Proximate Composition, Proteins and Amino Acids

The composition of *Amaranthus* seeds have been studied extensively since the 1970s (e.g. Becker *et al*., 1981; Saunders and Becker, 1984; Singhal and Kulkarni, 1988; Becker 1989; Bressani *et al*., 1992) (Table 13), and many attempts have been made to use amaranth grain in food (Betschart *et al*., 1981; Mendoza and Bressani, 1987; Breene, 1991; Bressani *et al*., 1992; Myers and Fox, 1994; Singhal and Kulkarni, 1990a,b, 1991). The chemical constituents of the seeds of the pseudo-cereal *Amaranthus* were reported by Correa *et al*. (1986a) as follows: (% dry matter): 14.4-16.9 protein (N x 6.25), 4.8-6.8 fat, 2.5-3.9 ash and 2.3-2.9 crude fiber. According to De Arellano *et al*. (1996) the raw seeds of *Amaranthus standleyanus* (a wild herbaceous plant) contained a crude fiber content of 110 g kg^{-1}, an amount much higher than those found in other *Amaranthus* species. The range of its protein content is large (13.5-22.5%) with an average of 15%. About 35% of the total protein is in the endosperm; the remaining 65% is distributed in the germ and seed coat (Matz, 1991; Wu and Corke, 1999). According to Becker (1989), proximate composition of *Amaranthus* seeds (dry basis) was 7.6% lipid, 15.5% protein, 64.5% starch, 3.2% ash, 0.06% tannins and 17.7% total dietary fiber. Pattacini *et al*. (2000) reported the chemical composition of the green part of *Amaranthus greggii* and *Amaranthus mantegazzianus* as follows: ash 26.80, 25.14; protein 28.28, 28.44; fiber 13.25, 12.14; lipids 2.18, 3.59; and carbohydrates 20.66, 20.56% respectively. *Amaranthus inamoenus* contained the largest amount of ash among 14 vegetables studied by Iwai *et al*. (1986), and the largest amounts of elements (Ca, Mg, Fe, Co, W, P, Mn, Zn, Sb, Si, Cu, Pb, Cr , and Be). Also, the leaves of *Amaranthus quitensis* contained high levels of Ca (274.3), Fe (6.4), and Mg (136.2 mg/100 g) (Rozycki *et al*., 1997). Gajewska *et al*. (2002) determined the contents of proteins, fats, carbohydrates, water, ash, energy, B vitamins (B_1, B_2, PP, B_6) and minerals (Ca, P, Mg, Fe, Na, K, Cu, Mn, Zn, Co, Ni, Cr, Cd, Pb) in amaranth seeds, flour and expanded (popped) seeds. The mean % contents of protein, fat, carbohydrates, water and ash in the 3 amaranth products examined were 13.5-14.4, 7.1-7.6, 63.8-71.7, 3.0-12.3, 3.1-3.4, respectively; the dietary energy content was 373-412 kcal/100g. The vitamins content (mg/100 g) were: 0.019-0.029 thiamin, 0.100-0.143 riboflavin, 1.02-1.20 niacin, and 0.563-0.615 pyridoxin. The levels of minerals (mg/100 g) were: 204-223 Ca, 712-792 P, 8.3-9.7 Fe, 200-235 Mg, 2.9-3.1 Zn, 1.03-1.38 Cu, 3.78-4.54

Table 13. Proximate analysis of the seeds of some *Amaranthus* species (g kg^{-1})*

Species	*Amaranthus gracilis*[b]	*Amaranthus paniculatus*[b]	*Amaranthus polygamous*[b]	*Amaranthus spinosus*[c]	*Amaranthus tenuifolious*[c]
Moisture	99.5±18.3	84.5±16.5	96.3±7.9	56.94±0.41	70.0±4.4
Ash	31.3±1.1	24.7±2.2	35.5±3.2	31.0±1.8	40.0±0.9
Protein[a]	155.4±6.2	142.8±6.1	188.0±13.8	111.1±0.08	232.7±8.4
Fat	61.4±0.3	68.6±7.2	52.4±0.2	59.8±1.7	193.6±3.5
Crude fiber	79.1±1.2	49.3±13.3	104.4±27.6	128.6±1.7	121.6±3.3
Carbohydrates (by difference)	652.4±25.9	679.4±32.0	627.8±25.1	612.6±5.2	341.5±16.8

a: N x5.85; b: Results are mean + SD of three samples, each determined in triplicate;
c: Results are mean + SD of one sample, determined in triplicate.
* Singhal and Kulkarni (1988)

