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Yield, Selected Chemical Composition and Nutritive Value of 14 Selections of Amaranth Grain Representing Four Species

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ABSTRACT

A set of 14 selections of four amaranth species were studied. Six yielded over 10 kg 36 m^{-2}*, and three below 5 kg 36 m*$^{-2}$*. Grain size varied from 1·55 to 2·14 mm, and seed weight from 0·46 to 1·18 mg seed*$^{-1}$*. There was no relationship between seed weight and yield. Protein content varied from 12·5 to 16·0%, while fat varied from 7·7 to 12·8%. The content of P, K, Ca, Mg, Na, Fe, Cu, Mn and Zn was similar among all selections. Trace amounts of C14 fatty acids were found, while C16 acids varied from 16·83 to 23·83% of the oil. The C18:0 fatty acids varied from 1·86 to 4·11%, the C18:1 from 20·29 to 35·46%, while the C18:2 fatty acids varied from 38·25 to 57·86%. Lysine varied from 0·73 to 0·84%, with tryptophan values ranging from 0·18 to 0·28%. Seeds from all selections were processed by hot-water soaking for 20 min followed by drum-drying, for protein quality evaluation.*

The three A. caudatus *had an average protein efficiency ratio (PER) of 2·45;* A. hybridus *a PER of 2·34;* A. cruentus *2·36 and* A. hypochondriacus *2·33. Differences were not statistically different. Light and dark coloured seeds had the same average value of 2·36. the study showed important genetic differences in chemical composition.*

Key words: Amaranth, chemical composition, amino acid content, protein quality.

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1 INTRODUCTION

Chemical information on amaranth grain is relatively available;[1–4] however, due to the agronomic potential of this ancient crop[1,5] and to its exceptionally high nutritive value,[6–8] additional information, particularly related to agronomic performance, is useful as a means to strengthen its potential as a food or a feed resource. Becker *et al.*,[2] reported on a compositional study of 10 amaranth grain samples representing single species or crosses between species grown under different agronomic conditions which according to the authors contributed significantly to the variability found. Saunders and Becker[1] recently reviewed the seed chemistry of amaranth and indicated that variations in grain composition grown under diverse conditions are considerable. This variability is evident from various studies which have been reported, particularly germ plasm coming from wide areas,[6] (Bressani *et al.*, unpublished); however, variability is also due, and may be even more important, to genetic make-up, as evidenced in a study of 25 selections of *A. caudatus* grown in one locality (Imeri, A. G. *et al.*, unpublished). With respect to nutritive value as established by biological assays, differences are obtained when the raw grain is fed;[5] however, these differences disappear to a large extent in processed samples[5] (Bressani, R. *et al.*, unpublished; Imeri, A. G. *et al.*, unpublished). The first observation, on raw grain, is probably due to unknown factors or nutrient bioavailability limiting animal growth, while the second is probably due to essential amino acid pattern (Bressani, R. *et al.*, unpublished). In this report, the selected partial composition of 14 amaranth grain selections representing four species is reported. All 14 selections were planted in one locality, thus, the differences in chemical composition should be due exclusively to genetic make-up. The nutritive quality of the protein of processed samples is also reported.

2 EXPERIMENTAL

The amaranth grain selections used in this study were sent to INCAP by Rodale, Kutztown, PA. They were received in late 1982 and planted at the INCAP Experimental Farm facilities in June 1983. The experimental farm is located at an altitude of 1500 m above sea level, with temperature fluctuations varying from 12 to 24°C. Rainfall occurs from May to October and total amounts average 1140 mm. The soils are heavy clays which become water saturated in August–September and begin to dry in late October. Each selection was planted in experimental plots 3×3 m with four replicates each, in a completely randomised block design. The number of plants per 9 m^2 was the same for all replicates and for all selections. During their development, plant height at flowering and at harvest was established. The identification of each selection, its species, grain colour, origin and plant type are presented in Table 1.

