were fractionated into albumin, globulin, prolamin and glutelin. The average proportions of the soluble proteins were 65:17:11:7 respectively. Albumin has the highest lysine content (7.3-8.2 %), and globulin had highest methionine (4.1-5.3 %), and phenylalanine (6.0-6.1 %) content. Prolamin had the highest threonine (4.6-5.4 %), and leucine (6.8-6.9 %) content, and glutelin had a very low methionin content (0.6-1.0 %). Several studies were reported on the isolation, characterization and composition of *Amaranthus hypochondriacus* albumin (Raina and Datta, 1992; Marcone *et al*., 1994a; Datta *et al*., 1997; Martinez *et al*., 1997) and globulin (e.g. Romero-Zapeda and Paredes-López, 1996). The 11S globulin of seed storage protein of *Amaranthus hypochondriacus*, termed amarantin, was isolated by Romero-Zepeda and Parades-Lopez (1996); its apparent relative molecular weight was estimated to be 389 kDa. The study of the structure of albumin 2 protein fraction of *Amaranthus hypochondriachus* (Martinez *et al*., 1997) revealed that it was formed by several major polypeptide subunits of molecular masses of 52.3 ± 0.8, 54 ± 2, and 56 ± 1 kDa. The former and the latter subunits was composed of a peptide of molecular mass between 31 and 38 kDa linked by *S-S* bonds with another peptide of molecular mass between 19 and 23 kDa. The 54 kDa subunit together with the 31-38 and 19-23 kDa subunits formed *S-S* linked aggregated polypeptides. Lypholized albumin 2 was highly polymerized, having a complex monomer component with a molecular mass of 300 ± 10 kDa. The polymers were partially stabilized by *S-S* linkages. Because of these structural characteristics, albumin 2 was very similar to amarantin except for the presence of the 54 kDa subunits and its tendency to polymerize. This suggests that the albumin 2 would be the same 11S type globulin that was found in the seeds under different conformational states and/or different degrees of polymerization (Martinez *et al*., 1997). Molina *et al*. (2008) tested the hypothesis that the albumin-2 fraction could be constituted by a non-processed 11S globulin (proglobulin). The obtained results confirmed the presence of unprocessed 11S precursor in mature amaranth seeds, this phenomenon cannot, however be attributed to low vacuolor processing enzyme activity during developing of amaranth seeds. The amino acid composition of *Amaranthus hypochondriacus* albumin-1 showed a high proportion of essential amino acids like lysine, leucine, threonine, phenylalanine, valine, and cystine that are otherwise deficient in the major seed proteins of legumes and cereals (Datta *et al*., 1997). L-Leucine was the limiting amino acid in 10 amaranth (*Amaranthus crunetus*) seed samples (Becker *et al*., 1981). The amino acid composition of 6 varieties of *Amaranthus hypochondriacus* was determined by Misra *et al*. (1983). There was no relationship between the status of the varieties (cultivated and wild) and the amount of protein and amino acids. The black seeded form (Ag-16) had a higher proportion of protein, but the cultivated form had more lysine. The amount of lysine in the protein was positively correlated with the amount of phenylalanine, alanine, isoleucine, valine, arginine, and histidine, but negatively correlated with aspartic acid, threonine, serine, glutamic acid, proline, glycine, and leucine. The contents of amino acids in whole amaranth flour from *Amaranthus hypochondriacus* were investigated by Dodok *et al*. (1997). In comparison with fine wheat flour, used in their study, high lysine content was observed (5.95 g/16 g N in comparison with 2.90 g/16 g N). The protein amino acid composition of seeds of *Amaranthus hypochondriacus* compared with amino acid data for wheat, corn, oats, barley and soybean, as well with previously reported data for *Amaranthus hypochondriacus* (Saunders and Becker, 1984; Segura- Nieto *et al*., 1992) is shown in Table 44 (Dodok *et al*.,

Table 44. Amino acid composition of whole amaranth flour form *Amaranthus hypochondriacus* and wheat flour, corn, oat, barley and soybean (g/16 gN)*

Amino acid	*A. hyp.* Whole flour	AAS [%]	Wheat flour	AAS [%]	*A. hyp.*[1]	*A. hyp.*[1]	Corn[1]	Oats[1]	Barley[3]	Soybean[4]
Lysine	5.95+0.10	108	2.90+0.71	53	5.5	5.7	2.7	4.0	3.6	6.4
Leucine	4.20+0.57	60	5.05+0.10	72	5.7	6.2	12.5	7.8	7.0	8.1
Isoleucine	2.71+0.69	68	2.60+0.22	65	3.9	3.9	3.7	4.0	3.8	4.9
Phenylalanine	4.70+0.30	104	5.80+0.33	129	4.0	3.4				5.1
Methionine	0.64+0.38	34	1.24+0.06	65	2.6	3.3				1.2
Threonine	3.25+0.57	81	2.46+0.32	62	3.6	5.1	3.6	3.5	3.5	4.4
Tryptophan	1.82+0.04	182	1.14+0.05	114		1.9	0.7	1.3	1.3	0.94
Valine	3.85+0.82	77	3.88+0.41	78	4.5	5.9	4.8	5.5	5.5	5.2
Histidine	3.80+0.02	141	3.08+0.02	114	2.5	3.0				2.5
Arginine	9.49+0.31	306	2.91+0.05	94		7.3				7.5
Alanine	3.30+0.47	97	2.75+0.02	81		6.6				4.7
Cystine	---		---		2.1	1.3				1.2
Glycine	6.77+0.49	339	3.02+0.06	151	7.4	10.7				4.6
Aspartic acid	8.20+1.63	109	4.88+0.08	65		7.9				12.9
Glutamic aicd	14.55+0.62	76	29.35+1.64	153		14.9				21.7
Proline	2.82+0.21	29	8.41+1.12	86		5.7				
Serine	4.85+0.76	128	3.62+0.09	95	6.3	7.3				4.5
Tyrosine	3.72+0.17	79	3.38+0.08	72	3.3					3.7
Limiting acid	Met		Lys		Leu	Leu	Lys, Try	Lys Thr	Lys, Thr	Met

1- Data according to Saunders and Becker (1984); 2. Data according to Segura-Nieto *et al.* (1992);
3- Data according to Davidek *et al*. (1983); 4. Data according to Kolarik and Marek (1979)
* (Dodok *et al*., 1997)

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1997). Amaranth proteins are relatively rich in tryptophan, histidine, valine, phenylalanine, lysine threonine and poor in methionine, leucine with respect to the value reported by the FAO/WHO (1973) amino acid pattern requirements for 2-5 years old children (Dodok *et al*., 1997). The flour of *Amaranthus hypochondriacus* showed in comparison with these data higher lysine value 5.95 g/16 g N, but methionine content was considerably lower - 0.64 g/16 g N (Dodok *et al*., 1997).

Pant (1983) studied the nutritional quality of grain amaranths (*Amaranthus cruentus* and *Amaranthus hypochondriacus*. Compositional studies showed that, as compared to common cereal grains such as wheat, grain amaranths had higher content of protein (14.5-17.9 %), lysine (4.7-5.82 g/16 g N), and Ca (197.5-389.0 mg/100 g) but had lower content of nicotinic acid (0.68-0.94 mg/100 g). The net protein ratio (NPR) of grain amaranths (3.82) was significantly higher than that of wheat (2.68) and supplimation with amaranth protein (amaranth:wheat = 3:6) significantly enhanced the NPR of wheat protein. According to Misra *et al*. (1985), *Amaranthus hypochondriacus* seeds contain protein ranging from 8.86 to 16.45 %. Aspartic acid, glutamic acid, methionine and lysine contents ranged 5.5-11.7, 11.9-17.2, 0.6-1.7 and 3.8-5.6 %, respectively. Burd and Kislichenko (2006) found that the aerial parts of *Amaranthus hypochondriacus* and *Amaranthus paniculatus* contain not less than 15 amino acids, including valine, leucine, isoleucine, threonine, methionine, lysine, phenylalanine, histidine, and arginine.

