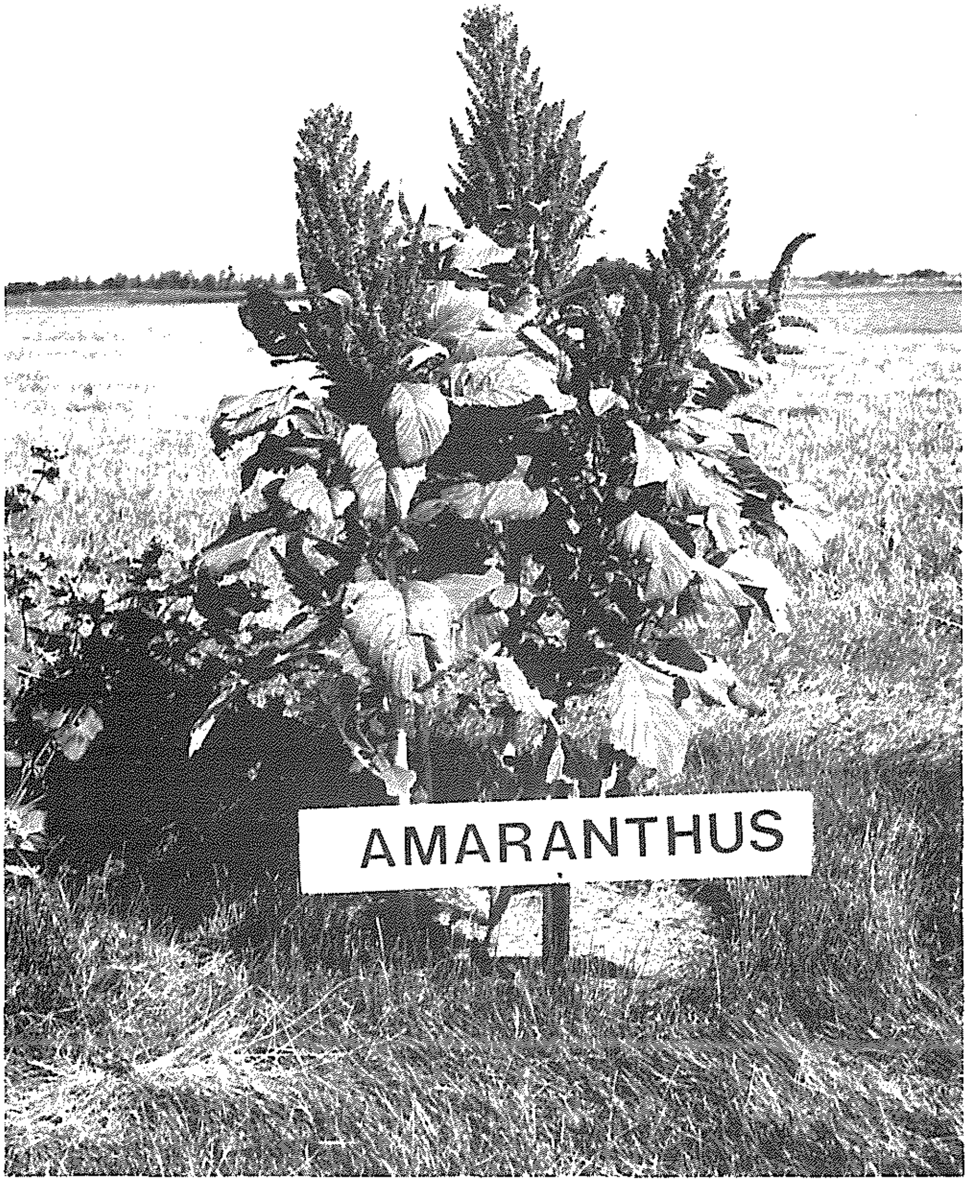
Amaranth, Quinoa, Ragi, Tef, and Niger: Tiny Seeds of Ancient History and Modern Interest

R.G. Robinson

Station Bulletin (571) AD-SB-2949
Agricultural Experiment Station
University of Minnesota 1986



Grain amaranth in September.

AMARANTH, QUINOA, RAGI, TEF, AND NIGER: TINY SEEDS OF ANCIENT HISTORY AND MODERN INTEREST

Robert G. Robinson[1]

Amaranth, quinoa, ragi, tef, and niger, old crops in developing countries, are potential new crops in Minnesota. These crops have been grown intermittently for about 20 years in research plots on silt loam soil at Rosemount and on sandy soil at Elk River or Becker. The crops differ in use, culture, and appearance, but small seed is their common characteristic. A major advantage of small seed is the very few pounds needed to plant an acre (Table 1) and the relatively small space needed to store planting seed over the winter.

