Amaranth: The nutritive value and potential uses of the grain and by-products

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In 1966 the National Academy of Sciences held a symposium on the Prospects of World Food Supply, at which Dr. Paul Manglesdorf presented a paper entitled "Genetic Potentials for Increasing Yields of Food Crops and Animals" [1]. Dr. Manglesdorf pointed out that, although humans during the course of their existence have used some 3,000 species of plants, only about 150 of those had entered commercial production. Apart from edible vegetables and fruits, approximately 21 species are today feeding humankind, including eight cereal grains, eight food legumes, two oil-containing food legumes, and three starchy food crops. Significant improvements in production and use have been realized throughout the years of intensive and continuous study by national and international agricultural research institutions. Still, it is recognized that this food base is narrow, and its exclusive use could lead to serious problems if the efforts against disease, insects, and environmental conditions are not continued. Furthermore, an important and vital activity in the effort to improve all these agricultural food crops is collecting their germ plasm as a source of needed genetic variability.

The relatively small number of edible grains suggests a need to introduce other food crops into production and commercial systems, and the logical choice would be those that are known to have played an important role in past civilizations and that are still produced and used today to some extent. There are several of these, and one of them is amaranth. Reports by a number of researchers indicate that amaranth was a very important crop in Aztec, Mayan, and Incan civilizations. Current thinking is that its production was significantly reduced as the result of restrictions imposed by the Spanish conquerors due to its association with religious festivities. Today, it is still produced, and foods such as *alegría* and *alboroto* are prepared on a small scale in Mexico and Guatemala respectively [2–6].

In Guatemala some native populations consume it as a porridge; however, it is considered a poor man's food. The leaves, consumed as a vegetable, are highly regarded, and their consumption is widespread throughout many countries. They are an excellent source of carotenes and have a high protein content, and supplement cereal grain efficiently [7, 8].

The research effort to bring amaranth back into production and commercial systems is a relatively recent undertaking. It has been reinforced by the economic support given by the National Academy of Sciences, through its Board on Science and Technology for International Development, to a number of researchers in various parts of the world such as Thailand, Kenya, Mexico, Guatemala, and Peru. In comparison with the funding given to other food crops and with the number of researchers involved, the support for amaranth is relatively small; however, some significant advances have been made, and recognition of the potential of this crop throughout the world is beginning to grow. Expectations for it are great because of its exceptionally high nutritional value [6, 9, 10].

Because of the present availability of high-quality maize, triticale, wing beans, quinua, and the like, the question arises whether amaranth grain will enter into commercial production in the underdeveloped world, where it is most needed. The possibilities are great if integrated research is continued and if the information obtained is disseminated at all levels within a country or region. By integrated research is meant research on all components of the food chain, as well as on their value as vegetable crops and the use of their by-products.

Agricultural production

Production is the starting point in the food chain, and most agricultural research has as its first objective to

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increase productivity through improved plant materials and appropriate practices within the environmental conditions prevailing at the site where the crop is to be grown. Increasing production through productivity is the result of two important components, agricultural practices and the genetic make-up of the crop. Although some important information is available for amaranth grain cultivation, a number of constraints still must be solved: seed germination, seeding methods and planting dates, control of the optimum planting density per hectare, weeding, fertilizer application and nutrient requirements, and insect and disease control, to mention a few agronomic practices that have been and are under investigation in developing countries [9–11].

As important as these elements are, plant characteristics are also of significance. Some constraints include plant height, lodging, harvest index, seed shattering, synchronous dry-down, grain size, and stem rigidity to hold a large inflorescence [12]. The structure of the inflorescence should be such as to allow homogeneous drying of the grain once it has reached physiological maturity. In many cases the inflorescence is quite compact, making water evaporation a slow process.

TABLE 1. Plant heights at harvest of groups of amaranth trials

	No. of selections	Height (m)	
		Range	Average
A. caudatus	25	1.90–2.60	2.34 ± 0.20
A. caudatus	3	2.10–2.40	2.27 ± 0.15
A. hypochondriacus	7	0.75–2.80	1.52 ± 0.84
A. cruentus	3	1.50–1.90	1.67 ± 0.21
A. hypochondriacus	3	1.60–2.30	1.87 ± 0.38
A. cruentus	9	1.60–1.95	1.78 ± 0.10
A. hybridus	3	1.10–1.65	1.46 ± 0.32

Sources: Refs. 13–15.

The problem of plant height is readily seen in table 1, which presents results of various agronomic trials conducted in Guatemala [13–15]. For 25 selections of *Amaranthus caudatus*, the plant height varied from 190 to 260 cm. A wide variation can be seen for *A. hypochondriacus*, while less variability is found for *A. cruentus*. The important finding is the variability, which suggests plant height can be reduced, it is hoped without reducing grain yield [13–15]. Similar results have been reported by others [9–12]. Tall plants make harvesting difficult. Furthermore, they tend to lodge and are susceptible to winds, which make it necessary to build supports, resulting in increased costs.

