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AMARANTH: A FOOD CROP FROM THE PAST FOR THE FUTURE

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History of Amaranth and its Native Habitats

Amaranth was a major grain crop in pre-Columbian times. Thousands of hectares were planted to the tall, leafy, reddish plants during the Inca and Aztec Dynasties of South America and Mexico. When amaranth grain was a staple cereal, it is believed some 20,000 tons were sent in annual tribute to the Aztec emperor Montezuma.

Amaranth was interwoven with legend and ritual. On ceremonious occasions, amaranth seeds were ground, mixed with honey or human blood, and shaped into figures representing gods or revered animals. The resulting products, called zoale, were eaten as part of religious rites (Hemmendinger). After the Spanish conquest of Cortez, the invaders prohibited amaranth cultivation as a means of eliminating established native religious rituals. Production declined greatly, and amaranth has remained largely dormant as a popular food crop.

The world relies on six crops--notably cereals, root crops, legumes, sugarcane, sugar beets and bananas--to provide the bulk of its calories and protein (National Academy Press, 1983). To diversify the food base, lesser-known indigenous crops such as amaranth should not be overlooked.

Amaranth Varieties

Amaranth is one of few non-grasses with the potential for diversifying the food base and increasing world food production. Amaranths are broad-leafed plants that produce significant amounts of edible cereal grain. They grow vigorously, resist

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drought, heat, pests and adapt readily to new environments. Throughout history, amaranth species have been consumed both as cereal grains and green vegetables. Table 1 displays the uses and areas of origin of amaranth species.

Grain Amaranth

The seeds of grain amaranth can be used in breakfast cereals or as confectionery ingredients. They can also be popped, parched or cooked into gruel. When milled, amaranth grain produces a sweet, light colored flour suitable for biscuits, breads, cakes and other baked goods. Amaranth grain contains no functional gluten, so it must be blended with wheat flour to produce yeast-leavened baked goods that "rise." A. caudatus, A. cruentus, and A. hypochondriacus have been identified as the three species of grain amaranth to produce large seedheads loaded with edible seeds (National Academy Press, 1983).

A. caudatus is grown primarily in South America, specifically the Andean highlands of Argentina, Peru, and Bolivia (Teutonico, 1985). Indians who maintain traditional customs usually plant it in small patches close to houses rather than in large fields as a staple crop. The grain is either ground into flour, toasted and popped, or boiled for gruel. However, the common use of this species is as an ornamental sold in Europe and North America.

A. cruentus is one of the most popular species grown. It is useful both as a grain and a leafy vegetable and is probably the most adaptable of all amaranth types. Its origins have been traced to southern Mexico or Guatemala and today it is grown in West Africa, the Caribbean, the Americas and Asia. Its primary use is as a source of red dye for coloring maize-based products by Indians in the southwestern United States and Mexico (National Academy Press, 1983).

TABLE 1. USES AND AREAS OF ORIGIN OF AMARANTHUS SPECIES

Species	How Found	Use	Area of Origin
A. blitum (A. lividus, A. oleraceus)	Cultivated	Vegetable Ornamental	Asia
A. caudatus (A. edulis, A. mategazzianus)	Cultivated	Grain Vegetable Ornamental	South America (Andes)
A. cruentus (A. paniculatus)	Cultivated	Grain Vegetable	South America (Guatemala)
A. dubius	Weed; Cultivated	Vegetable	South America
A. hybridus	Weed	Vegetable	South America
A. hypochondriacus (A. leucocarpus, A. leucosperma, A. flavus)	Cultivated	Grain Vegetable	North America (Mexico)
A. retroflexus	Weed	Vegetable	North America
A. spinosus	Weed	Vegetable	Asia
A. tricolor (A. gangeticus, A. mangostanus)	Cultivated	Vegetable Ornamental	Asia
A. viridis (A. ascendens, A. gracilis)	Weed	Vegetable	Africa

SOURCE: National Academy of Sciences, Washington, D.C., 1983

The highest yielding and most robust species of the grain amaranths is A. hypochondriacus. It was probably domesticated in Central America and is now primarily cultivated in India with smaller amounts being grown in Mexico, the southwestern United States, Africa and Asia. In particular, planting occurs in such widely scattered regions as the mountains of Ethiopia, the hills of southern India, the Nepal Himalayas and the plains of Mongolia (National Academy Press, 1983). In India, the most common usage of A. hypochondriacus seeds is in the form of candy known as laddoos, while in Nepal the grain is parched, ground into flour and eaten as gruel (Teutonico, 1985).