Table 1. Approximate planting rates for small-seeded potential crops compared with wheat

Crop	Seeds/ pound (number)	Planting rate/acre (pounds)	Planting rate/ square foot (seeds)
Amaranth	560,000	0.4	5
Quinoa	140,000	1.6	5
Ragi	230,000	5.0	25
Tef	1,815,000	2.0	85
Niger	150,000	4.0	15
Wheat	14,000	80.0	25

Commercial production of amaranth in the United States started in 1983 with about 400 acres followed by nearly 1500 acres in 1984 when production exceeded demand. This led to reduced acreage in 1985-86, but more farmers participated. Despite its small acreage, amaranth is a well-known and important crop in the United States. The large research program at the Rodale Research Center, Kutztown, PA 19530 since 1977 and the promotional efforts of the Rodale Press, Inc., Emmaus, PA 18049 aroused the interest of millions of Americans, and thousands have planted a few amaranth seeds.

Quinoa will be planted for seed increase in Colorado in 1986 and commercial production is planned. Ragi, tef, and niger are not grown commercially in the United States.

AMARANTH

Amaranth was a major grain crop during the Inca and Aztec dynasties of South America and Mexico and is now an important grain crop in parts of India, Pakistan, Nepal, and China. Amaranth is an important vegetable crop in parts of Africa, Southeast Asia, India, China, and the Caribbean. Grain amaranth species are *Amaranthus cruentus* (L.) Thell., *Amaranthus hypochondriacus* L., and *Amaranthus caudatus* L. The leaves of vegetable amaranth are used for boiled greens

[1]The author is a professor, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108.

and include *Amaranthus cruentus, dubius, tricolor, lividus, hybridus, palmeri, gangeticus*, and other species.

Amaranth species in Minnesota are the common weeds -- redroot pigweed (*Amaranthus retroflexus* L.) and prostrate pigweed (*Amaranthus blitoides* S. Wats.). These dark-seeded weeds are hardier than the crops, and redroot pigweed with its strong tap root and upright growth is a serious weed in amaranth (Figure 1).

Figure 1. Grain amaranth (left) and rough pigweed (right) on July 5.

Amaranth is drought-tolerant and grows best in warm, dry weather. Species differ in daylength requirements from short to long indicating a potential world wide adaptation from the equator through the temperate zones. Amaranth, like corn, uses the C_4 pathway of photosynthesis. These crops convert more atmospheric carbon to sugar per unit of water lost than most other crops that use the conventional C_3 pathway. Consequently, amaranth has great potential but undeveloped yielding ability.

Varieties

Varietal trials from 1977 to 1982 at Rosemount included about 20 varieties belonging to several species, and seed yields ranged from 300 to 3800 pounds per acre from hand-harvested plots. Heights ranged from a few inches for some vegetable varieties to over 8 feet for some *A. hypochondriacus* varieties. *A. cruentus* varieties headed about 9 days earlier than *A. hypochondriacus* varieties. Most of the United States crop consists of white-seeded varieties of *A. cruentus* and include:

R 1041 was selected by the Rodale Research Center in plantings made from seed collected in Mexico. R K112 is a white-seeded selection from a cross made at the Rodale Research Center between a black-seeded African and a white-seeded Mexican line. R 158 is a uniform selection of R K112 made by Johnny's Selected Seeds, Albion, ME 04910.

A. hypochondriacus varieties are also available but not commonly grown as a farm crop. Selections from crosses between *A. hypochondriacus* and *A. cruentus* are now available.

Amaranth is monoecious with one male flower in each group (glomerule) of female flowers. There has been no evidence of intercrossing between varieties in progeny of seed saved from plantings at Rosemount. The breeders at the Rodale Research Center are handling amaranth as a self-pollinated crop. In some other environments, outcrossing has been reported.

Seedbed Preparation and Planting

The home gardener can either plant seed by hand and thin or transplant started plants, but stand establishment is a major problem in farm fields. Germination and emergence should be fast and uniform so that the crop establishes before weeds. Amaranth requires a warm soil, preferably over 65° F, for germination. Soil temperature near the surface fluctuates with air temperature, but consistently warm temperatures are not achieved until June. A major advantage of delaying planting until June is that many weeds emerge earlier and will be destroyed by seedbed preparation tillage.

The small seed and weak seedlings make shallow planting (<0.5 inch) necessary (Table 2). A seedbed suitable for larger-seeded grain crops may have a layer of dry clods over 0.5 inches thick on the surface, but a seedbed for amaranth should be fine and firm on the surface. Seedbeds prepared with the common disk/spike-tooth harrow combination can be cultipacked before planting, or planters with press wheels in front of the furrow openers will firm the seedbed. Rolling basket, coil tine, flexible spike, and Meeker harrows can make fine, compact seedbeds without cultipacking.