Mn, 6.30-8.42 Na, 318-337 K, 0.040-0.055 Cr, 0.185-0.292 Ni, and 0.045-0.051 Cr. The mean contents of Cd and lead were 5-9 and 27-35 μ/100 g, respectively. Zelenkov and Ofitserov (2003) reported the following compositions of *Amaranthus* plant leaves (used for production of biologically active additives to food, food products, drinks with prophylactic properties) in native and dried form: water, 0.5-90; carbohydrates, 0.5-5, protein, 1.2-28; fats, 0.2-2.2; food fibers 0.3-38; pectin, 0.2-10; and ash residue, 0.2-30 %. The ash is characterized by high content of biogenic macroelements: Ca, K, Mg; and microelements: Si, Mn and Fe. The nutritional quality of vegetable and seed from five different accessions of *Amaranthus* in South Africa, has been studied by Mnkeni *et al*., (2007). There were significant differences in crude protein cotent between the vegetables from the different accessions. The crude fat and protein content of the seeds as well as the mineral concentration in the vegetables and seeds of five amaranth accessions are shown in Tables 14-17. *Amaranthus* obtained by cryogenic process contained 13.2% protein, 63.5% carbohydrates, 6.7% fat, 3.3% mineral elements, 17.7 mg % vitamin C, 0.29 mg % vitamin B_1 and 0.12 mg % vitamin B_2 (Simakhina *et al*., 1995). Rural children in India who were given amaranth at 30 g/day (supplying 100 μg β-carotene/day) lost their vitamin A deficiency symptoms, indicating adequate utilization of β-carotene (Srikantia, 1978). High content of ascorbic acid and carotenoids in amaranth was also reported by Gins *et al*. (2000). Tocopherol (vitamin E) content of *Amaranthus* species was 2.6 mg/100 g (Engel and de Vries, 1946).

Bejosano and Corke (1998) reported that the overall amino acid profile of *Amaranthus* species was extremely favourable. This attribute and its fairly good digestibity showed that *Amaranthus* was indeed a source of high quality proteins. The content of lysine in the dried *Amaranthus* leaves was in excess of that in the FAO/WHO (1973) reference. Dried *Amaranthus* leaves were also rich in all the other essential amino acids, and can be used for supplementing cereal-based diets that are limiting in lysine (Maeda, 1985).

Martinez *et al*. (1997) reported that the major protein fractions of amaranth seeds according to Osborne classification were globulin and glutelin. Even though there is no agreement, most of research papers state that the albumin is shown to be present in the largest amount, followed by glutelins, with globulins appearing in the third place (Segura- Nieto *et al*., 1994). Since seed storage proteins are found in the largest amounts (Fukuyima, 1991), it is striking that the albumin fraction, which usually accounts for the biologically proteins, is found in that highest amount in amaranth seeds, although albumins have been also described as reserve proteins in some plants (Higgins, 1984; Martinez *et al*., 1997). In amaranth, however, two types of albumin have been described (Konishi *et al*., 1991): albumin 1, removed with water and/or saline solutions; and albumin 2, extracted with water after the flour has been treated with saline solutions to remove albumin 1 and globulins. Because albumin 2 resists treatment with pronase, which digests albumin 1, it has been suggested that

Table 14. Vitamin C, protein and nitrate concentrations in the vegetable of five *Amaranthus* accessions (on dry mass basis)*

Amaranthus accession	Vitamin C mg$100g^{-1}$	Protein g $100g^{-1}$	Nitrate mg $100g^{-1}$
AMA 5	630.9	29.82	1413
V2	618.9	29.94	1474
AMA 18	522.5	25.79	790.5
AMA 17	496.5	31.21	790.9
VOP	569.7	28.56	729.3