Currently in the United States, the three most common types of grain amaranth available for production are A. cruentus, A. hypochondriacus, and an experimental breeding line from Rodale Research Center. Up to the present time, most of the acreage in the United States has been planted with A. cruentus landraces grown by farmers in Mexico. This species of amaranth requires approximately 110 days to mature and under optimum conditions will grow up to eight feet tall. Planting by early June in areas north of western Kansas is required to provide a growing season adequate for maturation. Yields in fields receiving a frost in September were too low to justify harvesting (Rodale Research Center, 1988).

A. hypochondriacus is another type of amaranth planted in the United States, also from landraces grown in Mexico. This species is limited to areas with about 150 frost free days and will also grow up to eight feet tall (Rodale Research Center, 1988).

The experimental variety was the most extensively grown breeding line in 1987. The plant may reach six feet tall when grown under optimum conditions. This line requires approximately the same maturation as A. cruentus. However, for some farmers in western Nebraska who planted in late June, it was the only amaranth species that matured (Rodale Research Center, 1988).

Vegetable Amaranth

Most amaranthus species have edible leaves and stems. Their mild spinach-like flavor has made them a widely popular vegetable crop in the humid tropics. Both uses and dominant areas where vegetable amaranth species are grown are shown in Table 1.

A. tricolor probably originated in southern Asia or India and is extensively cultivated in southern China. A. cruentus, described earlier as a grain type, is also used as an African leafy vegetable probably introduced from Central America. A. dubuis is native to South America. Today this weedy species of amaranth is used as a green vegetable in West Africa and the Caribbean and a home garden crop in Java and other parts of Indonesia. All three species are grown as soup vegetables or for boiled salad greens called potherbs (National Academy Press, 1983).

The widely distributed A. blitum is native to Asia. This species is a popular vegetable in India and southern and central Europe, especially Greece. The weedy types of amaranth are usually considered to be A. viridis, A. spinosus, A. retroflexus, and A. hybridus. These plants have varied areas of origin and widespread distribution (Table 1). These species frequently occur as pests in pastures, crops or along roadsides. A. retroflexus, commonly called pigweed, is one of the world's worst weeds (National academy Press, 1983). These weeds tend to be indeterminate and produce seeds at many different parts of the plant. The seeds are scattered during a long part of the season and are readily spread by birds and water. The cultivated grain types, on the other hand, tend to mature over a short period and have a dominant seedhead.

Amaranth Plant and its Needs

Amaranth species are widely distributed throughout the world's tropical, subtropical and temperate regions. There is a tremendous amount of genetic diversity within the amaranth grain species. Although traditionally cultivated within 30°

latitude of the equator, the crop is widely adapted and can be cultivated from sea level to over 10,000 feet above sea level.

Growth habits vary from prostrate to erect and branched to unbranched; leaf and stem colors range from red to green and seed colors range from white to black (National Academy Press, 1983). Only two of the three grain species, A. cruentus and A. hypochondriacus, can be grown in the United States.

Physiology

The normal photosynthetic process most plants generally use is the calvin cycle or C_3 pathway. Amaranth is among a group of plants that use a modification of the normal C_3 photosynthetic process and carry on photosynthesis by the specialized C_4 pathway. The C_4 process efficiently uses the carbon dioxide available in the air by concentrating it in the chloroplasts of specialized cells surrounding the leaf vascular bundles. The photorespiratory loss of carbon dioxide, the basic unit for carbohydrate production, is suppressed in C_4 plants. Therefore, plants using the C_4 pathway can convert a higher ratio of atmospheric carbon to plant sugars per unit of water lost than those possessing the classical C_3 pathway (National Academy Press, 1983).