Table 2. Planting depth and emergence of amaranth

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

Seeds can be sown with vegetable planters using celery or similar size plates, sugarbeet planters with modified seed plates, cultipacker seeders, or grain drills. If the small forage-seed box on a grain drill is used, the ends of the forage seed tubes should be placed in the furrow openers so that the seed is drilled shallow rather than scattered on the dry surface. Amaranth seed is too small for the grain box of a grain drill unless it is diluted with ground corn. Corn seeds ground in a hammermill and then separated into flour and various sizes of grits in a fanning mill make a good diluent. If a 0.5 pound per acre planting rate is desired, then mix 0.5 pounds of amaranth seed with 4.5 pounds of corn flour and/or grits and calibrate the planter for 5 pounds per acre. Corn flour alone may be satisfactory, but some grits are usually needed to prevent bridging unless there is continuous agitation. The best proportion of amaranth to diluent depends on the planter. Diluted amaranth mixtures are often helpful in home garden vegetable planters.

Modern agriculture is moving toward zero tillage to conserve soil, energy, and labor. Amaranth seedlings are weak and often break in the hypocotyl when exposed to strong winds in open fields, and zero tillage would resolve that problem. Consequently, zero tillage was compared with conventional seedbed preparation (moldboard plow in October, disk in June followed by a C tine-rolling basket harrow). The two zero tillage treatments were double cropped with oat or alfalfa planted in March-April and harvested for forage in June. Amaranth was planted in the oat and alfalfa stubbles and fallow (conventional tillage) strip, and the stubbles were sprayed with glyphosate (Roundup) to kill the remaining crop and weeds (Table 3, Figure 2).

Figure 2. Amaranth in July in rows 30 inches apart in oat stubble (foreground), alfalfa stubble (middle), and fallow (background). Amaranth was planted June 10 and then sprayed with glyphosate to kill all green vegetation.

Table 3. Comparisons of amaranth sown June 9-10 in oat stubble, in alfalfa stubble, or in a tilled fallow seedbed

	Oat or alfalfa				Amaranth								
	Forage yield/acre (pounds)[1]				Seed yield/acre (pounds)				Plants/acre	Planting to heading	Height	Weed control	Lodging
Seedbed	1980	1981	1982	1980-82	1980	1981	1982	1980-82	(thousands)	(days)[2]	(inches)[3]	(percent)[3]	(percent)[4]
Oat stubble	944	4137	968	2016	830	674	337	614	94	69	56	77	26
Alfalfa stubble	407	1287	194	629	887	699	323	636	80	69	66	74	19
Fallow	0	0	0	0	1166	618	461	748	96	64	69	53	14
LSD 5%					125	75	100	62	16	1	6	1	1

[1]Oven-dry. [2]1980,82. [3]1981-82. [4]1982.

Table 5. Amaranth performance in cultivated rows 30 inches apart and in noncultivated rows 6 inches apart at two planting rates and in rows 12 inches and 30 inches apart with winter rye between rows for soil cover

Row spacing (inches)	Seeds/acre planted (thousands)	Plants/acre at harvest (thousands)[1]	Seed yield/acre (pounds)				Planting to heading (days)[2]	Height (inches)[1]	Lodging (score)[1,3]	Weed control (percent)[1]
			1980	1981	1982	1981-82				
30	100	43	867[6]	693	483	588	68	77	2.8	82
6	100	98	1272[6]	661	383	522	67	66	2.2	70
6	250	110	--	770	394	582	67	65	3.2	71
12[4]	100	66	--	658	289	474	67	58	1.5	59
12[4]	250	99	--	709	319	514	67	57	1.6	64
30[4]	100	56[5]	--	537	--	--	--	59[5]	2.8[5]	55[5]
LSD 5%		14	--	141	129	96	1	3	0.5	10

[1]1981-82. [2]1980, 82. [3]1=erect, 9=flat. [4]Single row of winter rye sown at 28 pounds/acre between 12-inch rows of amaranth, and 4 rows of rye 6 inches apart sown at 44 pounds/acre between 30-inch rows of amaranth. [5]1981 data adjusted to be comparable with multi-year data. [6]Planted 500,000 seeds/acre.

The oat and alfalfa forage yields varied greatly among years with the highest yields in 1981 when weather permitted planting on March 25 compared with plantings on April 26 in 1980 and 1982. The slightly lower amaranth yields in zero tillage seedbeds were caused by much slower emergence in the stubbles. The slow emergence probably resulted from colder soil under the stubble, but drier soil also contributed. A residual nitrogen benefit after fallow and alfalfa was evident in both greener and taller plants than after oat. Both stubble seedbeds gave better weed control than conventional tillage because weed seeds were not moved into favorable locations for germination. Although not a factor in these small plots, the stubbles provided good protection against wind damage to amaranth and soil erosion by wind and water.