Seed shattering is an additional constraint that reduces grain yield if the inflorescence is allowed to dry in the field. Therefore, varieties should be found or should be developed so as to reduce this problem as much as possible in order to obtain higher yields [12].

TABLE 2. Seed weight

	No. of selections	Weight (mg/seed)	
		Range	Average
A. caudatus	25	0.50–0.93	0.75 ± 0.11
A. caudatus	3	0.46–0.72	0.61 ± 0.14
A. hypochondriacus	7	0.53–1.18	0.92 ± 0.24
A. cruentus	3	0.52–0.84	0.73 ± 0.18

Sources: Refs. 13–15.

The results of studies by various workers have shown an important variability in seed weight, which must be used to advantage (table 2). In 25 selections of *A. caudatus*, seed weight varied from 0.50 to 0.93 mg. Other species presented in table 2 showed similar variability, which suggests again the possibility of selecting materials with higher seed weight [11, 13–15]. Care should be taken, however, not to decrease yield at the expense of seed weight or protein or fat content. Larger seed size has some advantages at harvest and also in providing grain less contaminated by plant particles and dirt. Seed weight for a single type within a species probably does not affect protein or fat content; table 3 shows that the two are not significantly correlated [14]. Additional studies with other species should be carried out to verify this.

TABLE 3. Correlation coefficients between seed weight and protein and fat content in 25 selections of *A. caudatus*

	Correlation	Probability
Seed weight, protein	+.10	not significant
Seed weight, fat	−.06	not significant

Source: Ref. 14.

In the area where selections are tested for adaptability and grain production as carried out in Guatemala, planting is usually done in June to harvest in early October, when the rainy season ends. It is then too late to plant another crop, and the land will not be used until the start of the new rainy season in May. Since in October soils still contain available water, it would be advantageous to have a crop that could give a second and even a third harvest, if possible. Types of amaranth having this characteristic would be

TABLE 4. Effect of multiple harvest on yield of amaranth grain (Gua-17 *A. cruentus*)

Treatment	Yield (g/9 m²) 1st harvest	2nd harvest	Total
Fertilizer + irrigation	2,838 ± 153	879 ± 208	3,717 ± 323
Fertilizer (urea)	2,875 ± 463	923 ± 232	3,798 ± 558
Irrigation	2,407 ± 271	929 ± 116	3,336 ± 348
None	2,258 ± 284	972 ± 187	3,230 ± 414
Average yield			
g/9m²	2,594	926	3,520
kg/ha	2,882	1,029	3,911

Source: Ref. 16.

TABLE 5. Variability in protein and fat content in amaranth grain species

	No. of selections	Protein (%)		Fat (%)	
		Range	Average	Range	Average
A. caudatus	25	11.08–13.90	12.66 ± 0.96	6.41–11.43	8.44 ± 1.54
A. caudatus	3	12.50–14.77	13.27 ± 1.30	11.55–12.50	12.13 ± 0.51
A. cruentus	3	14.70–16.00	15.26 ± 0.95	9.20–12.85	10.98 ± 1.83
A. hypochondriacus	7	13.70–15.60	14.89 ± 0.61	8.25–10.60	9.39 ± 1.87

Sources: Refs. 13–15.

highly acceptable to farmers and should be developed, since amaranth seems to thrive under dry conditions. A type of *A. cruentus* from Guatemala seems to have this feature. One experiment tested four treatments (table 4). Although it is not clear how these treatments affect grain yield, what is of interest is that it was possible to obtain a second harvest, which increased total yield by 26% for a total of 3,911 kg per hectare [16]. Agrotechnology to optimize this characteristic should be pursued, since it will result in increased economic returns to the farmer.

Chemical composition and yield

Comprehensive reports on the chemical composition of amaranth grain have been published [2, 4, 5]. From the nutritional point of view, the two most important chemical components are protein and fat; levels of both are relatively high in comparison with those in cereal grains. It is therefore important to know the interrelationships of these two nutrients and yield.

Several reviews have suggested that environmental factors play an important role in determining protein and fat content in grain [2, 4, 5, 9, 14, 15, 17, 18]. The results of various studies, in which a number of types of several species were planted under equal soil and other environmental conditions, indicate that variability in protein and fat levels is due to genetic characteristics and is to be expected (table 5) [13–15].

TABLE 6. Correlations between yield and protein and fat content in *A. cruentus*, *A. caudatus*, and *A. hypochondriacus*

	Correlation
Fat content and yield	+.219
Protein content and yield	−.423
Fat and protein	−.464

Source: Ref. 15.