Sanchez-Marroquin *et al*. (1985) used slected *Amaranthus cruentus* ecotypes from different places of origin to prepare baking products. They found that wheat-amaranth mixtures can be used to improve the diet of the population's marginal sectors. Enriched cookies and French bread with net protein retention values of 3.63 and 4.35, respectively, slightly higher than casein (3.0 and 4.0), are especially recommended for this purpose. Bejosano and Corke (1998) evaluated the quality of *Amaranthus* protein in whole meal and as concentrates from five different genotypes. The studied genotypes were: K112, K350, K459 and R104 (all *Amaranthus cruentus* with yellowish-brown seed coat), and No 3 (*Amaranthus hybridus*) with a black seed coat. In this study they determined amino acid composition and *in vitro* protein digestibility of whole meal and isoelectric protein concentrates (IPC) from the five *Amaranthus* genotypes. Factors most likely to influence protein digestibility such as heating and presence of antinutrients were studied. Heating increased protein digestibility in whole meals but slightly decreased it in ICPs. Trypsin inhibitor level was negatively but weakly correlated to protein digestibility, and the level of polyphenolic compounds was negatively and significantly correlated to protein digestibility. A slight deficiency in leucine was noted for whole meals and in lysine for IPCs. However, based on both *in vitro* digestibility and amino acid profile, *Amaranthus* proteins were confirmed to be of better quality than those of other cereals. The average protein digestibility of the raw *Amaranthus* whole meal flours was 74.2 % (Table 45) (Bejosano and Corke, 1998). This is the same as found by Guzman-Maldondo and Paredes-Lopez (1994) in *Amaranthus hypochondriacus* whole meal using the same *in vitro* protein digestibility procedure. *Amaranthus cruentus* grain protein has been reported among the highest in nutritive quality of vegetable origin and close to those of animal origin products (Bressani *et al*., 1993). Generally, there appeared to be significant variation among the genotypes in amino acid profile of the whole meal or the IPCs (Table 46). The average level of essential amino acids in the samples and the corresponding amino acid scores based on 1984 FAO/WHO suggested patterns of amino acid requirements (Henley and Kuster, 1994) was calculated.There were slight differences between the amino acid profiles of the whole meals and the protein concentrates. Neverthless, the overall amino acid profile of *Amaranthus* protein was extremely favourable (Table 47).

Table 45. Crude protein content (g kg^{-1}), in vitro protein digestibility (%), trypsin inhibitor activity (TIU) (sample basis and protein basis), and polyphenolics (as tannic acid) content (mg g^{-1}) (sample basis and protein basis) of wholemeals and protein concentrates from different *Amaranthus* genotypes.

		Digestibility		Trypsin inhibitor activity		Polyphenolics	
Genotype	Protein	Raw	Heated	Sample	Protein	Sample	Protein
Wholemeal							
K112*	124	73.4	76.1	1.98	16.0	5.2	41.5
K350*	128	76.2	80.3	1.90	13.8	4.6	35.9
K459*	156	73.0	75.5	1.75	11.2	4.6	29.5
R104*	168	74.4	76.3	1.49	8.9	4.5	26.8
No 3**	151	74.0	76.3	0.26	1.7	4.1	27.2
LSD (P<0.05)	10	0.6	0.6	--	--	--	--
Protein concentrate							
K112*	674	78.7	77.7	2.68	4.0	17.7	26.3
K350*	753	81.1	80.3	1.76	2.3	13.5	17.9
K459*	692	81.7	81.0	5.24	7.6	11.6	16.8
R104*	718	82.0	82.0	5.45	7.6	7.2	10.0
No 3**	692	80.7	78.7	1.30	1.9	13.9	20.1
LSD (P<0.05)	16	0.9	1.3	--	--	--	--

* genotypes of *Amaranthus cruentus*
** genotypes of *Amaranthus hypochondriacus*
Bejosano and Corke (1998)

Table 46. Amino acid profile of *Amaranthus* wholemeal (WM) and isoelectric protein concentrates (IPC) expressed in mg g^{-1} protein (tryptophan was not determined)*

Amino acid	K112		K350		K459		R104		No 3	
	WM	IPC	WM	IPC	WM	IPC	WM	IPC	WM	IPC
Aspartic acid	81	91	85	90	82	85	83	84	87	90
Threonine	37	41	38	40	36	39	37	39	36	42
Serine	54	51	59	51	58	49	54	49	72	53
Glutamic acid	177	163	191	166	179	165	179	164	185	161
Glycine	73	49	77	49	74	48	72	48	86	50
Alanine	38	42	39	41	37	39	37	39	37	43
Cysteine	18	12	19	12	20	13	19	12	19	10
Valine	43	45	43	44	41	42	43	40	43	44
Methionine	22	19	21	17	21	18	20	18	21	18
Isoleucine	38	41	39	42	36	39	37	38	39	41
Leucine	57	70	59	69	56	64	56	63	58	71
Tyrosine	36	37	32	37	36	37	33	37	35	37
Phenylalanine	45	50	50	52	45	47	46	48	47	49
Lysine	58	53	59	50	58	51	57	50	56	51
Histidine	26	29	27	29	25	30	26	30	26	29
Arginine	92	94	96	97	94	98	92	99	95	96
Proline	39	44	41	47	37	40	38	43	39	44

*Bejosano and Corke (1998)

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Table 47. Essential amino acid content of protein (Content) in *Amaranthus* wholemeal flours and protein concentrates and their uncorrected amino acid score (Score), compared with standard FAO/WHO 2-5 year old reference pattern (Standard).*

Amino acid	Standard[a]	Wholemeal flour		Protein concentrates	
		Content[a]	Score	Content[a]	Score
Threonine	34	37	1.09	40	1.18
Methionine + cysteine	25	40	1.60	30	1.20
Valine	35	43	1.23	43	1.23
Isoleucine	28	38	1.36	40	1.05
Leucine	66	57	0.86	67	1.02
Phenylalanine + tyrosine	63	81	1.29	86	1.36
Lysine	58	58	1.00	51	0.88
Histidine	19	26	1.37	29	1.53
Tryptophan[b]	11	(10)[b]	(0.91)	--	--

[a]In mg g-1 protein; amino acid content of sample divided by the reference pattern equals the uncorrected amino acid score (Henley and Kuster 1994); b: (Becker *et al*., 1981)
* Bejosano and Corke (1998)

This attribute and its fairly good digestibility show that *Amaranthus* is indeed a source of high quality proteins (Bejosano and Corke, 1998). Digestibility and protein quality of raw and heat-processed defatted and nondefatted flours prepared with *Amaranthus cruentus* were studied (Garcia *et al.*, 1987).

The examination of ultrastructure of protein bodies in embryonic cells of *Amaranthus cruentus* seeds, by transmission electron microscopy, revealed that the seed protein bodies are morphologically similar to the globulin type of legumes, quinoa (*Chenopodium quinoa* Willd) and buckwheat (*Fagopyrum esculentum* Moench) (Konishi *et al*., 1995).