Amaranth adjusts to a wide range of plant population densities without greatly altering its performance (Table 4). Highest yields were obtained from planting rates of 100,000 to 250,000 seeds per acre which developed into plant population densities of 73,000 to 85,000 plants per acre or nearly two plants per square foot. The lowest population lodged least because of its larger, sturdier stems.

Table 4. Planting rates and amaranth performance, 4 trial average[1]

Seeds/acre planted (thousands)	Plants/acre at harvest (thousands)	Seed yield/acre (pounds)	Planting to heading (days)[2]	Height (inches)	Lodging (score)[3]	Weed control (percent)[4]
100	73	787	68	76	2	7
250[4]	85	847	67	75	4	7
500[2]	190	658	67	68	3	7
1000[5]	446	511	68	73	3	-
LSD 5%	14	96	1	3	1	1

[1]Data for planting rates not included in all trials are adjusted to be comparable with those in all trials. [2]3 trials. [3]1=erect, 9=flat. [4]2 trials. [5]1 trial.

Seed yields of amaranth in cultivated rows 30 inches apart and in noncultivated rows 6 or 12 inches apart planted at 100,000 seeds per acre in 1981 and 1982 did not differ significantly, however weed control was slightly better in the cultivated rows (Table 5, Figures 3 and 4). In comparisons at a higher planting rate of 500,000 seeds per acre in 1980, 6-inch rows produced higher yields than 30-inch rows.

Winter rye and amaranth were planted in alternate rows 12 inches apart (Figure 5) and with four rye rows 6 inches apart between amaranth rows 30 inches apart (Figure 6) in order to give wind protection to young amaranth, to control weeds, and to reduce wind and water erosion. Winter rye planted in June provides a leafy growth competitive with weeds and then dies in late July and August from heat, leaf rust, and competition from amaranth and weeds. Although yield and weed control were not improved in these trials, these techniques with more testing and modification may become useful in commercial production of amaranth on large, erosive fields.

Figure 3. Amaranth in September in cultivated rows 30 inches apart.

Figure 4. A black-seeded amaranth introduction of a different head type from Africa in rows 6 inches apart.

Figure 5. Amaranth and winter rye in July after planting in alternate rows 12 inches apart on June 10.

Figure 6. Amaranth and winter rye in July after planting four rye rows 6 inches apart between amaranth rows 30 inches apart on June 10.

Harvesting and Storage

Amaranth remains green and growing even after the earliest seeds are mature, dry, and starting to shatter. Consequently, a freeze to kill the plant followed by a week of dry weather is needed before combine harvest from the standing plants is efficient. Both amaranth plants and tall weeds should be dry so that wet juices don't stick amaranth seeds to the straw and insides of the combine.

Preharvest desiccant sprays do not have EPA approval, and many amaranth consumers do not approve of agrichemicals. Windrowing is not practical because drying of large heads and stems in the windrow is slow, and in contrast to other small grain crops, amaranth stubble is too sparse to hold up the windrow. Another untested alternative is to cut and bind the plants with a corn binder and then dry the bundles in shocks before threshing.

Shattering losses in combining the standing crop may be reduced by reel adjustment and removal of alternate bats. Combines with snout dividers between individual rows have lower shattering losses than those with small grain headers when harvesting wide-row amaranth. Seed catching pans used for sunflower harvesting might be effective in reducing shattering loss.

Small plantings can be harvested by removing the heads with a knife and then drying the heads in bags before threshing. Or the seed can be harvested several times from the same plants by shaking the ripe seeds into a bushel basket without injuring the plants.

The maximum moisture level for safe storage of amaranth seed is not known, but it is lower than that of the large-seeded grain crops. One estimate is 11 percent. Average test weight per bushel of mature amaranth seed harvested at Rosemount was 63 pounds. Consequently, less bin volume is needed to store a given weight of amaranth than that needed for other grain crops.

Pests

The only insects that noticeably damaged research plots at Rosemount were fleabeetles and lygus bugs. Fleabeetles often caused severe shot hole damage in the leaves of young plants. Damage was not noticeable in older, larger plants. A similar problem is the early defoliation of mustard crops by fleabeetle. The control in mustard is chemical seed treatment which protects the seedling in the first few days after emergence. Such treatments need research in amaranth. Enormous populations of lygus bugs were usually present in the heads. These sucking insects probably reduced yield by feeding on the immature seeds.

Diseases were not an evident problem, but seed treatments to enhance emergence and decrease damping off should be investigated.

After the seed forms, amaranth attracts goldfinches, sparrows, and other birds. Birdfeeding on seeds and/or insects in the heads probably caused more loss from shattering than from feeding.