The relationships between yield and protein and fat content for 13 cultivars representing three species are summarized in table 6. As shown in the table, yield and protein were negatively correlated; however, the correlation was not statistically significant. This could be interpreted to mean that higher yields do not reduce protein content. On the other hand, yield was positively correlated with fat content, but again this was not statistically significant. This would be expected, since protein and fat are negatively related [15]. On the basis of results obtained so far and of nutritional value, it would be ideal if the amaranth grain cultivars released for commercial production contained not less than 15% protein and not less than

TABLE 7. Amino acid content of amaranth gain (mg/g N)

	A. caudatus	*A. hypochondriacus*	*A. cruentus*	*A. edulis*	FAO reference pattern
Lysine	364	374	337	329	340
Threonine	230 (92.0)	268	238 (95.2)	212 (84.8)	250
Methionine	148	106	118	125	
Cystine	116	131	127	123	
Total sulphur amino acids	264	237	245	248	220
Valine	264 (86.8)	237 (76.4)	269 (86.8)	254 (81.9)	310
Isoleucine	218 (87.2)	250	222 (88.8)	216 (86.4)	250
Leucine	349 (79.3)	382 (86.8)	344 (78.2)	348 (79.1)	440
Phenylalanine	238	328	263	250	
Tyrosine	205	269	200	207	
Total aromatic amino acids	443	597	463	457	380
Tryptophan	86	84	75	59	60
Histidine	158	169	159	150	
Arginine	556	506	434	541	
Aspartic acid	495	506	485	500	
Serine	400	500	387	265	
Glutamic acid	1,003	1,037	956	870	
Proline	254	287	244	223	
Glycine	453	525	461	415	
Alanine	229	244	216	215	

Figures in parentheses indicate percentage of adequacy.

TABLE 8. Food intake, weight gain, and protein efficiency ratio (PER) of rats fed raw and cooked amaranth grain

	Raw grain			Cooked grain		
	Average food intake (g)	Average weight gain (g)	PER	Average food intake (g)	Average weight gain (g)	PER
A. cruentus (US)	377 ± 35.0	72 ± 12.7	1.98 ± 0.28	464 ± 34.5	114 ± 17.1	2.48 ± 0.21
A. hypochondriacus (US)	361 ± 31.7	86 ± 11.3	2.47 ± 0.19	458 ± 46.9	118 ± 19.8	2.56 ± 0.22
A. caudatus (Peru)	332 ± 3.08	75 ± 10.8	2.20 ± 0.17	437 ± 43.9	111 ± 17.8	2.60 ± 0.24
A. cruentus (Gua-17)	373 ± 33.9	93 ± 22.5	2.53 ± 0.28	438 ± 34.5	116 ± 13.6	2.86 ± 0.17

Adapted from ref. 21.

8% fat. Further studies are needed to understand and establish the relationships between yield and nutrient content.

Nutritive value

Growth inhibition of raw amaranth grain

One of the attributes always mentioned when describing amaranth grain is its high protein quality predicted on the basis of its relatively well-established essential amino acid patterns (table 7). The lysine content is given as the main reason for the high protein quality of amaranth, since the grain contains more of this essential amino acid than cereal grains [4, 5, 18–20]. It is now evident, however, that raw amaranth grain does not have biologically the protein quality suggested by its amino acid pattern. This is shown in table 8, where four amaranth selections representing three species induced a low weight gain, which if expressed as protein quality would be only 65% of the value of casein. It is important to note that some selections resulted in better animal growth when eaten raw.

What is of much interest is the significant improve-

TABLE 9. Nutritive value of crude oil from three amaranth species added to diet at two levels, compared with cottonseed oil

Level and kind of oil	Average food intake (g)	Average weight gain (g)	True oil digestibility (%)
5%			
Cottonseed	389.5 ± 36.6	95.8 ± 18.4	98.7 ± 0.4
A. caudatus	387.8 ± 19.7	101.4 ± 13.3	94.1 ± 1.5
A. cruentus	362.9 ± 49.1	95.9 ± 15.8	91.7 ± 0.7
A. hypochondriacus	349.6 ± 51.7	88.4 ± 17.8	93.2 ± 1.2
10%			
Cottonseed	353.3 ± 56.6	89.9 ± 15.0	98.8 ± 0.3
A. caudatus	344.8 ± 31.9	89.8 ± 15.0	93.8 ± 0.6
A. cruentus	348.3 ± 54.0	92.3 ± 19.9	91.1 ± 0.7
A. hypochondriacus	344.8 ± 14.0	87.1 ± 6.4	92.0 ± 0.9

Source: Ref 26.

TABLE 10. Effect of feeding fat-free amaranth (*A. caudatus*) flour, raw and cooked

	Average food intake (g)	Average weight gain (g)	PER	Digestibility (%)
Whole flour				
raw	314.1 ± 44.7	67.5 ± 18.8	2.0 ± 0.3	78.8 ± 2.3
cooked	379.9 ± 32.5	103.0 ± 14.4	2.6 ± 0.2	82.2 ± 1.3
Defatted flour				
raw	312.9 ± 62.9	65.0 ± 16.1	2.0 ± 0.3	82.3 ± 2.6
cooked	447.0 ± 41.3	112.1 ± 19.1	2.4 ± 0.3	79.4 ± 3.1

The same observations were made with *A. cruentus* and *A. hypochondriacus*.