* Mnkeni *et al*. (2007)

Table 15. Fat and protein contents of the seeds of five amaranth accessions*

Accession	Crude Fat %	Protein %
AMA 18	3.95	14.61
V2	4.82	14.66
VOP	Nd*	14.97
AMA 5	4.65	12.96
AMA 17	3.35	14.11
LSD (0.05)	0.18	0.64

*Nd: not determined. Values in the same column followed by the same letter are not significantly different ($p > 0.05$)
* Mnkeni *et al.* (2007)

Table 16. Mineral concentrations in the vegetable of five *Amaranthus* accessions (on dry mass basis).*

Accession	Mineral content (mg $100g^{-1}$)							
	P	Mg	Ca	Mn	Fe	Zn	Na	K
AMA 18	413.7	32.95	1287	8.30	12.23	4.21	32.11	4455
V2	396.0	39.56	1286	8.24	13.26	4.69	42.71	4801
VOP	426.0	36.63	1417	10.31	14.62	3.99	39.51	4521
AMA 5	409.7	41.26	1756	6.64	12.83	4.64	39.38	4669
AMA 17	457.3	42.52	1851	9.18	14.55	5.03	175.9	4892
LSD (0.05)	47.31	3.96	267	2.20	2.35	0.63	7.04	249.9

Values in the same column followed by the same letter are not significantly different ($p > 0.05$)
* Mnkeni *et al*. (2007)

Table 17. Mineral content of the seeds of five *Amaranthus* accessions.*

Accession	Mineral content (mg $100g^{-1}$)							
	P	Mg	Ca	Mn	Fe	Zn	Na	K
AMA 18	388.7	8.39	306.8	7.58	7.54	2.66	19.58	601.3
V2	395.7	9.42	278.8	10.78	6.80	2.70	15.98	546.4
VOP	389.7	6.19	160.2	6.90	7.29	3.76	14.21	500.6
AMA 5	381.3	9.59	272.4	7.8	6.75	3.15	22.43	520.5
AMA 17	345.3	8.55	370.1	23.37	6.51	4.86	29.45	470.7
LSD (0.05)	11.97	0.38	29.53	2.67	0.58	0.70	4.66	29.49

Values in the same column followed by the same letter are not significantly different ($p > 0.05$)
* Mnkeni *et al*. (2007)

the albumin 2 fraction is located in more protected sites, perhaps associated with protein bodies, which would account for its role as a storage protein. Because of its unique solubility characteristics, the reported differences of the main fractions (Segura-Nieto *et al*., 1994) could result from the sequence in which the solvent had been used; therefore, the albumin 2 fraction would appear as included in either the globulin or the glutelin fraction (Konishi *et al*., 1992).

Albumins 1 and 2 have been investigated by several researchers (Mora-Escobedo *et al*.,

1990, Segura-Nieto *et al*., 1992; Marcone *et al*., 1994a; Martinez *et al*., 1997). On the other hand, the globulin fraction has been thoroughly studied (Segura-Nieto *et al*., 1994) and a major globulin of the 11S type, amarantin (Konishi *et al*., 1985a, Marcone and Yada, 1991,1992; Barba de la Rosa *et al*., 1992; Romero-Zapeda and Paredes-López, 1996) has been described, together with a minor fraction of the 7S leguminous type (Barba de la Rosa *et al*., 1992; Segura-Nieto *et al*., 1992). The major globulin, with a dodecameric quaternary structure-similar to that ascribed to soy 11S globulin (Marcone *et al*., 1994b) was made up, similarly to those globulins, by acid subunits (A) of molecular masses in the range of 30-40 k Da and basic subunits (B) of about 20 kDa (Segura-Nieto *et al*., 1994). Furthermore, other monomeric peptides, which were not included in this category because of their higher or lower molecular weights, have been reported (Segura-Nieto *et al*., 1994).