At harvest, the influorescences were cut off by hand and thrown into the hopper of a thresher for grain separation and collection was done on a per-replicate basis. The seed size and seed weight per replicate for each selection were measured on 100 seeds. Moisture, protein, ash and ether extract content were determined by AOAC procedures[9] on samples from each replication. Pooled samples from all

TABLE 1
Identification of Samples

INCAP No.	*Rodale No.*	*Seed colour*[a]	*Amaranth species*	*Origin*	*Plant type*
1	A-73	C	*Caudatus*	Cusco, Perú	South American grain
2	A-982	O	*Caudatus*	Apurimac, Perú	South American grain
3	A-1113	C	*Caudatus*	Ayacucho, Perú	South American grain
4	82S-1004	O	*Hybridus*	Pakistan	Prima grain
5	82-1011	O	*Cruentus*	Mexico	Mexican grain
6	82S-434	C	*Cruentus*	Mexico	Mexican grain
7	82S-1034	O	*Cruentus*	Dahomey	African grain
8	A-718	O	*Hypochondriacus*	Oaxaca, Mexico	Aztec grain
9	A-720	O	*Hypochondriacus*	Oaxaca, Mexico	Aztec grain
10	82S-1023	C	*Hypochondriacus*	Mexico	Mercado grain
11	81S-1024	O	*Hypochondriacus*	Mexico	Mercado grain
12	82S-674	O	*Hypochondriacus*	Unknown	Spitee
13	82S-SP130	C	*Hypochondriacus*	Nepal	Nepal grain
14	82S-1008	C	*Hypochondriacus*	India	Nepal grain

[a]Seed colour: C=light; O=dark.

four replications were used for mineral analysis by atomic absorption spectrometry on the ash of samples weighing 1·0 g. Likewise, fatty acid content was determined by gas chromatography on pooled samples from all four replicates per selection. Lysine content was determined by paper chromatography of 6 N HCl hydrolysates[10] and tryptophan by the method of Villegas *et al.*[11].

For the biological assay of protein quality, 2·5 g of grain were soaked in water for 20 min and then passed through a double-drum drier at 2 rev min^{-1} using steam at 4·2 kg cm^{-2} pressure to heat the drums. The resulting product was ground and analysed for protein by the Kjeldahl method.[12] Diets were prepared by using processed amaranth flour to provide 10% protein. It was supplemented with 1% cod liver oil, 5% refined cottonseed oil, and 4% mineral mixture.[12] All diets were adjusted to 100% with refined maize starch and all were supplemented with a complete vitamin mixture at 5 ml 100 g^{-1} added in liquid form.[13]

Each diet was fed *ad libitum* to weanling rats (Wistar strain from INCAP's animal colony, eight rats per group), housed individually in all-wire screen cages with raised screen bottoms. Water was available all the time and feed intake and weight changes were measured every 7 days.

The data were statistically analysed using standard methods as described by Snedecor and Cochran.[14]

3 RESULTS AND DISCUSSION

3.1 Yield and grain size

Information on the development of the plant and the total yield for the four species is presented in Table 2. Days to flower varied from 26 to 92, at plant heights from 22 to 145 cm. *A. hypochondriacus* showed greatest variability in this respect, *A. caudatus* being least variable. Days to harvest, and plant height at harvest varied from 80 to 146 days, and from 75 to 280 cm, respectively. As before, *A. hypochondriacus* showed the largest variability in plant height at harvest. The total yield per selection, expressed as g 36 m^{-2} also indicate large