Source: Ref. 27.

ment in nutritive value upon appropriate thermal processing of the grain. The differences that existed when raw largely disappeared, all having essentially the same quality [21], although this observation had already been shown [22, 23]. The reasons for these effects, which include a higher food intake and protein quality, are not known. The common tryptin inhibitors, lectins, and tannins have been discarded as possible factors [14]. Possibilities under study include other kind of antiphysiological substances and amino acid availability, or even both. These findings were interpreted to mean that the low animal response to eating raw grain is more due to inhibitory substances or nutrient unavailability than to essential amino acid pattern.

Lipid digestibility

As indicated, fat content is a major nutritional component in amaranth grain because of the energy it provides and for its fatty acid composition [4, 15, 24, 25]. The quality of the raw crude lipid fraction of the grain has been studied, and some results are shown in table 9. Two levels of the crude oil, 5% and 10%, were added to a basal casein diet in comparison with the same levels of cottonseed oil. As shown in the table, the crude oil from *A. cruentus* and *A. hypochondriacus* reduced weight gain. The crude oil from all species had lower digestibility than that of cottonseed oil. The effects were not as marked at the 10% oil level, probably because the energy needs of the animals were met with less food intake [26].

Apparently the oil from *A. cruentus* was the least nutritious, and work is needed to learn the reasons for the lower digestibility. In any case, the oil did not show any toxicity. It should be pointed out that removing the oil did not improve the protein quality of the raw residue (table 10). Thermal processing of the lipid-free amaranth flour resulted in a significant improvement in animal performance, however, suggesting that the lipid fraction may influence nutritive value, but it is not responsible for the lower animal response observed from eating raw amaranth grain flour [27].

TABLE 11. Effect of amino-acid supplementation on the protein quality of processed amaranth grain

Amino acid added	Protein in diet %	Average weight gain (g)	PER
None	11.1	101	2.29
+0.1% DL-Thr	10.7	107	2.50
+0.2% DL-Thr +0.2% DL-Met	11.1	114	2.51
+0.2% DL-Thr +0.2% DL-Met +0.1% L-Leu	11.2	123	2.48
Casein	10.5	121	2.74

Source: Ref. 28.

Limiting amino acids

Literature reports indicate that the protein quality of amaranth grain is deficient in leucine [4, 5] (see table 7). The results in table 11, however, suggest that threonine is the amino acid that limits protein quality [16, 28]. This may be of importance in efforts to use amaranth flour in mixtures with cereal grain flours, for example, rice and wheat, that are deficient in the same amino acid, threonine, after lysine [29, 30]. The lysine contributed by amaranth grain to the total lysine in a mixture with wheat flour, for example, would make threonine the first limiting amino acid in the mixture, with only a small improvement in protein quality. Results would be similar with mixtures of rice and amaranth, with amino acids likely to become less available due to the high temperatures during processing [31–34].

Effects of processing

Processing is important with respect to the protein quality of amaranth grain. Although it is not possible to show comparative values of different kinds of processing on all grain species, it is of interest to show the effects of flaking, light roasting, popping, wet cooking, and extrusion on two species [32, 33] (table 12). The values clearly show that all processes increase the protein quality of amaranth grain, with roasting the least effective. This process, if carried out under more extreme conditions of time and temperature, destroys the quality of the product by reducing available lysine content [32–34]. Of interest is the extrusion process, which for *A. cruentus* and *A. caudatus* yielded cooked flour equal in protein quality to casein [35].

Other workers, rather than using the whole grain, are studying milling techniques and evaluating such products for the development of a number of food products [20–36]. Study in this area should be continued and expanded. However, the use of the whole grain as a food source merits greater attention, particularly as a weaning food, because of its excellent protein quality and relatively high energy content [37, 38]. Similarly, it is important to define better the conditions needed for optimum thermal processing of amaranth grain in view of its nutritive value when eaten raw.

TABLE 12. Effect of various types of processing on the protein quality (net protein ratio) of amaranth

	Protein diet (%)	Average weight gain (g)	Average food intake (g)	Net protein ratio (% of casein)
A. caudatus				
raw	8.6	7 ± 5.3	101	47.4
roasted	9.1	17 ± 6.7	131	61.4
flaked	9.3	26 ± 7.6	126	76.2
popped	9.1	37 ± 6.3	144	87.4
wet cooking	9.2	42 ± 8.2	177	84.1
Casein	9.6	52 ± 7.9	166	100.0 (3.65)
A. cruentus				
raw	—	29	164	69.3
extruded	—	64	210	107.3
A. caudatus				
raw	—	21	123	74.4
extruded	—	53	179	104.4
Casein	—	58	182	100.0 (3.16)

Source: Ref. 33.

