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Amaranth Rediscovered

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Amaranthus species were grown as the principle grain crop by the Aztecs 5,000 to 7,000 years ago, prior to the disruption of the South American civilization by the Spanish Conquistadors. Synonyms such as "mystical grains of the Aztecs," "super grain of the Aztecs," and the "golden grain of the Gods" were used to describe the nutritious amaranth grain. The grain was noted to be nourishing to infants and to provide energy and strength to soldiers on extended trips. While the early civilizations were aware of these nutrient factors by experience, it would take six centuries for modern biochemistry to confirm these facts. While the grain amaranths were the principle species used on the South American continent, amaranth have been cultivated as a vegetable crop by early civilizations over 2,000 years ago, and continue to be used essentially world-wide even at the present day (NAC 1985). Vegetable *Amaranthus* spp. were and are presently utilized for food from such diverse geographic areas as southwestern United States, China, India, Africa, Nepal, South Pacific Islands, Caribbean, Greece, Italy, and Russia. While various species of grain and vegetable types can be distinguished, often both the grain and leaves are utilized from individual types for use as both human and animal food (Saunders and Becker 1984; Tucker 1986). Present American production is estimated to be between 2,000 to 3,000 ha with the largest production in the Great Plains area, particularly Nebraska, with numerous smaller production areas throughout the Midwest. The stimulus for the present American production and marketing was initiated by the Rodale Foundation and the Rodale Research Center in the mid-1970s. The interest stimulated by the Rodale Foundation led to the establishment of the American Amaranth Institute in Bricelyn, Minnesota, and numerous Amaranth marketing companies, several of which deal exclusively in the purchase, milling, and distribution of amaranth products. In approximately only 15 years, American amaranth has gone from an obscure plant to a recognized grain.

Though quite small in comparison to other grains, amaranth has been extensively studied. There exists a surprisingly large volume of literature available, particularly on the nutritional qualities of amaranth. The strong interest in amaranth within the United States has been promoted by four National Amaranth Symposia and working group meetings by the American Amaranth Institute, and the first International Congress on Amaranth met in Oaxtepec, Mexico in 1991. Although amaranth is considered under new crop status, with minor production areas in the United States, unlike other "new crop candidates" there is an extensive literature and research base. Therefore, we will cite primary review papers in this paper; an overall review of amaranth was presented during the First National Symposium of New Crops (Kauffman and Weber 1990).

Since the historical, taxonomical, genetical, nutritional, processing, and marketing aspects of amaranth have been extensively reviewed, our objective is to focus primarily on production agronomics. Cultivar development and successful cropping management for economic production returns now hold the key to the future of the amaranth industry in the United States.

BOTANY

Taxonomy

The genus *Amaranthus* consists of approximately 60 species, however, only a limited number are of the cultivated types, while most are considered weedy species. *Amaranthus* germplasm is available in 11 countries (Sauer 1967; Toll and von Sloten 1982). Several thousand germplasm accessions are available in the United States at either the Rodale Research Institute, or the USDA North Central Regional Plant Introduction Station at Iowa State Univ., Ames. A taxonomic key for the cultivated species of *Amaranthus* has been developed by Feine-Dudley (Grubben and von Sloten 1981).

There is no distinct separation between the vegetable and grain type since the leaves of young grain type plants can be eaten as greens. The three principal species considered for grain production include: *A. hypochondriacus*, *A. cruentus*, and *A. caudatus*. The species grown as vegetables are represented primarily by *A. tricolor, A. dubius, A. lividus,* and *A. creuntus*. *Amaranthus palmeri* and *A. hybridus* were utilized by natives of early civilizations in the southwestern part of the United States. The weed amaranth, comes from *A. retroflexus* and is considered one of the worlds worst weeds (NAC 1984). The genetic and plant breeding characteristics among the cultivated *Amaranthus* spp. has been considered elsewhere (Kulakaw and Jain 1991; Weber and Kauffman 1990). The *Amaranthus* species have been separated into principally four groups: cultivated, wild and weedy, racial (based on geographic and morphological patterns), and landrace (populations from specific locations).

Physiology

Amaranth, a C_4 plant, is one of a few dicots in which the first product of photosynthesis is a four carbon compound. The combination of anatomical features in amaranth and C_4 metabolism, results in increased efficiency to use CO_2 under a wide range of both temperature and moisture stress environments, and contribute to the plant's wide geographic adaptability to diverse environmental conditions.