TABLE 2
Some Agronomic Characteristics of the Amaranth Grain Selections Studied

Selection	*Days to flower*	*Height to flower (cm)*	*Days to harvest*	*Height at harvest (cm)*	*Yield (g 36 m⁻²)*
1. *A. caudatus* (A-713)	61	110	129	240	3,093
2. *A. caudatus* (A-982)	61	100	129	210	12,755
3. *A. caudatus* (A-1113)	61	96	120	230	11,883
6. *A. hybridus* (82S-1004)	26	23	80	75	4,921
7. *A. cruentus* (82S-1011)	33	30	90	160	11,296
8. *A. cruentus* (82S-434)	34	56	90	190	13,206
9. *A. cruentus* (82S-1034)	63	28	95	150	10,960
4. *A. hypochondriacus* (A-718)	92	145	146	280	14,728
5. *A. hypochondriacus* (A-720)	61	140	129	260	9,759
10. *A. hypochondriacus* (82S-1023)	33	25	80	130	9,759
11. *A. hypochondriacus* (82S-1024)	33	25	80	140	8,791
12. *A. hypochondriacus* (82S-674)	26	24	80	90	7,905
13. *A. hypochondriacus* (82S-SP130)	33	27	80	90	9,624
14. *A. hypochondriacus* (82S-1008)	26	22	80	75	4,937

differences between selections. Yield varied from 3·093 to 14·728 g 36 m^{-2}. In this respect, *A. cruentus* showed less variability than the other two species. Statistical analysis of the yield data indicated differences to be highly significant. Plant height at flowering was highly correlated with plant height at harvest (r=0·9013), but plant height at flowering and yield were not related (r=0·3671), while some relationship was found between plant height at harvest and yield (r=0·4659<0·05). The difference between plant height at harvest and plant height at flowering was also not correlated with yield (r=−0·3897). The best yielding cultivar was *A. hypochondriacus* (A-718) with 4091 kg ha^{-1}, suggesting the high yield potential of amaranth.

Table 3 summarises size and weight of the seed of the 14 selections. The differences in both characteristics between cultivars of all species were statistically significant. Seed size varied from 1·55 to 2·14 mm and seed weight varied from 0·46 to 1·18 mg $seed^{-1}$, values which were similar to those reported for *A. caudatus* (Imeri, A. G. *et al.*, unpublished) and other species.[1,5] Seed weight was not correlated with yield as reported before (Imera, A. G. *et al.*, unpublished). Selection of cultivars of all species for higher seed size and weight is recommended, since it will make harvest easier with a cleaner seed. However, higher seed size should not affect yield or protein content.

TABLE 3
Grain Size and Weight

Selection	*Size (mm)*	*Weight (mg seed^{-1})*
1. *A. caudatus* (A-713)	1·55	0·46
2. *A. caudatus* (A-982)	1·71	0·66
3. *A. caudatus* (A-1113)	1·75	0·72
6. *A. hybridus* (82S-1004)	1·93	0·85
7. *A. cruentus* (82S-1011)	1·88	0·82
8. *A. cruentus* (82S-434)	1·92	0·84
9. *A. cruentus* (82S-1034)	2·11	0·52
4. *A. hypochondriacus* (A-718)	1·69	0·68
5. *A. hypochondriacus* (A-720)	1·58	0·53
10. *A. hypochondriacus* (82S-1023)	2·12	1·14
11. *A. hypochondriacus* (82S-1024)	2·14	1·18
12. *A. hypochondriacus* (82S-674)	1·98	0·93
13. *A. hypochondriacus* (82S-SP130)	1·89	0·93
14. *A. hypochondriacus* (82S-1008)	1·95	1·02

3.2 Chemical composition

Table 4 summarises the partial proximate composition of the samples studied. Differences in ether extract, protein and ash between cultivars were statistically significant. With respect to ether extract, *A. caudatus* had, on average, a higher content than *A. cruentus* and both had a higher content than *A. hypochondriacus*. This group, however, had one selection with the lowest lipid content in this study. With respect to protein content the *A. cruentus* selections were slightly higher in this nutrient than the other three species. Fat content was positively correlated with yield ($r=+0{\cdot}2912^*$) while protein content was negatively related to yield ($r=-0{\cdot}4127^*$). This last relationship is common to cereal grains as well as food legumes, and breeding programmes should select or breed materials, which, if

TABLE 4
Moisture, Ether Extract, Protein and Ash Content of 14 Amaranth Grain Selections (%)