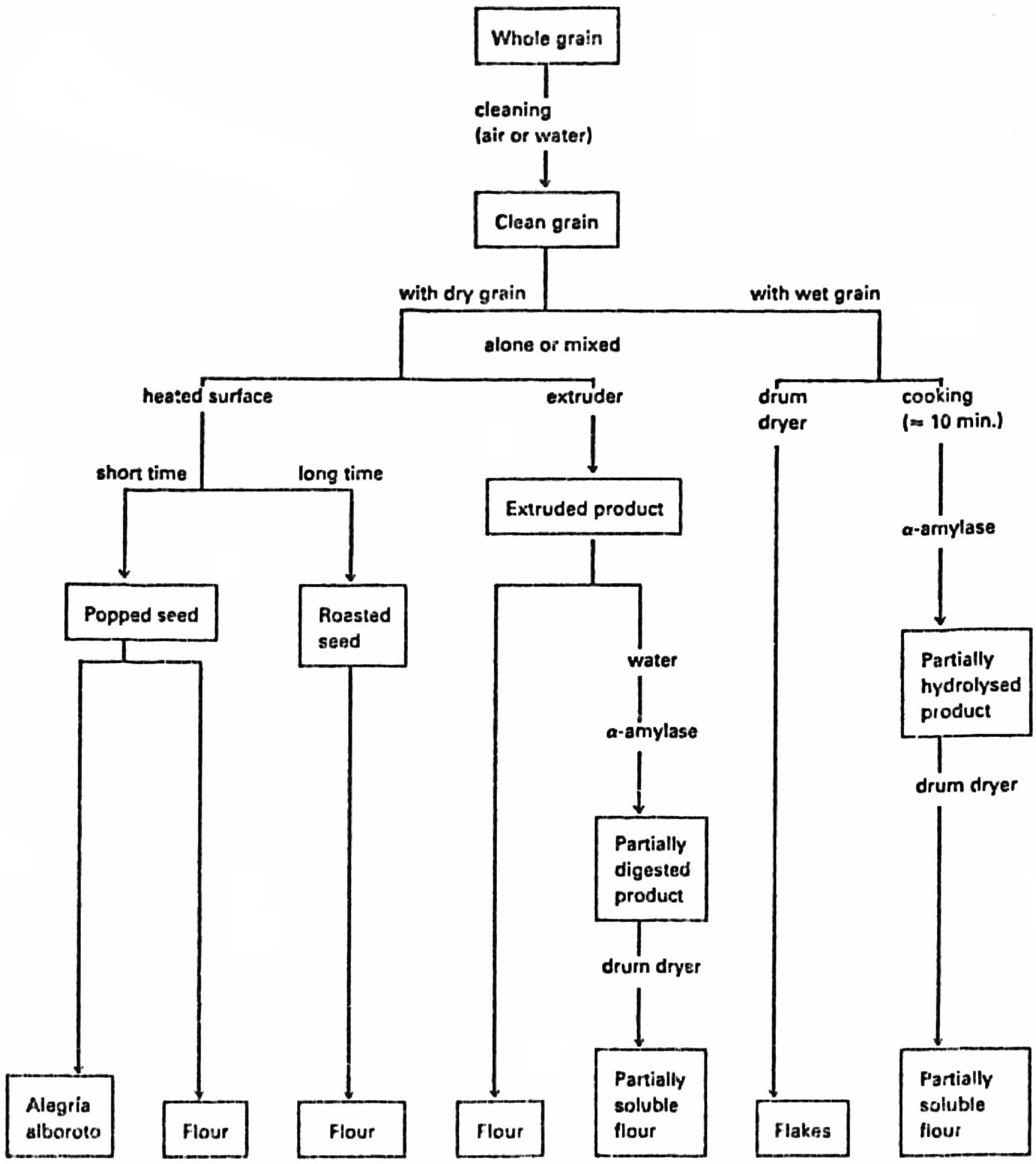

FIG. 1. Processing of whole grain

Food products

Amaranth used alone

Food product development and use are important areas of research since they give meaning to agricultural production efforts and create the driving force for a dynamic food chain. Many efforts are being made with the whole grain and milling fractions [2, 4, 5, 9, 10, 34–39]. The technologies being applied with whole grain are shown in figure 1.

After cleaning, which can be done by air or with water, the grain can be processed to be popped or expanded, and if wetted to 20%–25% moisture, it can be flaked. The dry grain can be extruded alone or mixed with other products such as soybeans to give extruded flours. After being suspended in water, these can be subjected to starch hydrolysis and dried to give a soluble product. Such a product can also be obtained by 10-minute cooking followed by starch hydrolysis and final drying.

This last product would be ideal for feeding children since it can be suspended in a 15%–20% solid solution. All could make excellent foods for weaning purposes. For this use, the levels of protein and fat suggested previously, 15% and 18% respectively, would be highly desirable.