Morphology

Grain type amaranth plants have a main stem axis that terminates in an apical large branched inflorescence. The flowers are unisexual, purple, orange, red or gold in color, and are developed on branched flower clusters (glomerules). A glomerule is described as a diachsial cyme that forms large flowering panicles. Vegetable types are generally smooth leafed, with an indeterminate growth habit which produces new succulent axillary growth. The floral buds arise directly in the leaf axils. Amaranth seeds are borne in a utricle, which are classified as dehiscent, semi-dehiscent, or indehiscent types (Brenner and Hauptli 1990). The amaranth seed is quite small (0.9 to 1.7 mm diam) and seed weights vary from 1,000 to 3,000 seeds/g. Seed colors can vary from cream to gold and pink to black. Actual stature of the amaranth plant will vary significantly dependent upon species and environment. In Montana, individual cultivars can vary in height from 91 to 274 cm in height and have stem diameters from 2.54 to 15 cm, dependent upon plant stand density and available soil moisture. Likewise, seed heads have varied from 30 to 112 cm in diameter at the base and varied in height from 13 to 61 cm.

AGRONOMY

Amaranth grain entry into the marketing distribution arena has confronted numerous challenges. In contrast to many other established agricultural commodities, crop production challenges are even greater than marketing to the success of an amaranth industry. In regard to crop production, amaranth certainly is a specialty crop, since every aspect of production, from planting to harvest and storage requires special attention and consideration. Twentieth century amaranth production is vastly different from that of early civilizations or even from primitive agriculture systems present today. In the case of both early civilization and present day primitive agricultural systems, amaranth crop production is grown essentially all by hand in small plots intercropped with numerous other crops or at the very most, small isolated monocultural plots. Crop production under these systems can utilize marginal soils, and disease and insect pressures are often low due to the sparse cropping practices. In contrast, modern day agronomic practices of mechanization and extensive crop monoculture require competitive economic crop returns, and special considerations to integrated plant pest control. Producer production guidelines have been published for several states including Minnesota (Myers and Putnam 1988), Montana (Schulz-Schaeffer et al. 1988), Wisconsin (Putnam et al. 1989), and Nebraska (Baltensperger et al. 1991). A series of comprehensive production guides has been published by the Rodale Research Institute (Kauffman et al. 1983; Weber et al. 1988, 1989, 1990).

To initiate amaranth production, the producer should select and prepare a seed bed similar to that for small seeded vegetables or legumes, preferably on soils having a pH above 6.0 (Schulte et al. 1991). The seedbed should be well worked and firmed by a packer prior to planting. A firm moist seed bed with soil temperatures above 15°C is required to establish a good plant stand. Seeding rates of 1.2 to 3.5 kg seed/ha planted to an average depth of 1.3 cm is recommended. The most accurate commercial seeding rates have been achieved by using vegetable seeders which use seed plates of various sizes to meter the seed. Planting depth needs to be controlled. However, many producers have successfully planted amaranth with either a standard grain drill, or by using the insecticide boxes commonly found on row crop planters for beets, beans, or corn. While seeding rates are less accurate using grain drills, growers drill the seed by either shutting down the openings and seeding heavier rates, or by diluting the amaranth seed with cracked corn or vermiculite. Row widths can be controlled on grain drills by merely taping over selected drill openings to achieve the desired row spacing. Regardless of the type of drill used it is important to firm the seed row with a press wheel which will firm the contact between the amaranth seeds and the soil.

Fertility studies results in Arkansas, Minnesota, Montana, and Tennessee have been quite variable, for both vegetable and grain amaranth types (Walters et al. 1988; Elbehri et al. 1990; Makus 1990b; Putnam 1990; Schaeffer et al. 1990a). A generally suggested fertility guide for amaranth would be 112 to 135 kg/ha of total available N, with a soil test of 15 to 30 ppm P and 80 to 120 ppm K. Fertility needs will vary significantly, depending upon soil type, prior cropping, and fertilizer history. Higher applications of nitrogen would be applied in the high rainfall areas of the Midwest and under irrigated management as compared to the low rainfall production areas in the Great Plains. As the interest in amaranth production increases, additional fertility studies will be needed for economic production practices.

Presently, there are no herbicides labeled for weed control in amaranth, and it is unlikely that any chemicals will become cleared for commercial use. Weed control in amaranth is achieved by cultivation, hand weeding, delayed planting, and by manipulation of plant populations using narrow row spacings. Late planting to avoid spring frosts (as the plant is very susceptible to frost) can aid in weed control, since early spring emerged weeds can be mechanically controlled. Planting amaranth on narrow row spacings of 18 cm or less may aid in weed control, by the shading effect of the amaranth plants.

Harvesting of amaranth is difficult. When plant populations of amaranth are low, the seed heads become extremely large and do not properly dry. When amaranth is harvested prior to a killing frost, plant moisture levels will complicate the harvest. Adequate plant population and a killing frost to dry down the plants prior to harvest is necessary for an effective efficient harvest. Amaranth can then be effectively harvested by grain combines which are seed tight, and by reducing the cylinder speed just high enough to effectively thresh the seed heads. Since amaranth grain must have 12% moisture or lower for storage, the producer must be prepared to dry the harvested seed prior to storage. Storage methods must be sanitary if the seed is to be processed for human consumption.