Selection	*Moisture*	*Ether extract*	*Protein*	*Ash*
1. *A. caudatus* (A-713)	11·72	12·50	14·77	2·94
2. *A. caudatus* (A-982)	12·12	12·35	12·55	2·65
3. *A. caudatus* (A-1113)	11·62	11·55	12·50	3·02
6. *A. hybridus* (82S-1004)	13·25	8·47	15·60	5·01
7. *A. cruentus* (82S-1011)	11·92	12·85	14·70	2·83
8. *A. cruentus* (82S-434)	12·27	10·90	15·07	3·18
9. *A. cruentus* (82S-1034)	13·32	9·20	16·00	3·36
4. *A. hypochondriacus* (A-718)	12·10	10·45	13·70	3·33
5. *A. hypochondriacus* (A-720)	11·90	10·35	14·75	3·93
10. *A. hypochondriacus* (82S-1023)	12·77	10·60	15·32	2·94
11. *A. hypochondriacus* (82S-1024)	12·85	9·17	14·75	3·91
12. *A. hypochondriacus* (82S-674)	13·55	8·25	15·07	3·42
13. *A. hypochondriacus* (82S-SP130)	12·77	9·17	15·05	3·28
14. *A. hypochondriacus* (82S-1008)	12·42	7·72	15·60	3·99

*Statistically significant at 0·05

yielding more, should not affect protein content. With respect to seed size, this was not associated with protein content ($r=+0{\cdot}2244$); however, seed size and fat content were negatively related ($r=-0{\cdot}4193^*$). Finally, protein and ether extract were negatively related ($r=-0{\cdot}4645^*$). Since both protein and fat content make amaranth attractive from the nutritional point of view, breeding and selection programmes for yield should consider minimum levels of these two nutrients. These could not be less than 15% for protein and not less than 8% for fat.

The fatty acid composition of the 14 cultivars studied are presented in Table 5. The values presented are similar to those published by other authors and reviewers.[1,2,15,16] The variability within species was as high as between species, being more evident for C18:0 and C18:2 than for C16:0 fatty acids. Since all materials were grown in the same locality and under the same agricultural practices, these differences are more of a genetic than of an environmental or agronomic nature. Amaranth's high linoleic acid content is obviously an attractive nutritional characteristic, and together with its high protein and oil content, make it a significant resource in human feeding as has been indicated before.[8,16] Oil digestibility, however, has been reported to be around 92%, which is slightly lower than other edible oils (Garcia, L. A., unpublished). Table 6 summarises the

TABLE 5
Fatty Acid Content of 14 Amaranth Grain Selections (%)

Selection	*C14:0*	*C16:0*	*C18:0*	*C18:1*	*C18:2*	*(C18:3+ C20:0)*
1. *A. caudatus* (A-713)	Tr.	17·18	1·86	25·17	51·57	3·17
2. *A. caudatus* (A-982)	Tr.	20·09	2·60	28·71	46·75	0·95
3. *A. caudatus* (A-1113)	Tr.	18·63	2·53	28·54	47·39	2·01
6. *A. hybridus* (82S-1004)	Tr.	19·01	2·92	22·23	53·29	1·40
7. *A. cruentus* (82S-1011)	Tr.	16·83	2·75	35·46	43·13	1·00
8. *A. cruentus* (82S-434)	0·88	21·58	4·00	34·46	38·25	—
9. *A. cruentus* (82S-1034)	Tr.	21·17	4·11	25·81	48·92	—
4. *A. hypochondriacus* (A-718)	Tr.	17·71	2·25	20·29	57·86	0·43
5. *A. hypochondriacus* (A-720)	Tr.	19·66	2·70	22·35	53·28	1·23
10. *A. hypochondriacus* (82S-1023)	Tr.	21·33	3·11	26·37	48·25	—
11. *A. hypochondriacus* (82S-1024)	Tr.	22·10	2·96	25·10	49·83	—
12. *A. hypochondriacus* (82S-674)	Tr.	21·56	2·91	22·96	52·56	—
13. *A. hypochondriacus* (82S-SP130)	Tr.	22·94	3·07	24·44	49·55	—
14. *A. hypochondriacus* (82S-1008)	Tr.	23·83	3·34	22·94	48·84	—

*Statistically significant at 0·05.