Alcohol soluble proteins from *Amaranthus* seeds differed from prolamin fractions of cereals and plants (Gorinstein, 1993). Zheleznov *et al*. (1997) reported a 13-21% variation in seed protein content in wild and cultivated forms of amaranth. They also stated that seed proteins of amaranth were highly nutritive and composed presumably of easily digestible albumins and globuilins (over 50% of total protein), of 20.8% alkali-soluble proteins-glutelins with similar nutritive value; and of 12% alcohol-soluble protein-prolamins, which were lacking in essential amino acids. Amino acid analysis demonstrated that albumins are good source of lysine but are deficient in leucine and threonine. Lysine content was lower in globulins, but globulins were richer in leucine. Most essential amino acids of both proteins were acceptable compared to the FAO/WHO/UNU reference pattern (Mora-Escobedo *et al*., 1990). Cheeke *et al*. (1980) reported that the amino acid content of *Amaranthus* leaf protein was comparable to that of soyabean meal.The purification and characterization of antiviral protein (AAP29) from the leaves of *Amaranthus magostanus* was described by Cho *et al*. (1995).

According to Lawanson *et al*. (1991), the highest amounts of total free sugars and vitamin C occurred in the different organs (leaves, stem, or shoots) of the mature leafy vegetable *Amaranthus dubius* at latter stages. Maximum levels of inorganic phosphate were observed at early stages of maturity of the plant in both leaves and stems.

Though the vegetative parts of amaranth (pigweed) are high in protein, Ca, K, Fe and vitamin C (indicating a high food potential), yet they also contain appreciable amounts of nitrate and oxalate. However, the nitrate and soluble oxalte were removed by extraction into cooking water (Hill and Rawate, 1982). Soluble and total oxalate (as % oxalic acid on moisture-free basis) in samples of *Amaranthus mitchellii* are 4.6 and 7.2 (Mathams and Sutherland, 1952). High oxalic acid content was found in *Amaranthus mantegazzianus* (Bertoni *et al*., 1984). Two other accessions (AMA5 and V2) had high nitrate levels (Table 14) and therefore their consumption should be limited so as not to exceed the recommended limit of nitrate. WHO and United Nations currently recommend an ADI of nitrate of 0 to 0.07 mg nitrate ion per kg body weight. High levels of nitrate intake can be a problem for individuals suffering from anaemia because of their lower baseline oxygen carrying capacity and therefore making them more susceptible to methaemoglobinaemia (blue baby syndrome) (Aletor and Adeoguin, 1995; Mnkeni *et al*., 2007). The administration of green amaranth with a high nitrate content to sheep resulted in methaemoglobinaemia and high rumen levels of nitrate and nitrite (Nakamura *et al*., 1972).

Carbohydrates

Lorenz and Gross (1984) studied the sugar composition of 8 grain samples of amaranth species and interspecies hybrids. Sucrose was the main sugar in 70% ethanol extracts of amaranth. The extracts also contained raffinose, glucose and fructose. *Amaranthus* starch has

been studied and some interesting findings have been reported, e.g. a wide range of viscosity, resistance to shear thinning, stable paste properties, and small starch granule size (e.g. Kazutoshi and Sakaguchi, 1981; Stone and Lorenz, 1984; Yanez *et al*., 1986; Paredes-López *et* al., 1988,1994; Paredes-López and Hernandez-López, 1991; Bahnassey and Breene, 1994; Myers and Fox, 1994, Zhao and Whistler, 1994; Bhattacharyya *et al*., 1995; Sudhakar *et al*., 1996). A wide range of variation was found in the various properties tested both among *Amaranthus* species and among genotypes of the same species (Corke *et al*., 1997; Wu and Corke, 1999). Physical and functional properties of starches from 93 non-cultivated genotypes of nine *Amaranthus* species from a wild germ plasma collection and an additional 31 cultivated *Amaranthus* genotypes were tested by Wu and Corke (1999). When comparing starches from cultivated and non-cultivated genotypes, it was generally found that amylose was lower; starch pasting profiles were more consistent with higher peak viscosity, lower breakdown and lower setback; the gelatinization temperature was lower and energy of enthalpy was higher. Under cool storage, the hardness of cultivated starch pastes was lower and the adhesiveness was higher. Amylose content was a primary factor affecting the physical and functional properties of *Amaranthus* starch. The average amylose content of all genotypes tested was 19.2% with means of 10.7 and 23.2% for cultivated and non-cultivated species, respectively (Table 18). Singhal and Kulkarni (1988) reported that *Amaranthus polygamus* had low amylose starch (111.7 g/kg) and *Amaranthus tenuifolius* had appreciable proportions of amylose (166.7 g/kg).