Naidu *et al*. (1982) investigated the relationship of leaf nitrate reductase (NR) and proteinase activities to the grain protein level and grain yield in 4 species of the grain amaranth (*Amaranthus caudatus, Amaranthus cruentus, Amaranthus edulis* and *Amaranthus hypochondriacus*) A strikingly positive correlation between the leaf proteinase activity and the grain protein content was found. *Amaranthus edulis*, with higher grain protein level, possessed high leaf proteinase activity, whereas *Amaranthus hypochondriacus*, with relatively lower grain protein content has lower leaf proteinase levels. Although there was no definite correlation between the leaf proteinase levels and the grain yield, the integrated leaf NR activity was positively correlated with the grain yield (Naidu *et al*., 1982). An α-amylase inhibitor (which belongs to a group of small proteins called "knottins") (Chagolla *et al*., 1995; Lu *et al*., 1999a) was isolated from *Amaranthus hypochondriacus* seeds.

The contents of nitrate, nitrite and vitamin C in leaves of 6 edible wild vegetables of Amaranthaceae were determined. The results indicated that *Celosia argentea* L. and *Amaranthus spinosus* L. had good quality because of medium content of nitrate and nitrite, and richer content of VC; and *Amaranthus paniculatus* L. was edible after cooking because of higher content of nitrate, higher content of VC and lower content of nitrite. Because the contents of nitrate in the leaves of *Alternanthera philoxeroides* (Mart.) Griseb., *Amaranthus tricolor* L. and *Amaranthus viridis* L. exceeded the limited standard, they must be cooked and the amount must be restricted (Qiu and Zeng, 2004).

"Table 48. Genetic variation in textural properties of *Amaranthus* species and reference starch pastes 24 hrs and 7 days at 4°C*

Species	Growth Location	No. of Genotypes	After 24 hr		After 7 days		Change from 24 hr to 7 days	
			Hardness	adhesiveness	Hardness	adhesiveness	Hardness	adhesiveness
1. *Amaranthus cruentus*	Beijing	14	118±97	1.2±1.8	224±190	1.4±2.1	90	11
	Wuhan	34	172±135	1.5±2.0	284±247	1.4±2.5	65	-7
2. *Amaranthus dubius*	Wuhan	3	136±97	3.0±5.2	257±201	1.0±1.7	89	-67
3. *Amaranthus hybridus*	Beijing	8	139±64	11.8±10.5	149±73	9.71±6.1	7	-17
	Wuhan	6	129±65	9.8±13.4	159±71	9.0±6.6	23	-8
4. *Amaranthus hypochondriacus*	Wuhan	6	55±95	7.8±10.9	67±119	2.3±2.3	23	-68
5. *Amaranthus pumilus*	Beijing	3	114±112	1.7±2.9	198±181	1.3±0.6	73	-20
6. *Amaranthus retroflexus*	Wuhan	3	289±36	3.3±0.6	375±178	2.0±3.5	30	-39
7. *Amaranthus spinosus*	Wuhan	4	240±55	7.5±10.6	531±162	7.5±6.4	121	0
8. *Amaranthus tricolor*	Wuhan	8	194±86	7.8±8.8	327±201	3.5±4.4	69	-55
9. *Amaranthus viridis*	Wuhan	3	70±11	7.0±8.5	63±13	4.0±2.8	-10	-43
10. Cultivated species		31	58±62	3.8±4.2	84±106	3.7±4.5	45	-2
11. Non-cultivated species		93	152±113	6.4±9.6	237±207	3.1±4.5	56	-52
12. Total		124	134±120	6.3±9.6	200±198	3.6±5.1	49	-44
13. Maize starch			560	36	764	0	36	-100
14. Rice starch			88	13	174	16	98	23
15. Wheat starch			481	40	447	21	7	-48

*Values + standard deviation (Wu and Corke, 1999).

Table 49 – Genetic variation in thermal properties of *Amaranthus* species and reference starches*

Species	Growth Location	No. of Genotypes	T_r (°C)	T_p (°C)	T_c (°C)	H(J/g)Δ	T_r (T_c-T_o)
1. *Amaranthus cruentus*	Beijing	14	68.8±2.5	77.8±1.8	89.1±1.3	13.1±2.7	20.3
	Wuhan	34	62.3±2.0	78.0±1.7	89.6±1.8	13.3±1.8	27.3
2. *Amaranthus dubius*	Wuhan	3	72.4±1.1	82.0±1.0	91.4±1.2	8.4±1.7	19.1
3. *Amaranthus hybridus*	Beijing	8	66.8±2.8	75.3±3.2	86.8±3.0	8.7±1.5	20.0
	Wuhan	6	68.0±2.7	78.8±2.6	89.1±1.3	10.8±2.3	21.1
4. *Amaranthus hypochondriacus*	Wuhan	6	66.1±2.0	73.9±2.0	88.8±1.0	14.5±1.0	22.6
5. *Amaranthus pumilus*	Beijing	3	69.6±0.7	76.1±0.5	86.5±1.5	7.3±0.8	17.0
6. *Amaranthus retroflexus*	Wuhan	3	68.9±2.0	78.1±1.4	89.2±1.1	11.2±0.6	20.4
7. *Amaranthus spinosus*	Wuhan	4	67.6±1.3	79.6±0.7	90.6±2.6	8.6±3.3	23.0
8. *Amaranthus tricolor*	Wuhan	8	73.0±2.5	82.0±1.3	91.5±1.2	10.0±2.3	18.5
9. *Amaranthus viridis*	Wuhan	3	71.9±0.7	80.2±0.9	87.9±3.3	6.7±1.4	16.0
10. Cultivated species		31	67.0±6.7	75.6±7.2	86.7±8.3	13.4±2.3	19.7
11. Non-cultivated species		93	68.8±2.7	77.9±2.8	89.2±2.1	11.5±2.9	20.4
12. Total		123	68.2±4.1	77.2±4.3	88.5±4.4	12.0±2.9	20.3
13. Maize starch			62.8	71.9	82.8	11.1	20.0
14. Rice starch			61.4	78.7	88.6	11.8	27.2
15. Wheat starch			56.6	63.9	75.1	9.2	18.5

[a]T_o= onset temperature; T_p= peak temperature; T_c= completion temperature; D*H* = energy of enthalpy (J/g). Values + standard deviation. *T*r = gelatinization temperature range (T_c-T_o).

* Wu and corke (1999)

Carbohydrates

Sucrose was the major sugar of *Amaranthus cruentus* seeds followed by raffinose. Inositol, stachyose and maltose were also found in small amounts (Becker *et al*, 1981).

The starch content of *Amaranthus hybridus* seeds was 7.9% of which amylose reprented 19.8% (Table 18). The thermal and texture properties of *Amaranthus hybridus* starch and other species are shown in Tables 48 and 49 (Wu and Corke, 1999). According to Baragano de Mosqueda and Ortega, 1990), no significant differences were found in seeds starch composition of cultivars K-112 (*Amaranthus cruentus* x *cruentus*), 1011 (*Amaranthus cruentus*) and 1024 (*Amaranthus hypochondriacus*). The highest amylose content was found in K-112, 27.24%, as compared with 12.47 and 12.61% in 1024 and 1011 respectively. The starch isolated from seeds of *Amaranthus cruentus*, *Amaranthus hypochondriacus*, and a hybrid of Mexican and African varieties of *Amaranthus cruentus*, had a protein content 0.90 to 0.93%. The fat content was higher in *Amaranthus cruentus* starch (2.63%). The amylose content varied from 12.47 to 12.61%, but the hybrid seed starch contained 27.34% amylose (Perez and Emaldi, 1998). Characterization of the starch from seeds of *Amaranthus cruentus* (55.41%) has been reported (Babor *et al*., 1994).