Amaranth For Food

A major focus of amaranth promotion is its nutritional value. Amaranth scores higher than major crops such as corn and wheat on nutritionists' scales of protein quality. Leucine is the limiting essential amino acid in amaranth, but that is unimportant because corn and other grains have excess leucine. Amaranth compared with corn and other grain crops that are members of the grass family is much higher in lysine amino acid and usually higher in protein. Diets containing protein from both amaranth and corn rank very high in amino acid balance. However, amaranth should be compared with buckwheat in the United States.

Buckwheat was an important crop in pioneer times because it provided a nutritious variation in the high grain and tuber diet required in a developing country. Buckwheat declined in importance because it yields less food and feed than other grain crops, and its distinctive flavor is not essential in American diets. Both amaranth and buckwheat are nongrass grain crops; both crops are planted in late spring or early summer; both crops and their products are high priced, specialty foods compared with staple food crops.

The 18 amino acids found in amaranth grown at Rosemount are ranked in descending order of their percentages of oven-dry amaranth seed in Table 6. Buckwheat seed is covered by a hull which is removed before it is used for food. Consequently, amaranth seed (column 2) should be compared with buckwheat seed (column 4) or buckwheat groat (column 5) depending on the intent of the comparison. Using either comparison, the amino acid profiles of amaranth and buckwheat are reasonably similar, and both crops are satisfactory sources of the essential amino acids for human nutrition. The columns headed protein (columns 3 and 6) in Table 6 show the amino acid composition of the true protein remaining after removal of the other constituents of the seeds. Comparison of the two columns show that the proteins of amaranth and buckwheat are nutritionally similar.

Table. 6. Average amino acid concentrations in amaranth and buckwheat seeds produced at Rosemount

	Amaranth[1]		Buckwheat[2]		
Amino acid	seed	protein	seed	groat	protein
	(percent)				
Glutamic acid	2.04	17.49	1.99	2.72	18.02
Arginine	1.21	10.37	1.47	2.01	13.30
Aspartic acid	1.02	8.73	1.20	1.64	10.86
Glycine	0.80	6.83	0.61	0.83	5.52
Leucine	0.73	6.26	0.75	1.02	6.75
Lysine	0.69	5.88	0.66	0.90	5.99
Serine	0.67	5.79	0.46	0.62	4.12
Valine	0.58	5.01	0.85	1.17	7.71
Phenylalanine	0.54	4.67	0.46	0.63	4.17
Proline	0.52	4.49	0.41	0.55	3.66
Isoleucine	0.48	4.12	0.39	0.53	3.48
Tyrosine	0.47	4.06	0.23	0.32	2.12
Alanine	0.44	3.75	0.45	0.61	4.03
Threonine	0.43	3.73	0.43	0.58	3.87
Histidine	0.38	3.29	0.23	0.32	2.11
Methionine	0.28	2.36	0.15	0.21	1.37
Cystine	0.26[3]	2.23[3]	0.18	0.25	1.66
Tryptophan	0.11[3]	0.94[3]	0.14	0.19	1.29

[1]1977, 1979 crops averaged. [2]1977-78 crops averaged.
[3]Data adjusted from other sources to be comparable.

Protein percentages of foods are calculated by various methods. However, the methods are calibrated to give protein percentages based on the product of percent nitrogen times a nitrogen-to-protein conversion factor. Factors of 6.25 and 5.85 have been used for amaranth, but 6.25 is used arbitrarily for most crops. Calculations based on the analyses reported in Table 6 show that 5.90 is the correct conversion factor for amaranth without inclusion of ammonia in the calculations and 5.46 with ammonia included. The comparable figure for buckwheat is 5.76 without ammonia.

Comparisons of amaranth seed and buckwheat groat (Table 7) show that they are similar in protein, carbohydrate, and ash concentrations, but amaranth seed is higher in fat and fiber. Elemental composition data (Table 8) may be used to calculate nutrient removal by crops and thus serve as a guide for soil fertility maintenance. At present yield levels, nutrient removal by these crops is minor.

Table 7. Average nutritional composition of amaranth and buckwheat seeds produced at Rosemount and Elk River[1]

	Protein[2]	Carbohydrate	Fat	Fiber	Ash
	(percent)				
Amaranth seed[3]	15.4	65.7	6.3	4.1	2.5
Buckwheat seed	12.3	73.3	2.3	10.9	2.1
Buckwheat groat	16.8	67.8	3.2	0.6	2.2

[1]12 percent moisture basis. [2]Nitrogen to protein conversion factor of 6.25. [3]Rosemount.