The study of physicochemical and functional properties of starches isolated from fifteen grain amaranth cultivars (*Amaranthus* spp.) produced in China, revealed that starches had low but diverse amylose contents, ranging from 4.7% to 12.5%. Wide variation was also found in physicochemical properties, such as swelling power, water solubility index, pasting, thermal and textural properties. Amylose content was significantly correlated with functional properties, including pasting, thermal and textural properties and appeared to be the important determinant for these properties. Correlations among pasting, thermal and textural parameters were also significant. Principal component analysis using 17 variables extracted four principal components that explained 88% of the total variance. The first component represented amylose content, pasting and gel textural properties and explained 59% of the total variance, while the second component represented the thermal properties and accounted for an additional 14.5% of the total variance (Kong *et al*., 2009).

Many *Amaranthus* starches were reported to be good thickners and stabilizers in food processing (Singhal and Kulkarni, 1991; Corke *et al*., 1997; Bello-Pérez *et al*., 1998; Wu and Corke, 1999). The monosaccharides, oligosaccharides and starch of amaranth have been reviewed by Lopez *et al*. (1994).

Lectins

Lectins were identified from *Amaranthus* species (e.g. Singh *et al*., 1993; Ozeki *et al*., 1996; Transue *et al*, 1997). *Amaranthus* is reported among the lectin-rich genera (Arora *et al*., 1987; Pelia and Sandhu, 1990). A lectin of molecular weight ~ 45,000 per subunit was isolated from *Amaranthus leucocarpus* seeds (Zenteno and Ochoa, 1988). It was found to be a glycoprotein (10% carbohydrate) containing six *N*-acetyl-D-glucosamines, four D-galactose, one D-glucose and traces of xylose residues for each D-mannose residues per molecule. Its amino acid composition revealed predominance of acidic residues (aspartic and glutamic acids and of glycine and alanine). In addition, the lectin contains an unusual amount of essential amino acids such as methionine, tryptophan and lysine. In contrast to *Amaranthus caudatus* hemagglutinin, *Amaranthus leucocarpus* lectin is inhibited by serum glycoproteins such as fetuin, it is mitogenic, and is not toxic (Zenteno and Ochoa, 1988). Calderon de la

Table 18. Genetic variation starch content, amylose content and pasting of *Amaranthus* and reference starches*