The physicochemical characteristics of *Amaranthus cruentus* extrudate have been studied. Whole *Amaranthus cruentus* seeds have been extruded under conditions of low (110°C), medium (150°C), and high (190°C) temperatures and humidity of 12, 14, 16 and 18%. Water absorption index has increased with the increase of extrusion temperature. Increased extrusion temperature and samples humidity increased water soluble index (Bodroza-Solarov *et al.*, 2006). Rheological properties of starches from *Amaranthus cruentus* and *Amaranthus hypochondriacus* (Baragano de Mosqueda and Ortega, 1990; Kong *et al*., 2010). Glutinous and non-glutinous starches were detected in seeds of *Amaranthus hypochondriacus* (Okuno and Sakaguchi, 1981). The characteristics of starch isolated from it have been extensively studied (e.g. Lorenz and Collins, 1981; Konishi *et al*, 1985b; Perez *et al*, 1993a,b; Bello-Pérez *et al*., 1996; Perez and Emaldi, 1998). Amylose content of *Amaranthus cruentus*, measured enzymatically was 7.8% (Qian and Kuhn, 1999). Sugimoto *et al.* (1981) reported that amylose content of *Amaranthus hypochondriachus* was about 14% and 0% of normal and waxy starches respectively. The mean amylose content of *Amaranthus hypochondriacus* starch was low (7.8%) as compared with 34.3% for *Amaranthus retroflexus* (Wu and Corke, 1999). The starch content of *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus mantegazzianus* was 58.6-63.4% (Bertoni *et al*., 1984b). The granules of starch isolated from seeds of *Amaranthus cruentus* and *Amaranthus hypochondriacus* were very similar in size. They were angular and polygonal in shape. Compared with corn starch, the amaranth starches had a higher swelling power, a lower solubility, a greater water-binding capacity, a lower susceptibility to α-amylase, a higher amylography viscosity, and much lower amylose content. The amaranth starches produced very poor quality breads and cakes (Stone and Lorenz, 1984). The physicochemical properties of starches from 3 cultivars (Mexican, African and A200D) of *Amaranthus cruentus* grains were studied by Hoover *et al*. (1998). The yield of starch was in the range of 29-38.3 % on a whole grain basis. The starch granules were polygonal with smooth surfaces. The granule size was in the range of 0.75-1.5 μm for all 3 cultivars. The free, bound, and total starch lipids ranged at 0.05-0.07%, at 0.16-0.28 and 0.20-0.35 % respectively. The total amylose content ranged at 3.9-5.7% of which 10.3-15.8% were complexed by native lipid. All 3 starches exhibited identical pasting temperatures. They differed with respect to the highest viscosity reached during the heating cycle, viscosity at 95^{o}C, the extent of breakdown in viscosity (during the holding cycle at 95^{o}C) and setback (Hoover *et al*., 1998). *Amaranthus cruentus* grain starch has thermal properties, apparent viscosity, and intrinsic viscosity similar to that of waxy cron starch (Uriyapongson and

Rayas-Duarte, 1994).

The proximate analyses, and the physico-chemical properties of wheat and *Amaranthus hypochondriacus* flours and starches are presented in Tables 41 and 50. The flour of amaranth was considerably higher in ash- and fat content and slightly higher in protein compared with wheat flour. The two wheat and amaranth starches had similar protein contents. The amaranth starch contained considerably more fat than wheat starch (Lorenz and Collins, 1981). Amylose content of the starch from *Amaranthus hypochondriacus* is considerably smaller than that of wheat starch, which greatly influences the physico-chemical properties of starch (Lorenz and Collins, 1981). The exsistence of both normal and waxy starch types in the same species of a grain amaranth, *Amaranthus hypochondriachus* was confirmed by Tomita *et al*. (1981). The characterization of starch granules from waxy, nonwaxy and hybrid seeds was studied by Konishi *et al*. (1985b). Perisperm starch granules of *Amaranthus hypochondriachus* were prepared from 2 homozygous lines (*WxWx* and *WxWx*) and a hybrid (*WxWx*) obtained by natural hybridization. The amylose content of *WxWx* starch was 16.9, that of *Wxwx* was 10.7, and *WxWx* was zero (Konishi *et al*., 1985b). Native and modified starches (by crosslinking with phosphate), isolated from *Amararanthus hypochondriacus* and *Amaranthus cruentus*, did not differ in crude protein or fat content and overall purity and contained about 90% amylopectin and 10% amylose.

Table 50. Physicochemical properties of starch from wheat and *Amaranthus hypochondriacus*

		Starch	
		Wheat	*Amaranthus hypochondriacus*
Amylose content (%)		22.2	7.2
Amylograph viscosities (B.U.)	at peak	350	320
	at 92°C	270	260
after 30 min	at 92°C	340	260
on cooling	to 35°C	510	280
after 60 min	at 35°C	810	320
Swelling Power			
Amylograph viscosities (B.U.)	at 60°C	4.77	1.02
	at 70°C	6.13	1.51
	at 80°C	8.28	3.44
	at 90°C	11.80	3.53
Solubility (%)			
Amylograph viscosities (B.U.)	at 60°C	1.67	9.12
	at 70°C	2.35	14.21
	at 80°C	2.48	32.76
	at 90°C	8.21	37.43
Water binding capacity (%)		71.8	127.3
Gelatinization temperature range (°C)			
initial		52	62
midpoint		55	64
final		56	68

* Lorenz and Collins (1981)

Molecular characterization of amylopectin isolated from *Amaranthus hypochondriachus* has been studied by Bello-Peréz *et al*. (1996). Marcone (2001) investigated the properties of starch isolated from sea-beach amaranth (*Amaranthus pumilus*, a threatened plant species) and compared it to that of commonly cultivated/commercially produced *Amaranthus hypochondriacus* K343 (Plainsam). Seeds of both investigated species were found to possess comparable quantities/levels of total starch. Although no significant differences ($P \geq 0.05$) were found between the composition of the two starches with regard to their moisture, ash, protein and fat contents, the starch of *Amaranthus pumilus* was found to contain significantly higher ($P \geq 0.05$) amounts of amylose than that of *Amaranthus hypochandriacus* (Marcone, 2001).

The starch, reducing sugars and pentosan contents, as well as the starch characteristics from the seeds of *Amaranthus paniculatus*, and some other species are shown in Tables 51 and 52 (Singhal and Kulkarni, 1988). The yield of starch from *Amaranthus paniculatus* was 61.2% of the whole grain (Wankhede *et al*., 1989). Also, Singhal and Kulkarni (1990c) reported that the seed of *Amaranthus paniculatus* contains 50-60% of waxy starch concentrated in the endosperm. The characterization of modified starch from the same species was reported (Singh *et al*., 2008a).

Table 51. Starch, reducing sugars and pentosan contents of the seeds of some *Amaranthus* species (g kg^{-1})*

Sample	Starch content	Reducing sugars	Pentosan content
Amaranthus paniculatus	507.1+26.0	4.2+0.4	33.9+2.2
Amaranthus polygamous	312.8+81.3	5.0+0.6	35.6+1.2
Amaranthus gracilis	288.2+56.7	2.9+0.6	33.6+3.8
Amaranthus spinosus	285.7+45.2	9.03+0.2	18.7+2.9
Amaranthus tenuifolious	133.0+20.9	2.47+0.1	Not done

* Singhal and Kulkarni (1988)

Table 52. Starch characteristics from the seeds of some *Amaranthus* species*

Sample[a]	Size μm	Amylose g kg^{-1}
Amaranthus paniculatus	1.5-2.5	0
Amaranthus polygamous	1.1-1.9	111.7+9.4
Amaranthus gracilis	1.1-2.1	97.1+10.4
Amaranthus spinosus	1.2-1.5	166.6+5.5
Amaranthus tenuifolious	0.8-2.3	245.0+25.0

[a]All samples were concentric and circular in shape.