Table 8. Elemental composition of amaranth and buckwheat seeds produced at Rosemount, Becker, and Elk River[1]

Element	Amaranth[2]	Buckwheat
	(percent)	
Nitrogen	2.8	2.2
Phosphorus	0.6	0.5
Potassium	0.5	0.6
Calcium	0.2	0.1
Magnesium	0.3	0.3
Sulfur	--	0.2
	(parts/million)	
Iron	100	53
Zinc	52	37
Manganese	36	30
Aluminum	13	25
Sodium	10	70
Boron	9	13
Copper	3	8
Lead	<1	<1
Nickel	0.6	2
Chromium	0.4	0.2
Cadmium	<0.1	<0.1
Molybdenum	--	<2.5

[1]Oven-dry moisture basis. [2]Rosemount.

Amaranth is grown for home consumption and as a commercial cash crop. The seeds can be popped like popcorn although it is difficult to prevent burning; popped seeds are still very small as popping expansion is about 4 to 1. The seeds can be soaked in water and cooked like oatmeal; time of soaking is adjusted to give the desired texture. Many amaranth products are available in food stores including seed, popped seed, flour, crackers, granola, cereal, cookies, and confections.

Antinutritive factors occur in amaranth seed but at similar levels to those in some legumes and sorghum, consequently, they are not expected to present any nutritional hazard.

Vegetable amaranth leaves are boiled in water and eaten like spinach. The protein quality of the leaves is high, and the leaves are excellent sources of vitamins, calcium, and iron. Amaranth, like other leaf vegetables, contains many antinutritional factors including nitrates and oxalates especially when grown under dry conditions. Cooking removes much of the nitrates and oxalates if the cooking water is discarded.

QUINOA

Quinoa (*Chenopodium quinoa* Willd.) has been grown for centuries in high altitude areas of Chile, Peru, and Bolivia. Quinua, a more native spelling of the common name, has also been used for the grain amaranth species, *Amaranthus caudatus*. Quinoa and amaranth, although of different botanical families, have similar characteristics, uses, and ancient history. Amaranth was more widely adapted and important than quinoa in ancient South America, but quinoa established its niche at high altitudes.

Quinoa is used for flour, soup, breakfast cereal, and alcohol. Seed of some varieties have bitter saponin compounds which must be removed in soaking water before consumption; other varieties are saponin-free. The leaves are eaten as a leafy vegetable like spinach.

Quinoa seed ranges from 12 to 18 percent protein, but the protein quality is better than that of grain crops like wheat. Like amaranth, it is high in lysine amino acid. Seed imported from South America and products containing it are sold as health foods at high prices in the United States.

Related species are common lambsquarters weed (*Chenopodium album* L.), canahua (*Chenopodium pallidicaule* Aellen), and wormseed *Chenopodium ambrosioides* L. *anthelminticum*.

Canahua or canihua is shorter, more branched, and smaller seeded than quinoa. The seed is black and shatters when the plants are shaken. It is grown at higher altitudes, 12,000 to 14,000 feet, than quinoa in the semi-arid plateau of the Andes Mountains. Canahua is tolerant of frost and cool weather. It can germinate at 40° F, flower at 50° F, and mature seed at 60° F.

Wormseed is grown for its oil, but acreage and markets in the United States are small. Wormseed oil is obtained by distilling the entire plant although most of the oil is in the seeds. About 40 pounds of oil are obtained per ton of plant. The oil contains ascaridole that is used in worm medicines.

Quinoa is mostly self-pollinated but cross-pollination occurs so isolation of about 650 feet is desirable for pure seed production.

Quinoa was planted in mid-May at Rosemount. It emerged about June 1 and was attacked by fleabeetles and aphids which necessitated spraying. It grew about 2 feet tall but did not flower or produce seed. High summer temperatures at Rosemount probably caused it to become dormant. Cool temperatures at the high altitudes where it is grown allow various varieties to mature within a range of 80 to 150 days.

The Colorado Agricultural Experiment Station is releasing an experimental yellow-seeded variety for production on about 50 acres in 1986. Agronomist D. L. Johnson estimates that the crop has a potential acreage of 6,000 in Colorado at elevations above 7,000 feet. The new variety grows 3 to 4 feet tall, matures in 100 days, and resists shattering. It will be grown in rows 20 to 30 inches apart, irrigated, and harvested with a combine. Yields of 1,200 pounds per acre are expected. Varieties adapted to lower elevations and of white seed color are expected in the future.

RAGI OR FINGER MILLET

Ragi or finger millet [*Eleusine coracana* (L.) Gaertn.], also called African millet, is a major grain crop in parts of the tropics, subtropics, and semi-arid tropics to about 30 degrees north or south latitude. Ragi is consumed in bread, porridge, puddings, and liquor in Africa and Asia. The grain is deficient in lysine but above average in the sulfur-containing amino acids and tryptophan, so it complements the deficiencies of pulse crops. Consumption of both ragi and pulses provides a good balance of amino acids in the diet.