In grain mixtures

The processed flour could be used as such or mixed with other nutrient sources, for example, other grains [31, 36, 39]. The results shown in table 13 are examples of the nutritive value when the protein from maize, wheat flour, and rice is replaced with amaranth-grain protein [16]. For wheat flour, there is a continuous increase in protein quality, as amaranth protein makes a greater contribution in the diet. This is to be expected on the basis of the higher lysine content in amaranth protein than in wheat-flour protein.

It is of interest that a complementary effect was observed with maize, a protein higher in leucine con-

TABLE 13. Protein quality of mixtures of cooked amaranth grain and maize, rice, and wheat flour

Mixture (%)		Net protein ratio		
Amaranth	Cereal	Maize	Rice	Wheat
100	0	2.94	2.77	2.62
75	25	2.79	2.80	2.47
50	50	2.64	2.62	2.17
25	75	2.56	2.48	1.94
0	100	2.36	2.21	1.69
Protein in diets (%)		8.7	7.8	11.9

TABLE 14. Protein quality of amaranth grain flour supplemented with various protein sources

Protein source	Level added (%)	Average final weight (%)	NPR[a]
None	—	45 ± 9.4	3.29 ± 0.30
Skim milk	12	59 ± 5.6	3.72 ± 0.30
Soybean flour	10	51 ± 6.1	3.43 ± 0.39
Cottonseed flour	20	54 ± 5.9	3.26 ± 0.30
Faba bean flour	12	53 ± 4.1	3.51 ± 0.19
Casein	—	61 ± 5.3	3.77 ± 0.21

a. 10.5% protein diets.

Source: Ref. 16.

tent than amaranth protein, which suggests that this amino acid does not limit the quality of amaranth protein, as was indicated previously [30]. A supplementary effect is observed as amaranth protein increases in the mixture, up to a point beyond which no additional effect is observed. The results with rice are also of interest. As amaranth protein replaced rice protein, quality was increased. These studies must be continued because of the interest in mixing amaranth grain with cereal grains.

With other protein sources

An attractive alternative is to use amaranth grain with other sources of protein. An example is shown in table 14, in which small amounts of milk, soybean, and cottonseed were added [16]. With the possible exception of milk, the other protein sources did not improve protein quality; however, the protein content in all the products was higher. The development of a milk-based product would be of interest [35, 37, 38].

This research must be continued, and the changes in chemical structure and functionality in the various primary products from amaranth must be established. It would be interesting to submit one or two such products to markets, using locally available industrial capacity, with the grain provided in a subsidized form. This could break the cycle of uncertainty for producers, who would like to have an assured market with adequate economic returns, and for the industry, who would be assured of having sufficient raw materials. If this were backed by appropriate advertising and a reputable institution, it might help significantly in promoting the commercial production of amaranth grain.

The use of by-products

At the beginning of this paper I indicated that the reintroduction of amaranth into commercial systems might be successful if research on the crop is carried out in an integrated manner based on the food chain. This concept implies also the use of the plant for animal-feeding purposes or, if grain is the main product, the use of by-products.

With respect to the use of the whole plant, table 15 shows data on the yield of dry matter and of protein per hectare with respect to time [40]. Although at 60 days the protein yield was higher, the product was probably of lower quality than that obtained at 40 days. This of course, depends on the kind of animal to be fed, with the higher-protein product for monogastric animals and the 60-day-old grain with higher fibre content for ruminants. This matter is under continued research, and could offer attractive solutions to developing countries. The problem is that undesirable factors in the dehydrated product limit its use at least in rabbits (table 16). The data show that 15% replacement of alfalfa leaf meal did not affect animal responses; however, higher levels reduced weight gain per day. Thermal treatment of the product seems to

TABLE 15. Dry biomass and protein yield of whole amaranth plants

Age at harvest (days)	Average dry-matter yield (kg/ha)	Protein (%)	Fibre (%)	Average protein yield (kg/ha)
25	66.6 ± 18.4	29.5 ± 1.0	11.1 ± 0.7	19.7 ± 18.4
40	681.8 ± 188.1	22.7 ± 2.4	14.3 ± 0.58	154.3 ± 66.8
60	3,452.0 ± 760.9	14.4 ± 2.6	17.0 ± 0.43	510.7 ± 213.5

Source: Ref. 40.

TABLE 16. Effect of amaranth plant meal on rabbit weight gain, feed efficiency, and carcass yield

Amaranth plant meal in diet (%)	Weight gain (g/day)	Food intake (g/day)	Feed effi-ciency	Carcass yield (%)
0	29.6	102.7	3.47	50.74
15	29.4	94.5	3.22	48.07
30	22.9	75.6	3.35	46.41
45	16.3	60.7	3.73	46.37
60	13.9	49.6	3.57	42.08
60[a]	21.2	58.1	2.77	42.42

a. Heat-treated.

Source: Ref. 41.