Species	Growth Location	No. of Geno-types	Starch (%)	Amylose (%)	PV (RVU)	HPV (RVU)	P_{time} (min)	CPV (RVU)	BD. (RVU)	SB (RVU)
1. *Amaranthus cruentus*	Beijing	14	22.0±18.5	19.2±14.2	248±83	173±70	7.7±0.3	210±111	75	38
	Wuhan	34	19.5±15.1	25.0±15.7	288±109	202±80	7.9±0.4	288±125	86	106
2. *Amaranthus dubius*	Wuhan	3	3.4±1.8	24.6±10.5	…	…	…	…	…	…
3. *Amaranthus hybridus*	Beijing	8	7.9±2.2	19.8±4.8	210±78	182±66	8.9±1.2	241±93	27	40
	Wuhan	6	5.3±2.1	22.3±6.6	213±70	174±36	8.6±0.9	244±80	39	117
4. *Amaranthus hypochondriacus*	Wuhan	6	37.6±16.6	7.8±12.7	172±56	127±56	8.3±0.4	151±79	45	49
5. *Amaranthus pumilus*	Beijing	3	5.1±0.4	19.7±6.9	104±20	102±25	9.0±1.4	121±28	2	121
6. *Amaranthus retroflexus*	Wuhan	3	6.1±0.6	34.3±3.5	222±9	223±5	7.9±1.0	289±38	-1	65
7. *Amaranthus spinosus*	Wuhan	4	3.2±1.3	18.1±11.6	207±82	217±86	9.2±0.6	253±109	-10	37
8. *Amaranthus tricolor*	Wuhan	8	4.0±1.0	29.0±9.9	162±104	176±87	9.9±1.1	190±84	-14	14
9. *Amaranthus viridis*	Wuhan	3	2.0±0.3	12.9±8.0	172±0	96±1	10.9±0.3	90±0	76	-6
10. Cultivated species		31	36.4±11.6	10.7±12.4	296±227	151±48	7.9±0.4	185.3±71	144	59
11. Non-cultivated species		93	14.5±15.1	23.2±13.2	229±99	176±72	8.4±1.0	233.3±112	52	57
12. Total		124	20.1±17.3	19.2±13.9	253±155	166±67	8.2±0.9	225.4±155	86	57
13. Maize starch			na	24.3	353	117	7.4	287	236	170
14. Rice starch			na	15.7	296	156	7.4	280	140	124
15. Wheat starch			na	28.1	312	187	8.2	362	125	175

*PV = peak viscosity; HPV = holding viscosity; P time = time to peak viscosity; CPV = cool paste or final or final viscosity. Values + standard deviation. BD = breakdown (PV-HPV); SB = setback (CPV-HP); Rvu = Rapid Visco Analyzer units; na = not available;...= *Amaranthus dubius* not tested for pasting properties (Wu and Corke, 1999)

Barca *et al*. (1985a) found that *Amaranthus leucocarpus* is improved in nutritive value by the extraction of hemagglutinin and has good potential as a complementary food because of its lysine content. The seed meal had a protein efficiency ratio of 2.15 when the lectins had been removed compared to 1.95 for control meal (Calderon de la Barca, 1985b).

Lipids

The lipid content of the grain of four *Amaranthus* species, studied by Opute (1979) ranged from 9.75% for the garden ornamental, *Amaranthus arthropurpureus* to 16.95% for the common weed *Amaranthus spinosus* (Table 19). Fifty-nine per cent of the fatty acids present in *Amaranthus muricatus* were unsaturated with linoleic acid amounting to 40% of the total fatty acid content (Escudero *et al*., 1999a). Free lipids of 8 varied *Amaranthus* varieties, studied by Lorenz and Hwang (1985) ranged from 5.69-7.23% and bound lipids from 0.42-0.91%. Crude fat content of grains of 21 *Amaranthus* accessions (eight species) ranged from 5.2-7.7% (Budin *et al*., 1996). The crude fat levels of some *Amaranthus* species are shown in Table 20. Study of the fatty acids revealed that the major fatty acids of the seeds were linoleic, oleic, stearic and palmitic acids. The unsaturated acids constituted about 70 % of the total acids. Trace amounts of the following acids were found in some studies: palmitoleic, linolenic, arachidic, and lignoceric (Opute, 1979; Bertoni *et al*, 1984; Fernandoand Bean, 1984, 1985; Lorenz and Hwang, 1985; De Arellano *et al*., 1996; Dailey *et al*., 1997; Dodok *et al*., 1997).