* Singhal and Kulkarni (1988)

The starch isolated from rajgeera (*Amaranthus paniculatus*) had circular granules of 3.2 μm size, was waxy (100 % amylopectin), and a higher gelatinization temperature and was more sensitive to disruption during heating, than corn starch (Modi and Kulkarni, 1975). Ahmed *et al*. (1997) evaluated the effects of starch content and type on oil absorption of fried noodle-like formulations. The study involved corn, *Chenopodium quinoa*, and *Amaranthus paniculatus* starches blended with commercial soya flour. The results obtained revealed that amaranth starch gave the lowest oil content in deep-fat fried snacks and could be used in the

development of low-fat fried formulations (Ahmed *et al*., 1997)

Suitabilty of *Amaranthus paniculatus* starch to substitute conventional thickness (e.g. maize starch) in textiles printing of indigosol (solubilized Vat) was reported (Teli *et al*., 1996). Also, the potential value of *Amaranthus hypochondriachus* starch as a major component of corrugated-board glues was reported (Wolkowski *et al*., 1997).

Pectic substances were isolated and characterized from the aerial parts of purple amaranth (*Amaranthus cruentus*). Galacturonic acid, galactose, rhamnose, xylose, arabinose, fructose, and glucose were the constituents of the pectic fraction (Sosnina *et al*., 1996).

The analysis of the seeds of *Amaranthus hybridus* and other seven species, revealed that the seeds did not contain (1→3) and (1→4) glucans and were low in trypsin-inhibitor activity (Budin *et al*., 1996).

Lectins

A lectin (ACL) was purified from the seeds of *Amaranthus cruentus*. The lectin was a dimer with an estimated molecular weight of 66,000 and a subunit molecular weight of 35,000. ACL-mediated agglutination was inhibited by D-GalNac and fetuin. ACL contained 2.2% neutral carbohydrate and relatively high levels of aspartic acid, glutamic acid, serine, and glycine. The purified lectin was relatively heat labile, (Koeppe and Rupnow, 1988). A *N*-acetyl-α-D-galactosamine-specific lectin from the seeds of *Amaranthus paniculatus* was isolated and found to be a homo dimer and a glycoprotein (10.5% carbohydrates) with molecular weight of a subunit of 27,000. Its amino acid composition revealed high content of valine, leucine, and acidic amino acid residues. This lectin also had high contents of methionine, tryptophan, and lysine. *Amaranthus paniculatus* lectin agglutinated normal and papain-treated rabbit and human A, B, and O erythrocytes (Sawhney and Bhide, 1992). A lectin (AHML) with no carbohydrate moiety was isolated from seeds of *Amaranthus hypochondriacus* var. *mexico*. AHML was specific for *N*-acetyl-D-glucosamine as were the other *Amaranthus* lectins. AMHL has a native molecular weight of 45.0 k Da and was composed of identical subunits with a molecular weight of 3.6 kDa (Ozeki *et al*., 1996).

Lipids

The lipid content of the seeds of *Amaranthus hybridus* amounted to 10.99 % and their fatty acid composition is shown in Tables 19 and 53 (Opute, 1979). The fatty acids of *Amaranthus hybridus* seeds, growing in Congo are: $C_{16:0}$, 16.51; $C_{18:1}$, 2.61; $C_{18:1}$, 28.55; $C_{18:2}$, 37.47; $C_{18:3}$, 0.65; $C_{20:0}$,0.5; $C_{20:5}$, 0.28; and $C_{22:6}\omega_3$, 11.76% (Kimbonguila *et al*., 2010). Batra *et al*. (1986) reported that the seeds contained about 0.66 % phospholipids; the major constituents of which were phosphatidylethanolamine, phosphatidylcholine and phosphatidylinositol. Other components present in small amounts were sphingomyelin and lysolecithin. Sarg *et al*. (1993) reported the presence of 22 fatty acids in *Amaranthus chlorostachys*, growing in Egypt; of which the following eighteen acids were identified: butyric (0.37), caproic ($C_{6:0}$, 0.39), caprylic ($C_{8:0}$, 1.83), isocapric ($C_{8:0iso}$, 1.74), capric ($C_{10:0}$, 0.84), hendecanoic (0.17), lauric ($C_{12:0}$, 0.61), lauroleic ($C_{12:1}$, 0.9), myristic ($C_{14:0}$, 3.14), myristoleic ($C_{14:1}$, 5.7), pentadecanoic ($C_{16:1}$, 3.5), stearic ($C_{18.0}$, 1.57), oleic ($C_{18:1}$, 5.51), linoleic ($C_{18:2}$, 11.37), and linolenic ($C_{18:3}$, 6.3%) acids. The study of the acid composition of the seed oil of *Amaranthus cruentus* revealed that 67% of the total acids are C_{18}-polyunsaturated linoleic and linolenic (Karaseva *et al*., 2000). Docosenoic acid ($C_{22:1}$) was present in *Amaranthus cruentus* at the level of 9% (Yanez *et al*., 1994).

Table 53. Fatty acid composition of the lipid classes of *Amaranthus hybridus**.

Lipid classes	Lipids weight %	% Fatty acids						
		14:0	16:0	18:0	18:1	18:2	18:3	20:1
Triglycerides	81.0	0.2	18.4	4.5	24.9	49.4	1.0	1.3
Steryl esters	5.4	t	14.2	3.6	21.0	60.1	0.6	t
Monogalactosyldiglyceride	1.3	0.2	19.9	2.9	23.7	53.0	T	1.1
Digalactosyldiglyceride	0.5	t	17.0	2.6	23.7	52.2	4.3	-
U_1	3.7	1.2	16.9	2.3	22.6	53.0	1.2	1.4
U_2	0.9	t	18.7	2.1	29.0	49.8	T	-
Phosphatidylcholine	1.8	t	21.2	1.4	25.4	51.8	T	t
Phosphatidylethanolamine	1.2	t	21.0	1.7	26.5	50.3	T	-
Phosphatidylinositol	0.6	t	16.2	1.8	29.8	51.7	0.3	t

t = trace amount, less than 0.1%: U_1 and U_2-unknown glycolipids, suspected to be cerebrosides.
* Opute (1979)

Sanchez-Marroquin *et al*. (1980) found 3.1-6.3% oil content of *Amaranthus hypochondriacus*, whereas Lorenz and Hwang (1985) reported a range from 4.9-8.1%. The fatty acids of *Amaranthus cruentus*, as compared to winged bean (*Psophocarpus tetragonolobus*) seed are shown in Table 54 (Fernando and Bean, 1985). Seeds of *Amaranthus cruentus*, *Amaranthus hybridus*, and *Amaranthus hypochondriacus* contained 6-9% oil. Major fatty acids were linoleic 39-55, oleic 18-34, palmitic 18-20, and stearic 3-4%. Dark-coloured seeds contained more linoleic acid, whereas lighter seeds were rich in oleic acid (Stanescu and Tamas, 1991). The oil and squalene contents in seeds and leaves, as well as the composition of fatty acids in grains of *Amaranthus cruentus*, *Amaranthus hybridus* and *Amaranthus hypochondriachus* are shown in Tables 22-24 (He and Corke, 2003). Oil content of five varieties of *Amaranthus cruentus* planted in 3 localities, in Guatemala, varied from 5.83 to 7.13%, palmitic acid from 17.06 to 21.35%, stearic acid from 3.05 to 3.80% oleic acid from 20.26 to 32.01% and linolenic acid from 33.52 to 43.88% (Berganza *et al*., 2003). The fatty acid composition of amaranth oil from *Amaranthus hypochondriacus* (4 accession) and *Amaranthus cruentus* were similar. The major fatty acids were linoleic (39.4-49.1%), oleic (22.8-31.5%), and palmitic (21.4-23.8%) acids. Other fatty acid detected were $C_{14:0}$, $C_{16:1}$, $C_{18:0}$, $C_{18:3}$, $C_{20:0}$, and $C_{22:0}$, $C_{20:1}$ was detected only in 3 accessions of *Amaranthus hypochondriacus* (Jahaniaval *et al*., 2000).