Amaranth grain yields are extremely variable dependent upon cultivar selection and the growing season, particularly with regard to available soil moisture. Grain yields have ranged from a high of over 5,000 kg/ha in irrigated cultivar trials of the Montana State University Southern Agricultural Research Center at Huntley, to below 112 kg/ha in dryland trials. Yields of 450 to 700 kg/ha dryland and 900 to 2,000 kg/ha under irrigated or high rainfall would be considered reasonable using the better cultivars available to producers.

Nutritive Value

The nutritive composition of both grain and vegetable amaranth has been extensively studied (Becker et al. 1981; Teutonico and Knorr 1985; Pedersen et al. 1987; Bressani 1990). Amaranth grain is considered to have a unique composition of protein, carbohydrates, and lipids. The unique protein composition with regard to quality and quantity has been studied and reviewed (Bressani 1989; Lehman 1989). Grain amaranth has higher protein (12 to 18%) than other cereal grains and has a significantly higher lysine content. The high lysine content of amaranth grain makes it particularly attractive for use as a blending food source to increase the biological value of processed foods (Pedersen et al. 1987). The protein value of amaranth grains is highlighted when amaranth flour is mixed with other cereal grain flours. When amaranth flour is mixed 30:70 with either rice, maize, or wheat flour, the protein quality (based on casein) rises from 72 to 90, 58 to 81, and 32 to 52, respectively (Bressani 1989). Amaranth seed protein also differs from other cereal grains by the fact that 65% is found in the germ and 35% in the endosperm, as compared to an average of 15% in the germ and 85% in the endosperm for other cereals.

The carbohydrates in amaranth grain consist primarily of starch made up of both glutinous and non-glutinous fractions. The unique aspect of amaranth grain starch is that the size of the starch granules (1 to 3 um) are much smaller than found in other cereal grains. Due to the unique size and composition of amaranth starch, it has been suggested that the starch may posses unique gelatinization and freeze/thaw characteristics which could be of benefit to the food industry (Becker et al. 1981; Lehman 1988). Several considerations for the use of amaranth starch in food preparation of custards, pastes, and salad dressing have been published in three papers (Singhal and Kulkarni 1990a,b,c).

Amaranth grain consists of approximately 5 to 9% oil which is generally higher than other cereals. The lipid fraction of amaranth grain is similar to other cereals, being approximately 77% unsaturated, with linoleic acid being the predominant fatty acid. The lipid fraction is unique however, due to the unusually high squalene content (5 to 8%) of the total oil fraction. Also present in the amaranth oil fractions were tocotrienols (forms of vitamin E) which are known to effect lower cholesterol levels in mammalian systems. Detailed studies and a review on amaranth grain oil have been published (Lyon and Becker 1987; Becker 1989; Lehman 1991). In addition to the unique characteristics of the major components of proteins, carbohydrates, and lipids, amaranth grain also contains high levels of calcium, iron, and sodium when compared to cereal grains (Becker et al. 1981).

In contrast to grain amaranth, vegetable amaranth has received significantly less research attention. While vegetable amaranth is used as a delicacy or a food staple in many parts of the world, use in the United States is limited to canned imports for ethnic uses, primarily in the New York City area. Vegetable amaranth has been rated equal to or superior in taste to spinach and is considerably higher in calcium, iron, and phosphorous (Makus 1984; Makus and Davis 1984; Igbokwe et al. 1988; Makus 1990a). Agronomic practices for vegetable production have also been published (Makus 1989, 1990b). The use of amaranth leaves and grain in feedstuffs has been reviewed (Cheeke and Bronson 1980; Sanders and Becker 1984; Teutonico and Knorr 1985; Pedersen et al. 1990; Wittaker and Ologunde 1990; Breene 1991; Pond et al. 1991). Results indicate that the amaranth used for human food should be heated for maximum nutritional benefit, while gains of lambs fed amaranth fodder, were similar to alfalfa (Pond and Lehman 1989). For uses of amaranth as livestock feed, see the review by Sanchez (1990).

Diseases and Pests

The most common insect and disease problems of amaranth have been described in 1990 Amaranth Grain Production Guide and the 4th National Amaranth Conference (Weber et al. 1990; Wilson 1990). A principle insect pest is the lygus bug, *Lygus lineolarius* (Polisot de Beauvois), which can extensively damage the flowering head. Amaranth can also suffer injury from the Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), cabbage looper, *Trichoplusia ni* (Huebner), corn ear worm, *Heliothis zea* (Boddie), cowpea aphid, *Aphis craccavora* (Koch), and the blister beetle, *Epicuata vittata* (Fab.). The amaranth weevil, *Conotrachelus seniculus* (le Cont) can cause severe damage to the roots resulting in lodging and predisposition to root diseases.