TABLE 6
Mineral Content of 14 Amaranth Grain Selections (mg 100 g^{-1})

Selection	P	K	Ca	Mg	Na	Fe	Cu	Mn	Zn
1. *A. caudatus* (A-713)	518	493	246	396	19	20	0·85	3·39	3·40
2. *A. caudatus* (A-982)	594	532	201	270	22	15	0·87	2·62	3·49
3. *A. caudatus* (A-1113)	597	571	205	290	24	28	0·85	2·56	3·41
6. *A. hybridus* (82S-1004)	565	532	303	344	26	104	4·10	5·18	3·45
7. *A. cruentus* (82S-1011)	589	545	202	334	24	17	1·68	2·51	4·19
8. *A. cruentus* (82S-434)	544	518	263	311	24	34	1·69	3·38	4·22
9. *A. cruentus* (82S-1034)	536	511	260	386	27	27	1·71	4·27	4·27
4. *A. hypochondriacus* (A-718)	625	549	287	372	25	30	1·63	3·28	4·10
5. *A. hypochondriacus* (A-720)	667	556	256	368	26	100	3·51	4·39	4·39
10. *A. hypochondriacus* (82S-1023)	586	570	204	323	24	22	1·70	2·55	4·12
11. *A. hypochondriacus* (82S-1024)	556	590	222	333	24	55	2·56	4·27	3·42
12. *A. hypochondriacus* (82S-674)	589	538	308	359	22	26	1·71	3·42	3·42
13. *A. hypochondriacus* (82S-SP130)	576	516	206	309	22	31	1·72	2·58	3·43
14. *A. hypochondriacus* (82S-1008)	605	621	223	327	22	111	3·98	3·98	3·98

TABLE 7
Lysine and Tryptophan Content of 14 Amaranth Grain Selections

Selection	Lysine		Tryptophan	
	g%	g 16 g^{-1} N	g%	g 16 g^{-1} N
1. *A. caudatus* (A-713)	0·82	5·55	0·19	1·36
2. *A. caudatus* (A-982)	0·74	5·89	0·18	1·44
3. *A. caudatus* (A-1113)	0·80	6·40	0·20	1·70
6. *A. hybridus* (82S-1004)	0·84	5·38	0·20	1·45
7. *A. cruentus* (82S-1011)	0·82	5·58	0·28	1·85
8. *A. cruentus* (82S-434)	0·81	5·37	0·25	1·87
9. *A. cruentus* (82S-1034)	0·79	4·94	0·18	1·10
4. *A. hypochondriacus* (A-718)	0·77	5·62	0·23	1·79
5. *A. hypochondriacus* (A-720)	0·74	5·02	0·18	1·34
10. *A. hypochondriacus* (82S-1023)	0·81	5·29	0·21	1·51
11. *A. hypochondriacus* (82S-1024)	0·79	5·35	0·20	1·41
12. *A. hypochondriacus* (82S-674)	0·79	5·24	0·18	1·19
13. *A. hypochondriacus* (82S-SP130)	0·78	5·18	0·23	1·58
14. *A. hypochondriacus* (82S-1008)	0·73	4·68	0·20	1·37

mineral content of the amaranth cultivars studied. The values fall within values reported by other workers.[1,2] There seems to be little variation between cultivars of the same species and between species.