There are other reports on the squalene (one of the dominant components of the seed oils), as well as the composition of fatty acids of *Amaranthus cruentus* (Lyon and Becker, 1987) and *Amaranthus hypochondriacus* (Korenskaya *et al*., 2011).

The oil yield from *Amaranthus hybridus* has been found to vary over a wide range depending on conditions and place of cultivation (Semenishin *et al*., 2010). The following four fatty acid esters were isolated from the roots of *Amaranthus hybridus*: 8'-hydroxynonadecanyl-n-decanoate, *n*-docos-11-enoic acid, *n*-pentacosonyl-*n*-octadec-9-enoate, and *n*-tricosanyl-*n*-octadec-9,12-dienoate (Singh *et al*., 2011a).

The fatty acids in whole amaranth flour from *Amaranthus hypochondriacus* in comparison with wheat, corn, oats, barley and soybean, were reported by Dodok *et al*. (1997). From the composition of fatty acids (Table 55), there is an evidently higher content of

Table 54. Fatty acid composition of weedy and vegetable species of some *Amaranthus* species and winged bean seeds*

Fatty acids	*Amaranthus. tricolor*[a] (78S-113)	*Amaranthus retroflexus*[a] (78S-73)	*Amaranthus hybridus*[a] (81S-394)	*Amaranthus tricolor*[b] (79W-294)	*Amaranthus. dubius*[b] (78S-223)	*Amaranthus cruentus*[b] (78S-40)	Winged bean[c]	
Myristic acid	14:0	0.05 (1)[d]	0.10 (1)	0.09 (1)	0.07 (1)	0.10 (1)	0.09 (1)	-- --
Palmitic acid	16:0	7.01 (18)	9.43 (21)	9.01 (21)	10.01 (23)	11.01 (25)	8.91 (20)	0.64 (9)
Stearic acid	18:0	1.13 (4)	2.00 (3)	1.23 (2)	1.71 (4)	1.63 (3)	1.73 (4)	0.43 (6)
Oleic acid	18:1	9.62 (25)	8.98 (20)	9.72 (23)	8.93 (21)	9.53 (21)	9.66 (22)	2.52 (26)
Linoleic acid	18:2	20.01 (51)	23.43 (51)	21.01 (50)	20.91 (48)	21.01 (47)	21.45 (50)	1.81 (26)
Linolenic acid	18:3	0.36 (1)	0.48 (1)	0.30 (1)	0.29 (1)	0.38 (1)	0.41 (1)	0.51 (7)
Arachidic acid	20:0	0.26 (1)	0.31 (1)	0.30 (1)	0.38 (1)	0.29 (1)	0.31 (1)	0.12 (2)
Behenic acid	22:0	-- --	-- --	-- --	-- --	-- --	-- --	0.96 (13)
Lignoceric acid	24:0	0.20 (1)	0.21 (1)	0.26 (1)	0.27 (1)	0.21 (1)	0.31 (1)	0.06 (1)
Total mg fatty acid		38.91	44.94	41.92	42.47	44.16	42.87	7.05
Ratio (sat/unsat)		0.29	0.37	0.35	0.41	0.43	0.36	0.45

[a]Weedy amaranths; [b]vegetable amaranths,[c]Bean, *et al*. (1984), [d]Quantities expressed as mg/g dry weight and (%) of total fatty acid.
* Fernando and Bean (1985)

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linolenic acid present to the amount of 50.08%. The saturated acid comprised 20.9% and the unsaturated acids 77.1%. The ratio of unsaturated to saturated fatty acids is 3.7 (Dodok *et al*., 1997). The seeds of *Amaranthus hypochondriachus* contained ~ 7% oil consisting mainly of palmitic, 19.7; stearic, 2.93; oleic, 17.75; linoleic, 54; and linolenic acids, 1.15% (Lepojevic *et al*., 2000). The study of the fatty acid composition of *Amaranthus hypochondriachus* whole flour revealed the presence of myristic, palmitic, stearic, oleic, linoleic and linolenic acids; linolenic acid is the main component (50.1%) (Dodok *et al*., 1994).

Badami and Patil (1976) reported that *Amaranthus paniculatus* seeds contain myristic, 0.6; palmitic, 18.7; stearic, 5.2; arachidic, 1.9; behenic, 2.6; oleic 30.7; and linoleic, 38.7%. Later, Mahmood *et al*. (1992) stated that *Amaranthus paniculatus* (syn. *Amaranthus caudatus*) seed oil contains palmitic, 19.4; stearic, 3.9; oleic, 21,9; linoleic, 43.9; vernolic, 7.8; malvalic, 1.5, and steruclic, 1.6% acids. Acyl lipids and their constituent fatty acids were studied in leaves, chloroplasts, and bundle-sheath strands of *Amaranthus paniculatus*, grown under normal and 4% oxygen-containing atmosphere (Knacker and Schaub, 1984). In all fractions, the major lipids were monogalactosyldiacylglycerol, digalactosyldiacylglycerol, sulphoquinosyldiacylglycerol, and phosphatidylglycerol. Significant quantities of phosphatidylcholine and phosphatidylethanolamine were restricted to leaves and bundle-sheath strands. All lipids, except phosphatidylglycerol, where 3-*trans*-hexadecenoic acid was also present, contained palmitic, stearic, oleic, linoleic and linolenic acids. There were no significant differences in the degrees of saturation-unsaturation of total acyl lipids for the plants grown in the low oxygen and normal atmospheres, although under 4% oxygen the phosphatidylglycerol contained an increased proportion of 3-*trans*-hexadecenoic acid at the expense of palmitic acid.

Leon-Camacho *et al*. (2001) reported that the composition of hydrocarbons of *Amaranthus cruentus* is remarkable, mostly the high content of squalene (4.16 g/kg of seed) as well as concentration of *n*-alkenes ($C_{23:1}$ - $C_{33:1}$) that reaches 332 ppm, while the concentration of *n*-alkanes (C_{23} - C_{33}) is only 155 ppm. The high concentration of β-tocopherol (546 ppm) and the profile fatty acids show that amaranth oil is not protected against rapid oxidation, while most of the sterols are esterified.

Grain amaranth has been suggested as an alternative to marine animals as a natural source of squalene. Oil contents, squalene contents, and fatty acid profiles were determined in 11 genotypes of four grain amaranth species. Although the oil contents of grain amaranth were low (from 5.1% in *Amaranthus tricolor* to 7.7% in *Amaranthus cruentus*) as compared to other oil-containing grains, high concentrations of squalene were found in total lipids, ranging from 3.6% in *Amaranthus hypochondriacus* to 6.1% in *Amaranthus tricolor*. The major fatty acids in *Amaranthus* oil consisted of palmitic acid (19.1-23.4%), oleic acid (18.7-38.9%), and linoleic acid (36.7-55.9%). A high degree of unsaturation was observed in *Amaranthus* oils, with saturated/ unsaturated ratios of 0.26-0.32 (He *et al*., 2002).

α-Spinasterol, α-spinasterol glucoside, β-sitosterol glucoside, lupeol, lupeol acetate, long chain ester and long chain ketonic ester were identified from *Amaranthus chlorostachys*, growing in Egypt (Sarg *et al*., 1993). Endo *et al*. (1995) reported that the major sterol of the seeds from varieties of *Amaranthus caudatus, Amaranthus cruentus* and *Amaranthus hypochondriacus* was sitosterol. *Amaranthus cruentus* has been reported as an important and alternative source of squalene (Sala *et al*., 1998). Although the seeds of *Amaranthus cruentus* contain chondrillasterol (5α-stigmasta-7,22-dien-3β-ol) and its 3-*O*-glucopyranoside (Junkuszew *et al*., 1998). β-Sitosterol is the major sterol of the seeds of *Amaranthus hypochondriachus* (Endo *et al*., 1995). Other sterols identified in *Amaranthus cruentus, Amaranthus hybridus* and *Amaranthus hypochondriachus* are shown in Tables 1, 2, 34 and 56 (Fernando and Bean, 1985; Xu *et al*., 1986; Patterson *et al*., 1991).