C_4 plants such as amaranth perform better than C_3 plants under adverse conditions. The stomata of the plant will close when it is under environmental stress such as drought or salinity, resulting in relatively high rates of carbon dioxide fixation. The reduced stomatal opening reduces water lost by transpiration and consequently the plants can tolerate some lack of water without wilting or dying. Thus, the plant can adapt to survive periods of drought. The ability to photosynthesize at high rates under high temperatures is another physiological advantage of C_4 photosynthesis (National Academy Press, 1983).

Plant Conditions

Growth of individual amaranth plants is basically dependent on three ecological factors, temperature, soil, and rainfall. Seed germination is dependent on moisture and warmth with the optimal temperature range being 61°F (16°C) - 95°F (35°C). Grain amaranth grows best when the daily high temperature is at least 70°F (21°C). The two grain amaranth species grown in the United States, A. hypochondriacus and A. cruentus, tolerate high temperatures and resist frost conditions. Growth ceases at approximately 46°F (8°C) and the plants are injured by temperatures below 39°F (4°C). For amaranth lines available in the United States, a killing frost is needed at maturity to dry plant stems and leaves sufficiently to permit direct combine harvest.

Field observations indicate amaranth grows well on soils containing widely varying levels of nutrients. Grain amaranth requires well-drained sites and appears to prefer neutral or basic soil types (pH values > 6). When the soil is heavy or compacted, root growth of amaranth is constricted and plant growth and yields are reduced (Rodale Research Center, 1988).

Shallow planting requirements on a well-moistened soil are required for amaranth seeds to germinate and establish roots. However, once seedlings are established amaranth does well with limited water. The optimal growing conditions are dry warm weather. Grain amaranth has been grown on dry-land agriculture in areas receiving as little as 7.87 inches of annual precipitation (National academy Press, 1983). Farmers in areas with dry weather during the fall have been the most successful in producing high quality grain amaranth. Most regions east of the Mississippi River are not well suited for amaranth production (Rodale Research Center, 1988). Farmers need to consider three basic factors when deciding on whether to plant grain amaranth: good soil moisture during planting; dry warm weather during maturation; and a killing frost at maturity.

Diseases

Commercial dryland amaranth growers have not experienced economically important disease problems. However, some amaranth lines are susceptible to soil-borne organisms associated with poorly drained soils (Rodale Research Center, 1988). There is also evidence a foliar disease possibly caused by air pollution affects amaranthus cruentus in the United States (National Academy Press, 1983).

Insects

Insect problems are not well documented. Two major insects infesting grain amaranth have been identified. The most prevalent is the tarnished plant bug, Lygus lineolarius. The tarnished plant bug pierces the developing seed and feeds on the succulent plant tissue leaving the grain shrunken and discolored. Fortunately, the damaged grain is lighter in weight and can be separated during the cleaning process.

The second potentially serious pest of grain amaranth is the amaranth weevil, Conotrachelus seniculus. The larvae bore into the root tissue and occasionally the stems of the plant, making tissue suspectable to disease by organisms. Stems and roots are weakened and lodging may occur (Rodale Research Center, 1988).

Amaranth Production

Grain amaranth is grown under a wide variety of conditions. Historically it is grown in small plots or home gardens using labor intensive practices in tropical underdeveloped cultures. However, where chemical fertilizers and modern insect and disease controls are readily available, large-scale mechanized farming has been attempted. Planting methods, yields and harvest management are three factors for consideration when producing grain amaranth.

Planting Methods

Amaranth is a warm season crop with germination occurring when soil temperatures are at or above 60°F. The average optimal planting date across much of the grain growing areas of the United States is considered to be mid May to early June (Rodale Research Center, 1988). Grain amaranth is usually seeded directly into the field and requires a fine, loose and well drained seedbed which can be firmed to provide seeds with good soil contact. Seeds planted in compacted soil are prone to drying out due to large spaces in the seed zone provided by soil clods. Compacted soil should be tilled to provide a layer of fine soil on the surface of the seedbed. A shallow tillage prior to planting can provide good weed control.