The average oil content in *Amaranthus* grain of 104 genotypes from 30 species was 5.0%, ranging from 1.9 to 8.7%. Squalene concentration in oils ranged from trace to 7.3%, with an average concentration of 4.2%. The average contents of three major fatty acids in *Amaranthus* grain were 22.2, 29.1, and 44.6% for palmitic, oleic, and linoleic, respectively. The average fat content in dried mature leaves of 45 *Amaranthus* genotypes (including *Amaranthus hybridus* and *Amaranthus palmeri*) was 1.63%, ranging from 1.08 to 2.18%. The squalene concnentration in leaf lipid extracts averaged 0.26%, ranging from trace to 0.77%, which is much lower than that from seeds. The major fatty acids of leaf extracts were linolenic, linoleic, and palmitic. Linolenic ranged from 56.5 to 62.0% of total fatty acids; linoleic, from 15.5 to 24.7%; and palmitic acid, from 13.5 to 15.5%. As for the fatty acid compositions at different growth stages, fatty acid content in leaf lipid was lower in mature leaves than in young leaves. The saturated/unsaturated ratio decreased when the leaf grew to maturity. Principal component analysis (PCA) revealed that the first two components accounted for 70% of the total variance (38.3 and 21.7%, respectively). There was a positive correlation between oil content and squalene yield, and negative correlations were found between linoleic and either of the other two major fatty acids, palmitic and oleic. The taxonomic relationship among the species was also elucidated by PCA (He and Corke, 2003).

Fernando and Bean (1985) studied the sterols of seeds of weedy and vegetable species of *Amaranthus.* The major sterol was spinasterol, which ranged from 46 to 54% of the total sterol mixture. Δ^7-Stigmasterol occurred in the next higher amount, with lesser amounts of ergosterol, stigmasterol and 24-methylenecycloartenol (triterpene). The desmethylsterol content of nineteen species and varieties of Amaranthaceae (*Amaranthus* and *Celosia*) varied from 0.0084 to 0.034% of the total dry weight (Xu *et al*., 1986). In these species spinasterol and 7-stigmasterol were the dominant sterols, although low levels of five unsaturated sterols were detected. Minor sterols identified in $\geq$ 1 species included cholesterol, campesterol, stigmasterol and sitosterol as well as 7,22-stigmastadienol, 7,24(8)-ergostadienol, 7-ergostenol, 7,25-stigmastadienol, and 7,24(8)-stigmastadienol. Stigmastanol and 24-methylenecycloartenol were also present (Xu *et al*., 1986). The study of sterols and

Table 19. Total lipid and fatty acid composition of some *Amaranthus* species*

Species	Total lipids	Fatty acids						
		14:0	16:0	18:0	18:1	18:2	18:3	20:0
1. *Amaranthus arthropurpureus*	9.75	0.3	22.5	2.5	29.1	44.2	0.8	0.6
2. *Amaranthus hybridus*	10.99	0.2	21.1	5.4	21.3	50.4	0.7	0.8
3. *Amaranthus spinosus*	16.95	0.2	19.3	4.3	24.0	48.7	0.5	0.9
4. *Amaranthus tricolor*	9.92	0.3	19.8	4.4	20.2	53.7	0.4	1.1

* Opute (1979)

Table 20. Crude fat levels of some *Amaranthus* species*

Species	Crude fat (%)	Reference
1. *Amaranthus arthropurpureus*	9.8	Opute (1979)
2. *Amaranthus caudatus*	6.7	Garcia *et al*. (1987)
	11.6-12.5	Bressani *et al*. (1987)
	9.6	Bertoni *et al*. (1984a)
3. *Amaranthus cruentus*	7.9	Lehmann (1991)
	7.9	Garcia *et al*. (1987)
	9.2-12.8	Bressani *et al.* (1987)
	7.0-7.8	Lorenz and Hwang (1985)
	7.7-8.0	Becker *et al.* (1981)
	7.9	Ayorinde *et al.* (1988)
4. *Amaranthus edulis*	8.1	Becker *et al.* (1981)
5. *Amaranthus gracilis*	6.1	Singhal and Kulkarni (1988)
6. *Amaranthus hypochondriacus*	7.1	Garcia *et al.* (1987)
	7.7-10.6	Bressani *et al.* (1987)
	7.5-7.8	Lorenz and Hwang (1985)
7. *Amaranthus hybridus*	6.4	Lehmann (1991)
	11.0	Opute, (1979)
	6.5	Lorenz and Hwang (1985)
8. *Amaranthus paniculatus*	6.9	Singhal and Kulkarni (1988)
9. *Amaranthus polygamous*	5.2	Singhal and Kulkarni (1988)
10. *Amaranthus retroflexus*	7.0-8.0	Christensen and Miller (1941); Tkachuk and Mellish (1977); Lehmann (1991)
11. *Amaranthus spinosus*	6.0	Singhal and Kulkarni (1988)
	17.0	Opute, (1979)
12. *Amaranthus tenuifolius*	19.3	Singhal and Kulkarni (1988)
13. *Amaranthus tricolor*	10.0	Opute (1979)