Although plantings in May were satisfactory in Minnesota, experience from 1967 to 1981 indicated that June plantings were best. Most introductions did not produce seed in Minnesota. In one trial of 28 introductions from India and eight African countries, only one introduction produced seed on some plants (Figure 7). Selection continued for several years, and data reported here are primarily from this selection. The grain yield of ragi was not high enough in Minnesota to compete with adapted grain crops. Consequently, research was focused on its forage potential. The early maturing Minnesota selection was used even though later maturing lines had greater forage yield.

Empire is a recommended variety of foxtail millet [*Setaria italica* (L.) Beauv.]. Comparisons of ragi and Empire planted in June in rows 6 inches apart indicate that Empire is about the same or slightly higher in forage yield and much higher in seed yield (Table 9). However ragi averaged higher than Empire in forage protein and digestibility.

Ragi leaves retain green color and density to the base of the plant long after heading (Figure 8). The top leaf blade on all plants tends to be bent or broken by August. The large flat stems elongate slowly so tall, leafy plants have short stems for a long time. However, early cutting to avoid stems in the forage required two harvests (Table 10). Although digestibility and protein decreased as the stem elongated, good digestibility compared with alfalfa was retained through the heading to seed stage (Table 10). The increase in digestibility at the heading to seed stage may be attributed to the seed. Pasturing of the high quality forage before stem elongation is untested but should be practical. Ragi has a very strong, dense root system in contrast to the weak root system of foxtail millet.

Figure 7. Minnesota ragi selection (center) heads earlier than most ragi introductions.

Table 9. Comparison of finger and foxtail millets grown in rows 6 inches apart at Rosemount and Elk River, 1967-76

Location	Years of trial	Finger millet	Foxtail millet
		forage/acre (pounds)[1]	
Rosemount	9	7,770	8,430
Elk River	3	3,550	5,880
Elk River irrigated	1	8,020	7,760
		forage protein (percent)[1]	
Rosemount	5	9.4	8.6
Elk River	3	7.7	6.9
Elk River irrigated	1	7.1	7.4
		forage digestibility (percent)[2]	
Rosemount	4	64	58
Elk River irrigated	1	59	62
		grain/acre (pounds)[3]	
Rosemount	2	950	1890

[1]Oven-dry. [2]Good alfalfa standard was 64 percent. [3]Separate plots not harvested for forage.

Figure 8. Ragi produces high yields of forage. The common name, finger millet, is derived from the appearance of the heads.

Table 10. Growth stage at harvest and performance of finger millet at Rosemount, 1972-75

Harvest stage stem length (inches)	Forage yield/acre (pounds)[1]	Digestibility (percent)[2]	Protein (percent)[1]
1 to 9	6149[3]	65.9	16.3
12 to 16	6757[4]	61.2	12.4
19 to 29	7836	61.2	14.9
headed to seed	8382	63.7	9.8
LSD 5%	719		

[1]Oven-dry. [2]Good alfalfa standard was 64.3. [3]Harvested twice. [4]Harvested twice in 1975; once in other years.

Minnesota ragi, Empire foxtail millet, Minhybrid 7301 corn (Becker), Minhybrid 7301 and M 309 corn (Rosemount), and NK Sordan 77 (sorghum X sudangrass) hybrid were compared in rows 30 inches apart. The corn and sorghum were planted May 13-26 and the millets June 2-29 (Table 11). All were harvested once at mature silage stage except for two cuttings of the ragi that was cut before the stem elongated. Grain yields at maturity were determined on adjacent plots not harvested for silage.

Table 11. Comparison of finger millet (ragi) with foxtail millet, corn, and sorghum X sudangrass hybrid grown in rows 30 inches apart at Rosemount from 1978-81 and at Becker from 1979-81

		Forage[1]						Grain[2]	
	Growth	Yield/acre (pounds)[3]		Protein (percent)[3]		Digestibility (percent)[4]		Yield/acre (pounds)	
Crop	stage	Rosemount	Becker	Rosemount[6]	Becker[5]	Rosemount	Becker[5]	Rosemount[6]	Becker[5]
Ragi	<5-inch stem	6,590[5]	3,150	17.0[5]	18.0[7]	63	65	--	--
Ragi	silage	11,560	6,540	10.8	12.0	61	63	1,680	1,760
Foxtail	silage	10,680[6]	5,380	10.5	10.5	56	60	2,190	1,910
Corn	silage	18,710[6]	7,360[5]	7.0	8.6[7]	66	64	5,620[5]	4,480
Sorghum	silage	15,750	8,920	7.1	7.6	60	62	3,590[5]	2,790[7]

[1]Includes grain present at harvest. [2]Separate plots not harvested for forage. [3]Oven-dry. [4]Calculated from acid detergent fiber analyses. [5]2 years adjusted to be comparable with multi-year data. [6]3 years adjusted to be comparable with multi-year data. [7]1 year adjusted to be comparable with multi-year data.