Table 55. Fatty acid composition of *Amaranthus hypochondriacus* whole flour, wheat, rye, barley, oats, rice, corm and soybean*

Fatty acids	Content of fatty acids (%)								
	A. hyp[1]	*A. hyp*[1]	Wheat[2]	Rye[2]	Barley[2]	Oats[2]	Rice[2]	Soybean[2]	Corn[2]
Myristic	--	Tr.-3.1	--	--	--	--	--	--	--
Palmetic	20.0	10.9-31.1	14-17	2-6	9	10	13-16	8.5	7.5
Stearic	0.9	0.08-3.7	1-3	3-8	3	2	1-2	4.5	3.0
Oleic	26.8	20.9-43.2	20-45	18-35	33	59	42-52	30.0	47.5
Linoleic	50.1	24.7-55.0	20-45	18-35	33	59	42-52	30.0	47.5
Linolenic	0.20	Tr.-0.5	2-3	1-2	Tr	--	Tr	--	--

Total saturated fatty acids: 20.9% , Total monoenic fatty acids: 26.8% , Total dienic fatty acids : 50.1% , Total trienic fatty acids: 0.2°%, Essential fatty acids: 50.3% , Unsaturated : saturated ratio: 3.7 ,

1- Data according to Prakash *et al.* (1995), 2- Data according to Davidek *et al*. (1983).

* Dodok *et al.* (1997)

Table 56. Sterol composition of weedy and vegetable species of amaranths and winged bean seeds

Sterols	Varieties						
	Amaranthus tricolor[a] (78S-113)	*Amaranthus retroflexus*[a] (78S-73)	*Amaranthus hybridus*[a] (81S-394)	*Amaranthus tricolor*[b] (79W-294)	*Amaranthus dubius*[b] (78S-223)	*Amaranthus cruentus*[b] (78S-40)	Winged bean
Stigmasterol	0.03 (11)[c]	0.03 (10)	0.02 (11)	0.03 (13)	0.03 (12)	0.03 (11)	0.07 (22)
Δ^{-7} Ergosterol	0.05 (14)	0.05 (15)	0.02 (12)	0.04 (14)	0.05 (15)	0.04 (14)	-- --
Spinasterol	0.19 (52)	0.18 (54)	0.12 (53)	0.14 (46)	0.13 (48)	0.17 (50)	-- --
Δ^{-7} Stigmasterol	0.05 (16)	0.05 (16)	0.03 (16)	0.05 (16)	0.04 (18)	0.05 (15)	-- --
24-Methylenecycloartenol	0.02 (7)	0.01 (5)	0.01 (8)	0.03 (11)	0.02 (7)	0.03 (10)	-- --
Campesterol	-- --	-- --	-- --	-- --	-- --	-- --	0.02 (9)
Sitosterol	-- --	-- --	-- --	-- --	-- --	-- --	0.21 (69)
Total sterol (mg/g dry) wt.	0.36	0.35	0.22	0.30	0.28	0.34	0.31

[a]Weedy amaranths; [b]vegetable amaranths, [c]Quantities expressed as mg/g dry weight and (%) of total sterol.

* Fernando and Bean (1985)

Flavonoids and Other Phenolic Compounds

Kawashty *et al*. (1999) reported that *Amaranthus hybridus*, growing in Egypt contains the following flavonoids: quercetin 3-glucoside-7-rhamnoside, 3-hydroxyflavone-7,4'-diglucoside, daidzein 7-galactoside and traces of isorhamnetin 3-rutinoside. *Amaranthus hybridus* has phenolic compound concentration of 1.127 ± 0.133 mgGA/100 mg (Chitindingu *et al*., 2007). The flavonoids identified by Steffensen *et al*. (2011a) in the aerial parts of *Amaranthus hybridus* are rutin (the most abundant one), isoquercetin and nicotiflorin.

The contents of hydroxybenzoic acids (protocatechuic acid, 4-hydroxybenzoic acid, vanillic acid) and hydroxycinnamic acids (caffeic acid, *p*-coumaric acid and ferulic acid) and their variation in aerial parts of young, Field-grown *Amaranthus hybridus* and *Amaranthus mantegazziauns* were reported (Steffensen *et al*., 2011a). The flavonoid rutin exhibited large variations with varying environmental conditions whereas the flavonoid, nicotiflorin, was affected less. The variations between location / environmental condition were primarily described by the variations in the content of *p*-coumaric acid and protocatechuic acid in the seed samples (Steffensen *et al*., 2011b).

Amaranthus chlorostachys has been found to contain quercetin and rutin (Sarg *et al*., 1993). Three flavonoids: 6,8-di-*C*-methyl quercetin 3-methylether, eucalyptin and gnaphaliin were isolated from the leaves and stems of *Amaranthus paniculatus* (Bratoeff *et al*., 1997).

Aerial parts, foliage and infloresences of *Amaranthus cruentus* contained 0.35, 0.43 and 0.58 air-dried weight % rutin (Khaziev *et al*., 1992). According to Cao *et al*. (2010), *Amaranthus cruentus* contains kaempferol 38.7 mg Kg^{-1} (fresh wight).

The quantitative content of total phenolic compounds in *Amaranthus cruentus*, and a method to isolate and purify them was developed in order to evaluate the prospects of using the plant for practical preparation of phenolic compounds (Karaseva *et al*., 2001). Kalinova and Dadakova (2009) investigated the rutin and total quercetin content in the individual plant parts of *Amaranthus* spp., at the beginning of the growth, the flowering stage and at the maturity stage of five *Amaranthus* species. The rutin content in amaranth ranged from 0.08 (in seeds) to 24.5 g/kg dry matter (in leaves). Comparison of the determined total quercetin content and the calculated content of quercetin released from rutin did not prove important presence of quercetin or other quercetin derivatives than rutin. Only amaranth leaves sampled at the maturity stage probably contained quercetin or quercetin derivatives. Significant differences in the rutin content was established among species as well varieties. *Amaranthus hybridus* and *Amaranthus cruentus* were the best sources of rutin (Kalinova and Dadakova, 2009). *Amaranthus caudatus, Amaranthus hypochondriachus, Amaranthus paniculatus* and hybridus K-432, cultivated in Slovakia, contained flavonoids of the quercetin type mainly in the leaves. The content of flavonoids in dry leaves ranged 0.29-0.75 %. The content of flavonoids varied with the time of herb sample collection, with maximum content found in the bud formation and bloom periods. *Amaranthus paniculatus* had the highest content of flavonoids (Tekelova and Marlianova, 2002). Barba de la Rosa *et al*. (2009) reported that the flour of *Amaranthus hypochondriacus* contains polyphenols as rutin (4.0-10.2) and nicotiflorin (7.2-4.8 μg^{-1}).

Leaves of different cultivars of *Amaranthus hypochondriachus* and *Amaranthus tricolor* have different colours, including red, purple, and green. Cultivars with red or purple leaves have more anthocyanin in leaves. The contents of chlorphylls a and b in leaves of different cultivars do not differe significantly (Yang and Lee, 1986).

Two coumarins, umbelliferone and scopoletin and one chromone derivative, piliostigmin were isolated from the leaves and stems of *Amaranthus paniculatus* (Bratoeff *et al*., 1997).