TABLE 17. Dry weight distribution of plant parts of nine selections of *A. cruentus*

	Dry weight (g)		Distri-bution (%)
	Range	Average	
Stem + leaves	47–126	76 ± 23	39.2
Flower (– grain)	36–57	46 ± 8	23.7
Grain	55–89	72 ± 13	37.1
Total	158–244	194 ± 31	100.0

help, however, since 60% amaranth plant meal, which was blanched before drying, improved the animals' weight gain [41].

The use of the by-products from grain harvest and cleaning is also of interest. This aspect is justified by the results presented in table 17, which shows the weight percentages of grain, of the inflorescence, and of the plant residue, with respect to the weight of the whole plant. The grain weight averaged 37.1% of the total weight of the plant, while the flower, and the stem and leaves averaged 23.7% and 39.2% respectively. The total weight of by-products is significantly higher than the weight of grain. Therefore, these products must be used based on their chemical composition. This is partially shown in table 18. The two

TABLE 18. Chemical composition of agricultural residues from amaranth

	Stems + leaves	Flower		Seed calyx
		– seed	+ seed	
Moisture	11.3	—	10.0	14.4
Crude fat	1.9	—	3.1	3.1
Crude fibre	35.8	—	17.9	30.2
Protein (N × 6.25)	7.2	9.4	15.7	11.9
Ash	11.1	—	15.9	10.2
Carbohydrate	32.7	—	37.4	30.2

components that are of interest are crude fibre and protein. The table shows the composition of an additional fraction, the seed calyx. The use of these by-products would be limited by their high fibre content; however, the stems and leaves fed to young ruminants gave results similar to corn stover, and the seed calyx was comparable to wheat middlings in preliminary studies with baby chicks [42, 43].

The inflorescence is presently being tested, and relatively good silage has been produced. As with the whole young plant, thermal treatment of the grain calyx improves its quality. These by-products must be studied further, which will be of great value in introducing amaranth production in our countries.

To conclude, activities should be continued and expanded in the following areas:

—agrotechnology, with significant activities in genetics, with a focus on nutritive value, increased yield, and the physical and chemical characteristics of the plant and grain;
—development of an agro-industry to use the grain, particularly in developing countries;
—increased knowledge on the limiting nutritional factors of raw and processed grain;
—improved processing technologies to achieve attractive functional properties and nutritive value;
—use of the whole plant, and/or plant residues after grain harvest;
—increased dissemination of information.

References

1. Manglesdorf P. Genetic potentials for increasing yields of food crops and animals. In: The prospects of world food supply. Washington, DC: National Academy of Sciences, 1966.
2. Sánchez-Marroquín A. Potencialidad agro-industrial del amaranto. Mexico: Centro de Estudios Económicos y Sociales del Tercer Mundo, 1980.
3. Marx JL. Amaranth: a comeback for the food of the Aztecs. Science 1977;198:40.
4. Saunders RM, Becker R. Amaranthus. In: Pomeranz Y, ed. Advances in cereal science and technology. Vol. 6. St. Paul, Minn, USA: American Association of Cereal Chemistry, 1983.
5. Teutonico RA, Knorr D. Amaranth: composition properties and applications of a rediscovered food crop. Food Technol 1985;39:44-60.
6. National Research Council. Amaranth: modern prospects for an ancient crop. Washington, DC: National Academy Press, 1984.
7. Devadas RP, Saroja S. Availability of iron and B-carotene from amaranth to children. In: Proceedings Second Amaranth Conference. Emmaus, Pa, USA:

school child growth in rural Punjab: the Narangual experiment. In: Kielmann AA, et al. eds. Integrated nutrition and health care. Vol. 1. Baltimore Md, USA: Johns Hopkins University Press, 1977:157.
20. Grewal T, Gopaldas T, Gadre VJ. Etiology of malnutrition in rural Indian preschool children (Madhya Pradesh). J Trop Pediatr 1973;19:265.
21. Keller WE, Muskat E, Valder E. Some observations regarding economy, diet and nutritional status of Kikaya farmers in Kenya. In: Kraut H, Cremer HD, eds. Investigation into health and nutrition in east Africa. Munich: Weltforum Verlag, 1969:243.
22. Central Bureau of Statistics, Ministry of Economic Planning and Community Affairs, Republic of Kenya. Child nutrition in rural Kenya. Kenya: UNICEF, 1979.
23. Wasonga L, Lisiner L, Test K, Rafferty A, Mason J. Preliminary analysis of nutritional and agricultural data, Eastern Province, Kenya. Cornell nutritional surveillance program working paper no. 8. Ithaca, NY, USA: Division of Nutritional Sciences, Cornell University, 1982.
24. Field JO, Miller RL, Drake WD. Malnutrition, intervention and development in a south Indian district. Vol. III. Ann Arbor, Mich, USA: US Agency for International Development, and Community Systems Foundation, 1981.
25. Ryan JG, Bidinger PD, Prahland Rao N, Pushpamma P. The determinants of individual diets and nutritional status in six villages of southern India. Research bulletin no. 7. Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics, 1984.
26. Ramprasad V, Kulkarni PM. Determinants of child health status: a study in rural Karnataka, India. J Trop Pediatr 1985;31:276.
27. Omawale. Nutrition problem identification and development policy implications. Ecol Food Nutr 1980; 9:113.
28. Hassan N, Ahmad K. Household distribution of energy intake and its relationship to socio-economic and anthropometric variables. Food Nutr Bull 1986;8(4):3.
29. Nabarro D. Social, economic, health, and environmental determinants of nutritional status. Food Nutr Bull 1984;6(1):18.
30. Rawson J, Valverde V. The etiology of malnutrition among pre-school children in rural Costa Rica. J Trop Pediatr 1976;22:12.
31. Cervantes S, Salazar S, Rojas Z. Socio-economic characteristics of functional groups of the malnourished population in Costa Rica. UNICEF Soc Stat Bull 1981;4(2):1.
32. Valverde V, Martorell R, Meijia-Pivaral V, et al. Relationship between family land availability and nutritional status. Ecol Food Nutr 1977;6:1.
33. Mason JB, Ahlers T, Henderson C, Shorr LJ, Tabatabai H. Identifying nutritional considerations in planning a rural development project in N. Haiti. Ecol Food Nutr 1985;18:1.
34. Omawale, Rodrigues AM. Nutrition considerations in a cassava production program for Guyana. Ecol Food Nutr 1980;10:87.
35. Desai P, Standard KL, Miall WE. Socio-economic and cultural influences on child growth in rural Jamaica. J Biosoc Sci 1970;2:133.
36. Bantje HFW. Household circumstances and infant malnutrition in western Jamaica. CFNI-J44-74. Kingston, Jamaica: Caribbean Food and Nutrition Institute.
37. McLeod J. A study of undernutrition, poverty and national development in Jamaica. PhD thesis. Kingston, Jamaica: University of the West Indies, 1985.
38. Melville BF, Lawrence O, Williams MV, Francis V, Collins L. Determinants of childhood malnutrition in Jamaica. Food Nutr Bull 1988;10(1):43-47
39. Beaton GH, Ghassemi H. Supplementary feeding programmes for young children in developing countries. Am J Clin Nutr 1982;35(suppl.):864.
40. LeFranc E. Social structure, land use, and food availability in the Caribbean. Food Nutr Bull 1981;3(4):5.
41. Dewey KG. Agricultural development, diet and nutrition. Ecol Food Nutr 1979;8:265.
42. Fleuret P, Fleuret A. Nutrition, consumption and agricultural change. Hum Organiz 1980;39:250.
43. Smith MF. The impact of changing agricultural systems on the nutritional status of farm households in developing countries. Food Nutr Bull 1986;8(3):25.
44. Fillmore CM, Hussain MA. Agriculture and anthropometry: assessing the nutritional impact. Food Nutr 1984;10:2.
45. Eicher CL, Baker DC. Research on agricultural development in sub-Saharan Africa: a critical survey. MSU international development paper no. 1. East Lansing, Mich, USA: Michigan State University, 1982:213.
46. Longhurst R. Agricultural production and food consumption. Food Nutr 1983;9:2.
47. Marchione TJ. Food and nutrition in self-reliant national development: the impact on child nutrition of Jamaica government policy. Med Anthropol 1977;1:57.
48. Shipton P. The Kenyan land tenure reform: misunderstandings in the public creation of private property. Development discussion paper no. 239. Cambridge, Mass, USA: Harvard Institute for International Development, Harvard University, 1987.
49. Cohen JM. Agrarian reform in Ethiopia: the situation on the eve of the revolution's 10th anniversary. Development discussion paper no. 164. Cambridge, Mass, USA: Harvard Institute for International Development, Harvard University, 1984.
50. Barraclough S. A preliminary analysis of the Nicaraguan food system. Geneva: United Nations Research Institute for Social Development, 1982.
51. Neff J. Agrarian reform and nutrition in Peru: assessment of the Cornell-Peru project at Vicos. Ithaca, NY, USA: Dept. of Agricultural Economics, Cornell University, 1976.

Rendimiento y composición química de las partes vegetativas del amaranto (*Amaranthus hypochondriacus*, L.) a diferentes épocas de corte. Arch Latinoam Nutr 1987;37:108-121.
41. Alfaro MA, Ramírez R, Martínez A, Bressani R. Evaluación de diferentes niveles de harina de amaranto (partes vegetativas) en sustitución de harina de alfalfa para conejos en crecimiento. Arch Latinoam Nutr 1987;37:174-185.
42. Bressani R, González JM, Uso potencial del residuo de la materia seca vegetativa del amaranto en la alimentación de rumiantes: estudios preliminares. In: El amaranto y su potencial. Arch Latinoam Nutr, Bol 4. Guatemala, 1984.
43. Bressani R, González JM. The nutritive value of the amaranth seed calyx as tested in growing chickens. Amaranth Newsletter, no. 1. Guatemala: Arch Latinoam Nutr, 1986.