The lysine and tryptophan content of the samples of amaranth grain under study are shown in Table 7, expressed as weight percentage and on the basis of 100 g of protein. These amino acids were chosen because they are deficient in maize protein,[17] which could benefit from supplementation with amaranth grain. The results show that cultivars with higher protein contain slightly more lysine and tryptophan on a weight basis as has been shown before.[3] However, this relationship is more evident with lysine. The relationship becomes negative when the two amino acids are expressed on a protein basis. Although lysine and tryptophan levels are higher in amaranth than in cereal grain particularly, the amounts are not exceedingly high. Therefore, breeding or selection programmes when breeding for high yield should take lysine content which should not fall below a value of 400 mg g^{-1} N on the basis of an 85% true protein digestibility. This is an important consideration since lysine content in amaranth is one of the positive nutritional attributes of this grain.[1,8]

3.3 Protein quality

Table 8 summarises the biological evaluation of the 14 cultivars of amaranth assayed on processed samples. Statistical analysis of weight gain, food intake and PER showed that no two groups are significantly different at the 0·050 level of significance. Even though protein quality values are not statistically different, PER varies from 2·23 to 2·59 for all samples. Among *A. caudatus*, the range is between 2·38 and 2·59, for *A. cruentus*, between 2·23 and 2·55, and for *A. hypochondriacus*, between 2·23 and 2·41, smaller than for the other species. These values are 81–94% of the value of casein, making amaranth protein quality exceptionally high as has been reported before[5] (Bressani, R. *et al.*, unpublished; Bressani, R. *et al.*, unpublished; Imeri, A. G. *et al.*, unpublished). Protein content of the samples was found to be negatively related to protein quality ($r = -0{\cdot}5035$). However, this is not uncommon since it is also the case for cereal and legume foods that are deficient in essential amino acids.[18] Usually as protein content is higher, the content of the limiting amino acid on a per gram of protein basis becomes smaller.[19–21]

In the present case, no significant relationship was found between lysine percentage, on a weight basis, and PER; however, the relationship became stronger when lysine was expressed as g 16 g^{-1} N with a correlation coefficient of $r = +0{\cdot}4397$ (NS). With respect to tryptophan, the relationship to PER, both as weight percentage or on the basis of protein was positive but not statistically significant.

The importance of yield per unit area of land is, of course, the most important objective for amaranth as it is for all cereal grains and food legumes. However, in achieving such an objective it is also important to consider the nutrient content levels so that the high nutritional quality of amaranth is kept, particularly if intended for human feeding.

TABLE 8
Protein Quality of 14 Selections of Amaranth Grain

Selection	*Seed colour*[a]	*Weight gain (g)*[b]	*Food intake (g)*[b]	*PER*[b]
1. *A. caudatus* (A-713)	C	107±12·7	403±34·7	2·39±0·23
2. *A. caudatus* (A-982)	O	113±24·9	390±55·9	2·59±0·29
3. *A. caudatus* (A-1113)	C	118±17·8	415±41·7	2·38±0·17
6. *A. hybridus* (82S-1004)	O	114±13·5	440±44·0	2·34±0·17
7. *A. cruentus* (82S-1011)	O	108±19·4	417±56·0	2·55±0·17
8. *A. cruentus* (82S-434)	C	117±25·1	438±60·4	2·31±0·22
9. *A. cruentus* (82S-1034)	O	106±27·9	460±70·6	2·23±0·26
4. *A. hypochondriacus* (A-718)	O	108±10·7	424±34·8	2·30±0·16
5. *A. hypochondriacus* (A-720)	O	100±15·6	411±42·6	2·37±0·16
10. *A. hypochondriacus* (82S-1023)	C	113±9·9	428±25·5	2·38±0·17
11. *A. hypochondriacus* (82S-1024)	O	105±17·9	445±46·7	2·23±0·23
12. *A. hypochondriacus* (82S-674)	O	113±16·1	452±41·8	2·29±0·14
13. *A. hypochondriacus* (82S-SP130)	C	117±19·3	445±67·5	2·41±0·08
14. *A. hypochondriacus* (82S-1008)	C	119±29·4	453±63·3	2·32±0·27
Casein				2·74

[a]Colour: C=light; O=dark.
[b]Average±SD.

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