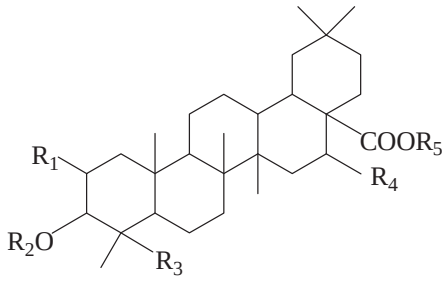
Hydroxycinnamic acid esters, e.g. (*E*)-caffeoylisocitric acid (major), and *p*-coumaroyl- and feruloyl-isocitric acids (minor) were isolated from the cotyledons of *Amaranthus*

cruentus (Strack *et al*., 1987). Thirteen and fifteen phenolic acids were identified from the fruits and herbs of *Amaranthus paniculatus*, respectively (Table 21) (Sokolowska-Wozniack, 1996). Ferulic and *p*-coumaric acids were identified as the main phenolic acids in *Amaranthus hypochondriacus* dry stems. The two acids have been reported as germination inhibitors of *Amaranthus hybridus* (Tejeda-Sartorius *et al*., 2004).

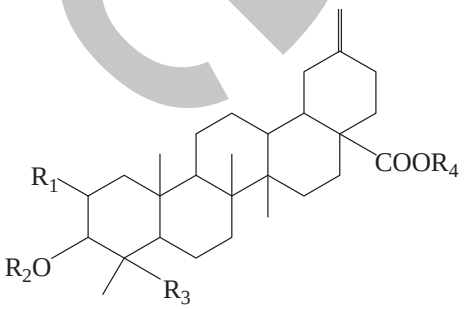
Saponins

Amaranthus chlorostachys has been reported to contain two triterpenoidal saponin glycosides (Sarg *et al*., 1993). The percentage of saponin in *Amaranthus chlorostachys*, growing in Egypt, amounted to 2.19 % (Ateya, 1992). The following four saponins have been identified from the seeds of *Amaranthus cruentus*: 3β-*O*-[α-L-rhamnopyranosyl(1→3)-β-glucuronopyranosyl]-2β,3β-dihydroxyolean-12-en-28-oic acid 28-*O*-[β-D-glucopyranosyl] ester, 3β-*O*-[α-L-rhamnopyranosyl(1→3)-β-glucurono-pyranosyl]-2β,3β,23-trihdroxy-olean-12-2-en-28-oic acid 28-*O*[β-D-glucopyranosyl] ester, 3β-*O*-[α-rhamno-pyranosyl(1→3)-β-glucuronopyranosyl]-2β,3β-dihdroxy-23-oxoolean-12-en-28-oic acid 28-*O*-[β-D-glucopyranosyl] ester, and 3β-*O*-[β-*O*-[β-glucuronopyranosyl]-2β,3β-dihydoxy-30-norolean-12,20(29)-diene-23,28-dioic acid 28-*O*-[β-D-glucopyranosyl] ester and two others (Junkuszew *et al*., 1998). The total concentrations of four triterpenoid saponins in seeds of *Amaranthus cruentus* was 0.09-0.1 % of dry matter. In germinating seeds an increase in concentration to 0.18 % was observed after 4 days of germination, which remained stable for the next 3 days and later dropped to 0.09 %. The hydrophobic fraction obtained by the extraction of seeds with methylene chloride showed no toxicity. It was concluded that low contents of saponins in amaranth seeds and their relatively low toxicity guarantee that amaranth-derived products create no significant hazard for the consumer (Oleszek *et al*., 1999). Oleanolic acid was separated from the sapogenins present in the leaves. The sugar moiety was identified as rhamnose (Escudero *et al*., 1998).

The following four triterpenoid saponins were isolated from *Amaranthus hypochondriachus*: 3-*O*-α-L-rhamnopyranosyl (1→3)-β-D-glucuronopyranosyl-2β,3β-dihydroxyolean-12-en-28-oic acid 28-*O*-β-D-glucopyranosyl ester (**80**), 3-*O*-α-L-rhamnopyranosyl(1→3)-β-D-glucuronopyranosyl-2β,3β-dihydroxyolean-12-en-23-al-28-oic acid 28-*O*-β-D-glucopyranosyl ester (**81**), 3-*O*-α-L-rhamnopyranosyl(1→3)-β-D-glucurono-pyranosyl-2β,3β-dihydroxy-30-norolean-12,20(29)-dien-28-oic acid 28-*O*-β-D-gluco-pyranosyl ester (**82**), and 3-*O*-α-L-rhamnopyranosyl(1→3)-β-D-glucuronopyranosyl-2β,3β-dihydroxy-30-norolean-12,20(29)-dien-23-al-28-oic acid 28-*O*-β-D-glucopyranosyl ester (**83**) (Kohda *et al*., 1991).



	R_1	R_2	R_3	R_4	R_5
80	OH	$glcUA_{\underline{3}}$- rha	CH_3	H	glc
81	OH	$glcUA_{\underline{3}}$- rha	CHO	H	glc



	R_1	R_2	R_3	R_4
82	OH	- $glcUA_{\underline{3}}$- rha	CH_3	- glc
83	OH	-$glcUA_{\underline{3}}$- rha	CHO	- glc

PDF

Other Constituents

Glycinebetaine and trigonelline were identified in *Amaranthus hypochondriacus* (Table 35) (Blunden *et al*., 1999). Two betacyanins, amaranthin and isoamaranthin were isolated from leaves and petioles of *Amaranthus cruentus* (Zakharova *et al*., 1995). The typical pigment of the tinted amaranth is amaranthine (5-*O*-[2-*O*-(β-D-glucopyranosyluronic acid)-β-D-glucopyranoside]) of the betanidine (Piattelli and Minale, 1966; Mabry and Dreiding, 1968). *Amaranthus hypochondriachus* has amaranthine distributed all over the plant (Scoles *et al*., 2000). Choline and betaine were isolated from *Amaranthus paniculatus* (Borkowski *et al*., 1966). *Amaranthus chlorostachys* contains choline and a basic nitrogenous substance, m.p. 271-272^{o}c (Sarg *et al*., 1993).

The uptake and accumulation of Cd, Pb and Zn in vegetables (*Amaranthus hybridus* L.) grown in the valley bottom soils of some cities in southwestern Nigeria were investigated. The concentration of heavy metals in vegetable leaves ranged from 0.4 to 2.0 for Pb (CV, 33), 0.38 to 1.20 for Cd (CV, 25) and 8.2 to 30.4 for Zn (CV, 33). In the vegetable stems, the concentration ranged from 0.8 to 2.6 for Pb (CV = 33), 0.6 to 2.5 for Cd (CV, 22) and 11.4 to 18.9 for Zn (CV, 35). Concentration of metals in vegetable roots ranged from 2.2 to 5.1 for Pb (CV, 33), 1.4 to 4.9 for Cd (CV, 22) and 10.2 to 29.0 for Zn (CV, 35). Transfer factors (TF) were in the range of 0.22 and 3.00, with Cd having the highest TF of 3.00. Estimated intake vegetables in μg day^{-1} ranged from 72 to 82 for Cd, 69 to 120 for Pb and 105 to 200 for Zn. The intakes were above the recommended minimum risks levels. Potential risks, particularly for Cd and Pb intake, exceed the daily requirement for consumers of the leafy vegetable at all the sites (Oluwatosin *et al*., 2010). Several studies showed that *Amaranthus cruentus* (Li *et al*., 2011), *Amaranthus hybridus* (Egila *et al*., 2010, 2011; Zhang *et al*., 2010a,b) and *Amaranthus hypochondriacus* (Li *et al*., 2010b) are favourable for sorbtion and removal of metals (e.g. Cd, Co, Pb) and have potential phytoremediation capability. Bioremediation of crude oil polluted soil with *Amaranthus hybridus* has been also reported (Salami and Elum, 2010).

Reprint