* Lehmann (1991)

in the seeds of *Amaranthus inamoenus* revealed the presence of spinasterol (ca. 80%), three minor sterols, 24ϵ-methyl-5α-cholest-7-en-3β-ol, 24 ϵ -ethyl-5α-cholest-7-en-3-ol and 24 ϵ -ethyl-5α-cholesta-7,24(28)*Z*-dien-3β-ol and castasterone (a brassinosteroid) (Takatsuto *et al*., 1999). The ecdysteroids: amasterol, ecdysterone and pterosterone, and a sesquiterpene lactone, iresin, were isolated from *Amaranthus indica* Mill. (Bratoeff *et al*., 1996).

Flavonoids and other Phenolic Compounds

Flavonoids were determined in 54 *Amaranthus* species, and 2 of them were identified as rutin and quercetin. Rutin was found in all 54 species studied; with highest amounts found in *Amaranthus albus, Amaranthus flavus* and *Amaranthus spinosus* (1.9%) (Bech *et al*., 1977). The isolation and identification of flavonoids from *Amaranthus* species have been reported by other researchers (e.g. Bratoeff *et al*., 1996, 1997; Kawashty *et al*., 1999). Tlatlancuayin (isoflavone) was isolated from *Amaranthus indica*. The following flavonoids were identified from *Amaranthus muricatus* (Moquin) ex Hicken: quercetin, rhamnetin, isorhamnetin, quercetin 3-*O*-galactoside, quercetrin, rutin, jaceine, rhamnetin, isorhamnetin 3-*O*-galactoside, isorhamnetin 3-*O*-rutinoside, robinin, centaurein, patuletin, patuletin 3-*O*-glucoside and patuletin 3-*O*-rutinoside (De Ruiz *et al*., 2001).

Two anthocyanin pigments *viz*. malvidin 3-glucoside and peonidin 3-*O*-glucoside (both acylated with caffeic acid) were identified in the Ganges amaranth (Yoon *et al*., 1978). Colour, spectral characteristics, and stability of betacyanin pigments of 21 genotypes from 7 *Amaranthus* species were evaluated. The characteristics of *Amaranthus* pigments give them considerable potential for development for use in the food industry, particularly for low-temperature uses (Cai *et al*., 1998b). Total betacyanins in these *Amaranthus* species ranged from 46.1-199 mg/100 g of fresh plant material. Cultivated species contained much more betacyanin than the wild species and had much higher biomass, indicating that certain cultivated genotypes had greater potential for commercial use as sources of natural colourant (Cai *et al*., 1998a). L-Tyrosine was reported as a good precursor of betacyanine, amaranthine, in *Amaranthus* var. Molten Fire (Garay and Towers, 1966).

Sokolowska-Woźniak (1996) identified the following 16 phenolic acids in some *Amaranthus* species: ellagic, gallic, chlorogenic, protocatechuic, homoprotocatechuic, caffeic, genistic, *p*-coumaric, ferulic, syringic, vanillic, salicylic, *p*-hydroxybenzoic, *p*-hydroxyphenylacetic, 3,4-dimethoxycinnamic and γ-resorcylic acids (Table 21). Tannin levels in 8 varieties of amaranth (0.043-0.0116 % catechin equivelant) were small in comparison with those of sorghum and millets (Lorenz and Wright, 1984).

Four anthraquinones were isolated from *Amaranthus muricatus viz*. chrysophanol, dantron (1,8-dihydroxyanthraquinone), emodin and rhein (De Ruiz *et al*., 2001).

Other Constituents

Trigonelline (a betaine) was detected in eight of nine species of *Amaranthus* investigated by Blunden *et al*. (1999).