Amaranth seeds are very small, only 1/16 inches in diameter. The small seeds require shallow planting. In an experiment designed at the University of Minnesota to determine the effects of seeding depth on emergence, Robinson reported a depth of more than 1/2 inches decreased emergence. Table 2 shows percent emergence was highest with a planting depth of 1/2 inches or less on experimental varieties supplied by the Rodale Research Center and planted on a silt loam soil at Rosemount, Minnesota (Robinson, 1986). In dryland areas a planting depth of more than 1/2 inches may be necessary to obtain adequate moisture for germination.

TABLE 2. PLANTING DEPTH AND EMERGENCE OF AMARANTH

Depth (inches)	Emergence (percent)		
	R102	R125	Average
0.25	48	45	46
0.50	37	65	51
0.75	10	28	19
1.00	23	4	13

SOURCE: University of Minnesota, Agricultural Experiment Station Bulletin, 1986.

Amaranth adjusts to a wide range of plant population densities without greatly altering its performance. Low plant densities of grain amaranth usually produce a bushy plant with thick stalks. Increasing plant densities reduces the size of plant stems and the amount of branching, resulting in plants better suited for mechanical harvesting. High plant populations are one way of limiting plant height due to the plants' competition for moisture and nutrients. Current grain amaranth varieties grow to a height of six to eight feet under optimal growing conditions. Growers may have to experiment with different planting rates to determine the best seeding rates for their soil and moisture conditions.

Plant density trials at Rodale Research Center indicate the best plant habitat and highest yields were obtained at plant densities of 130,000 to 145,000 plants per acre. To achieve this density a rate of 1 to 2 pounds of seed per acre is required. Robinson (1986) found the highest yields were obtained from planting rates of 100,000 to 250,000 seeds per acre. These planting rates developed into population densities of 73,000 to 85,000 plants (Table 3).

TABLE 3. TRIAL AVERAGE AMARANTH PLANTING RATES

Seeds/acre planted (thousands)	Plants/acre at harvest (thousands)	Seed yield/acre (pounds)
100	73	787
250	85	847
500	190	658
1,000	446	511

SOURCE: University of Minnesota Agricultural Experiment Station Bulletin, 1986.

A variety of planters can be used for planting amaranth. However, the planter must have the capability of planting at a uniform shallow depth, metering 1 to 2 pounds of seed per acre and provide good seed-to-soil contact (Rodale Research Center, 1988). A press wheel on the planter may be essential to provide seed-to-soil contact to insure rapid germination and emergence. Amaranth seeds can be sown with vegetable planters using celery or similar sized plates, sugarbeet planters with modified seed plates or cultipacker seeders. Grain drills have also been used, but with varying degrees of success. The limitations of drills include lack of shallow depth control and difficulty in adequately reducing seeding rates due to small seed size. Robinson (1986) reported diluting amaranth seeds with corn flour and/or grits helped sufficiently reduce seeding rates. Growers need to consider six important points prior to planting:

1). Soil should be warm (60 - 65°F).

2). Good soil moisture is needed at planting time.

3). A firm seedbed is needed to maintain soil moisture.

4). Seed depth is important to emergence.

5). A press wheel helps establish seed-to-soil contact.

6). Seeds should be planted at a rate of 1 to 2 pounds/acre.

Yield

Table 4 shows yield figures for the three grain amaranth varieties produced in the United States. From 1985 to 1987 yields in 11 trial plots with no supplemental irrigation in Kansas, Minnesota, North Dakota, and Nebraska ranged from as low as 146 pounds/acre for A. hypochondriacus to as high as 3,319 pounds/acre for experimental breeding lines produced at Rodale Research Center. Estimates on amaranth acreage planted, harvested and average yields are listed in Table 5. These estimates are indications of trends of amaranth production in the United States. The

TABLE 4. AMARANTH YIELD POTENTIAL

Varieties	Yield (pounds/acre)
A. cruentus	210 - 1,229
A. hypochondriacus	146 - 907
Experimental breeding lines	260 - 3,319

SOURCE: Rodale Research Center and American Amaranth Institute, 1988.