In Montana, we have observed extensive damage to young seedlings caused from the potato flea beetle, *Epitrix cucumeris*. We have also identified serious problems induced by the curly top virus disease which is transmitted by the beet leafhopper, *Circulifer temellus* (Stallknecht et al. 1990). Both insect problems appear to be associated with large areas of sugar beets grown in south-central Montana, which is a host to these insects. The only chemical which has been approved for insecticidal use on grain amaranth is Pyrenone Crop Spray (Wilson 1990). Fungal pests of amaranth have been documented as *Pythium, Rhizoctonia* and *Aphanomyces* sp. causing seedling damping off, and stem cankers caused by either *Phoma* or *Rhizoctonia sp*. (Weber 1990). *Alternaria* leaf spot appears to be the most serious foliar pathogen (NARC 1985).

Cultivars

The first line of amaranth registered by The Crop Science Society of America was Montana-3 (MT-3) (Schulz-Schaeffer et al. 1989a). MT-3 is an *A. cruentus* from a selection of RRC-1041 obtained from the Rodale Research Center, Emmaus, PA. MT-3 is light green flowered, produces white seeds, and was selected for uniform height and high yields. Also registered in 1989, was Montana-5 (MT-5) an *A. cruentus* from a single selection of RRC-425 (Schulz-Schaeffer et al. 1989b). MT-5 is green flowered and has white seeds. MT-5 was selected for advanced dry-down characteristics, with the seed head dry down simultaneous to stalk dry down. The third amaranth selection released by Montana State University was named 'Amont' (Schulz-Schaeffer et al. 1991). 'Amont' is a selection taken from MT-3 (Fig. 1). 'Amont' is green flowered and has white seeds, and has resistance to lodging. The plant height of `Amont' can vary from 91 to 244 cm dependent upon the moisture available through the season, and plant population. A semi-dwarf selection from RRC, K432 grows to 92 cm under irrigation, and is grown by producers for commercial production (Fig. 2). The Nebraska Agricultural Experiment Station is presently in the process of releasing the grain amaranth cultivar, 'Plainsman' (PI 358322). 'Plainsman' is a red-flowered, golden seeded selection of *A. hypochrondriacus* (Fig. 3). 'Plainsman' was selected in part based on its early maturity. Also available as a grain amaranth line is A200D which was selected for domestic production by Nu-World Amaranth, Naperville, IL.

FUTURE PROSPECTS

It has been three years since the report on grain amaranth in the First National Symposium on New Crops (Kauffman and Webber 1990). During these past three years, United States amaranth production has risen from approximately 1,000 to 1,800 ha. Nebraska reported an estimated 1,200 ha planted in 1991, Colorado 120 ha, Minnesota 80 ha, and Montana 30 to 40 ha. Reports of production increase of 800 ha though quite small for an agronomic crop, is nearly a doubling in three years.

In a survey response sent to all 50 states, six Land Grant agronomists estimated 2 ha or less of amaranth while 26 reported that they knew of no amaranth production in their respective states. Another 10 states indicated amaranth production of 12 to 1,200 ha, with 14 states not responding to the amaranth questionnaire. Personal communication with the millers and marketers, indicated that while not all grain supplies have been sold, amaranth sales in the market place has been quite active.

Perhaps the key issue with the future of amaranth will be determined by the end-use product. If the primary amaranth product use will continue to be the niche organic health food market then we do not foresee a major expansion of production acreage. However, if amaranth can be incorporated into a major flour milling blend for large volume uses, then significant expansion could follow.

The 1988 amaranth report summarized, "grain amaranth as a new crop that is in its adolescence." In our 1991 report, we can report a small significant healthy growth in the entire industry, from basic and applied research studies, to continued grower innovations, and to a strong viable processing, milling, and marketing industry. Successful agronomic production and cultivation development will be the determining factor to both maintaining and/or expanding the amaranth industry. In Montana, the most successful method to establish amaranth stands can be achieved by fall ridging of the 76 cm rows, spring de-ridging, and planting into firm moist soil. Since the major production areas are in the semi-arid high plains area of the western United States, stand establishment will be most important along with weed control. Weed control can be successful by use of mechanical cultivation and hand weeding when necessary. Given our experiences with grain amaranth during the past nine years, we have been encouraged by the growth of the amaranth industry, particularly the positive attitude of the amaranth marketers. This in turn has encouraged us to suggest to Montana producers that they consider small trials for production considerations (Schaeffer et al. 1989, 1990, 1991).

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Fig. 1. 'Amont' amaranth growing under irrigation, Montana State University, Southern Agr. Res. Center, Huntley.

Fig. 2. 'K 432' amaranth grown under irrigation, Montana State University, Southern Agr. Res. Center, Huntley.

Fig. 3. Field of Pioneer amaranth growing in Sidney, Nebraska, 1991.

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