TABLE 5. ESTIMATED AMARANTH PRODUCTION, 1980-1987

Year	Number of Growers	Acreage Planted	Acreage Harvested	Avg. Yield (pounds/acre)
1980	2	4	*	*
1981	3	17	*	*
1982	7	215	*	*
1983	16	800	250	160
1984	27	1,600	1,250	256
1985	16	1,000	900	235
1986	11	700	700	340
1987	20	1,300	1,050	330

* No data collected.

SOURCE: Rodale Research Center and American Amaranth Institute, 1988.

trend seems to indicate acreage planted, acreage harvested, and average yield are increasing.

Harvesting

Amaranth plants remain green and maintain a high moisture content in the stems and leaves even after the seeds are mature, dry and starting to shatter. Therefore, the plants must be killed by a frost followed by a week of dry weather before harvesting standing plants is efficient.

Growers have successfully used many types of combines for harvesting amaranth. Ground speeds for harvesting amaranth need to be reduced. The major combine modification made by most growers is using an alfalfa or clover screen to improve grain cleaning. The cylinder speed of the combine should be reduced as much as possible to minimize grain damage. Farmers can expect some damage or shattering even under the best harvest conditions. Grain loss and shattering in harvesting the standing crop may be reduced by using individual row harvesting units, particularly if lodging is a problem. Reel adjustment and removal of alternate reel bats are minor modifications growers can make if they do not have access to row headers. When harvesting wide-row amaranth, combines with snout dividers between individual rows have lower shattering losses than those with small grain headers. Seed-catching pans used for sunflower harvesting may be effective in reducing shattering loss (Rodale Research Center, 1988).

Plant residue must be removed from the grain, since residue mixed with grain increases risk of mold development and off-flavors during storage, which makes the grain unmarketable. Growers limit cleaning amaranth to scalping the bulk of trash from the grain. The final cleaning is usually done at local grain elevators that have specialized equipment. Amaranth grain harvested during dry weather conditions may need little additional drying. The grain should be dried to a moisture level of 10 - 12 percent for storage. To maintain the grain in quality food condition it should be placed in rodent-proof storage with adequate air movement to prevent condensation.

Quality Factors

A major focus of amaranth promotion is its nutritional value. It has a protein content of about 16 percent as compared to wheat (12-14 percent), rice (7-10 percent), maize (9-10 percent) and other widely consumed cereals shown in Figure 1. The

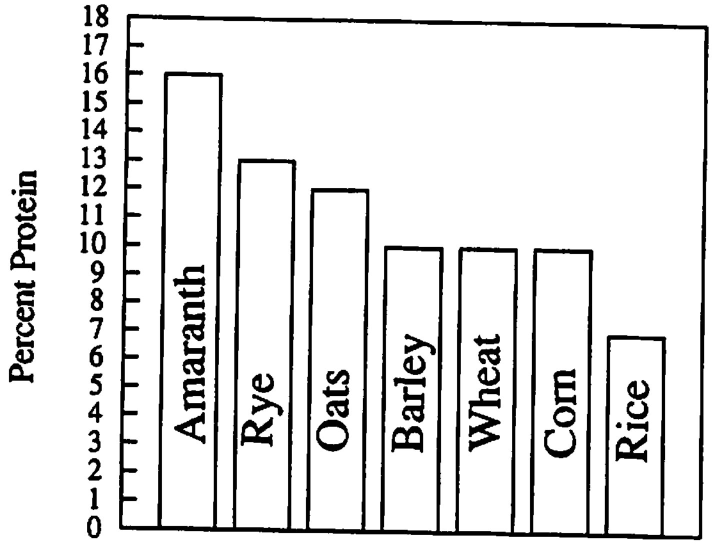

Figure 1. Protein Content of Amaranth as Compared to other Grains
SOURCE: National Academy Press, 1983

amaranth seed contains protein of unusual quality. It is also high in the amino acid lysine. Cereals are considered "unbalanced" in terms of amino acid composition because they generally lack sufficient amounts of lysine for optimum health. However, as seen in Figure 2, amaranth protein has nearly twice the lysine content of wheat protein, three times that of maize, and in fact as much as found in milk - the standard of nutritional excellence. Amaranth protein is low in the limiting essential amino acid leucine, but this amino acid is found in excess in conventional plant protein sources such as corn (National Academy Press, 1983).

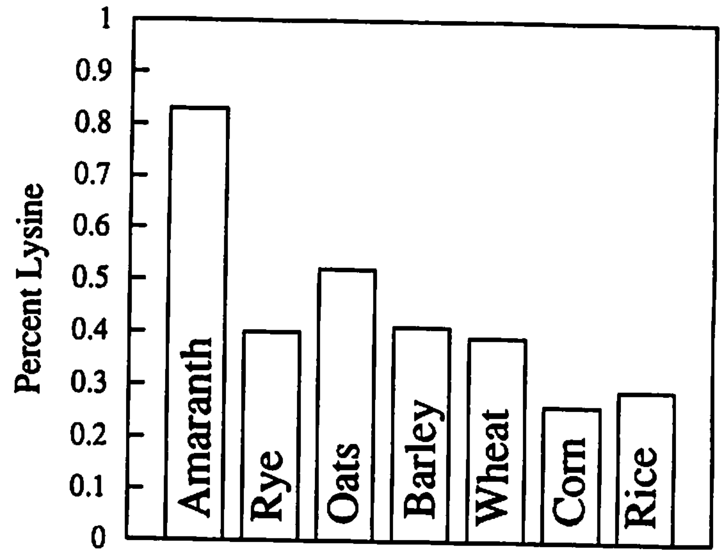

Figure 2. Percent Lysine in Amaranth as Compared to other Grains

SOURCE: National Academy Press, 1983

Conclusions

Growers experience many and varied advantages and disadvantages of producing new crops. A discussion of both advantages and disadvantages relating to amaranth is presented below.

Why Grow Amaranth?

Large grain surpluses accompanied by low grain prices has aroused interest of farmers and researchers for alternative crops. Three arguments can be posed as to why amaranth has the potential to become an alternative crop.

First, grain amaranth has shown indications of being a drought-tolerant crop. Researchers in China report the water requirements for growing species of grain amaranth is 42-47 percent of wheat, 51-62 percent of corn and 79 percent of cotton (Rodale Research Center, 1988). Therefore, amaranth may be an alternative dryland crop for farmers in semi-arid regions and also a prospective crop in irrigated areas where farmers are seeking to reduce irrigation costs.

Second, amaranth grain has a higher protein content than found in other cereals. The seed also contains protein of unusual quality. It is high in the amino acid lysine. In addition, amaranth may be used as a grain substitute for people with food allergies.

Finally, amaranth is a way to diversify a farming enterprise. During the past 15 years it has been common practice for farmers to specialize in only a few crops. Increasing diversity of crops by planting such crops as amaranth can reduce the risk of insect, disease and weed pests becoming serious problems and helps insulate farmers from price variations of a single commodity market. However, as with any aspiring enterprise, researchers and farmers must experiment in learning how to grow and manage new crops.

Problems Growers May Encounter

Some of the needs and management requirements are impediments in producing a crop of amaranth, and there are some major obstacles for farmers to consider before planting amaranth. First, varietal development of amaranth is in its early stages, so the best variety for a particular region or farm may not be available. Second, optimal harvest time for amaranth is after a killing frost. However, shattering losses increase as time between maturity and harvest increases. Third, crop establishment needs special attention because of the small seed size of amaranth. Also, seed size requires combine adjustments to adequately clean the grain without losing it. The cylinder speed of the combine should be reduced as much as possible to minimize grain damage. Cleaning plant residues from the grain at the time of harvest may be necessary for food quality grain. Finally, opportunities for large volume sales of grain amaranth are limited. Contract acreage should be obtained prior to planting.

Amaranth tends to be grown, harvested, and consumed by labor-intensive practices. Therefore, if amaranth is to be developed on a large scale, regardless of location, it must be able to compete economically with alternative crops. Contacts were made to secure information on technical processing equipment to develop processing coefficients for grain amaranth. Everyone contacted has been unsuccessful in acquiring information needed to derive processing costs. Currently, only a few thousand acres of amaranth are planted in the entire United States. Most of the current production is popped and used in specialty health foods. Additional efforts will be made to cooperate with other researchers in the process of developing budgets and processing cost estimates.

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