Ragi cut before stem elongation had extremely high protein, but yields were almost doubled by waiting until silage stage. Ragi was slightly higher in forage yield and decidedly better in quality than foxtail millet. Foxtail millet is not as well adapted to 30-inch rows as ragi. Corn and sorghum X sudangrass are well adapted to 30-inch rows, and they were much higher in yield but lower in protein than the millets. Corn produced the highest grain yields. Empire outyielded ragi but grain yields of both were sufficiently high to allow seed production for sale to farmers at a reasonable price.

Ragi is self-pollinated. Less than 1 percent natural crossing was reported by researchers in Africa. Test weights per bushel of mature seed harvested at Rosemount ranged from 49 to 54 pounds.

A related species is goosegrass [*Eleusine indica* (L.) Gaertn.] which is an annual grass weed in the tropics. Introductions from India and Kenya made a spreading growth like crabgrass rather than upright like ragi. They grew about 2 feet and headed but did not mature seed at Rosemount.

TEF OR TEFF

Tef [*Eragrostis tef* (Zucc.) Trotter] has been a major grain crop in Ethiopia since antiquity. The crop is little grown outside of Ethiopia where it is called t'ef (tee-ef). The scientific name used to be *Eragrostis abyssinica* (Jacq.) Link., in recognition of Ethiopia's old name, Abyssinia. White- and brown-seeded varieties are grown. The grain is ground into flour and used for unleavened bread since there is little gluten in the grain.

Tef is a warm-season grass and a poor weed competitor until fully grown, so a high seeding rate is suggested for weed control (Table 1). Four introductions were tested at Rosemount, and they required 67 to 80 days from planting to heading when planted June 5 (Figure 9). Earlier plantings did not emerge. Only the early variety produced seed -- 1,000 pounds per acre from June 5 planting and 220 pounds per acre from June 24 planting. The plants remained green and leafy, and the seed shattered easily. A killing frost or a preharvest desiccant would be needed for combine-harvest of the standing crop. Otherwise the crop would need to be dried in windrows before combining.

Figure 9. The earliest maturing introduction of tef did not head until mid-August.

Tef is fine stemmed and the plants remain green and leafy to the base, indicating that it might have value for forage. Related species are used as perennial, warm-season pasture grasses from Texas-Oklahoma to California. Weeping lovegrass [*Erag-*

rostis curvula (Schrad.) Nees.] and sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood.] are examples of the *Eragrostis* species used in the United States for forage. Stinkgrass (*Eragrostis cilianensis* All.) is a common annual weed in Minnesota.

Tef is self pollinated, so isolation is not needed for pure seed production.

Tef and ragi were compared in forage production at Rosemount and Elk River (Table 12). Ragi yielded more forage than tef and was higher in protein or digestibility in five of six comparisons. The Minnesota ragi selection is higher and more dependable in seed yield than any of the tef introductions. Consequently, ragi has greater potential than tef as an annual, warm-season, grass forage crop in Minnesota.

Table 12. Comparative performance of tef and ragi (finger millet) for hay (single cut) or pasture (two or three cuts)

Year and trial	Location	Tef	Ragi	Tef	Ragi
		yield/acre (pounds)[1]		protein (percent)[1]	
1968 hay	Rosemount	6,353	6,666	7.3	12.4
1969 pasture total	Rosemount	--[2]	4,932	--	--
first cut		--[2]	2,142	--	25.0
second cut		--[2]	1,710	--	20.2
third cut		--[2]	1,080	--	20.8
1970 hay	Rosemount	5,016	11,144	16.1	11.2
1970 pasture total	Rosemount	1,440	2,256	--	--
first cut		932	690	24.8	26.2
second cut		508	1,033	--	--
third cut		--	533	--	--
1971 hay dryland	Elk River	3,249	4,211	8.2	10.5
1971 hay irrigated	Elk River	6,190	8,614	7.8	8.8
		digestible dry matter (percent)			
1971 hay irrigated	Elk River	--	--	57.0	59.1

[1]Oven-dry. [2]Failed to establish satisfactory stands.

NIGER

Niger [*Guizotia abyssinica* (L.) Cass.], also called Nigerian thistle, is imported from India (formerly from Ethiopia) and used for birdfeed in the United States. It has been a major oilseed crop in Ethiopia since antiquity and is also used as an oilseed crop in India. It is in the same plant family as sunflower, an important oilseed crop in Minnesota, but the seed and plants resemble thistles without spiny leaves (Figure 10).

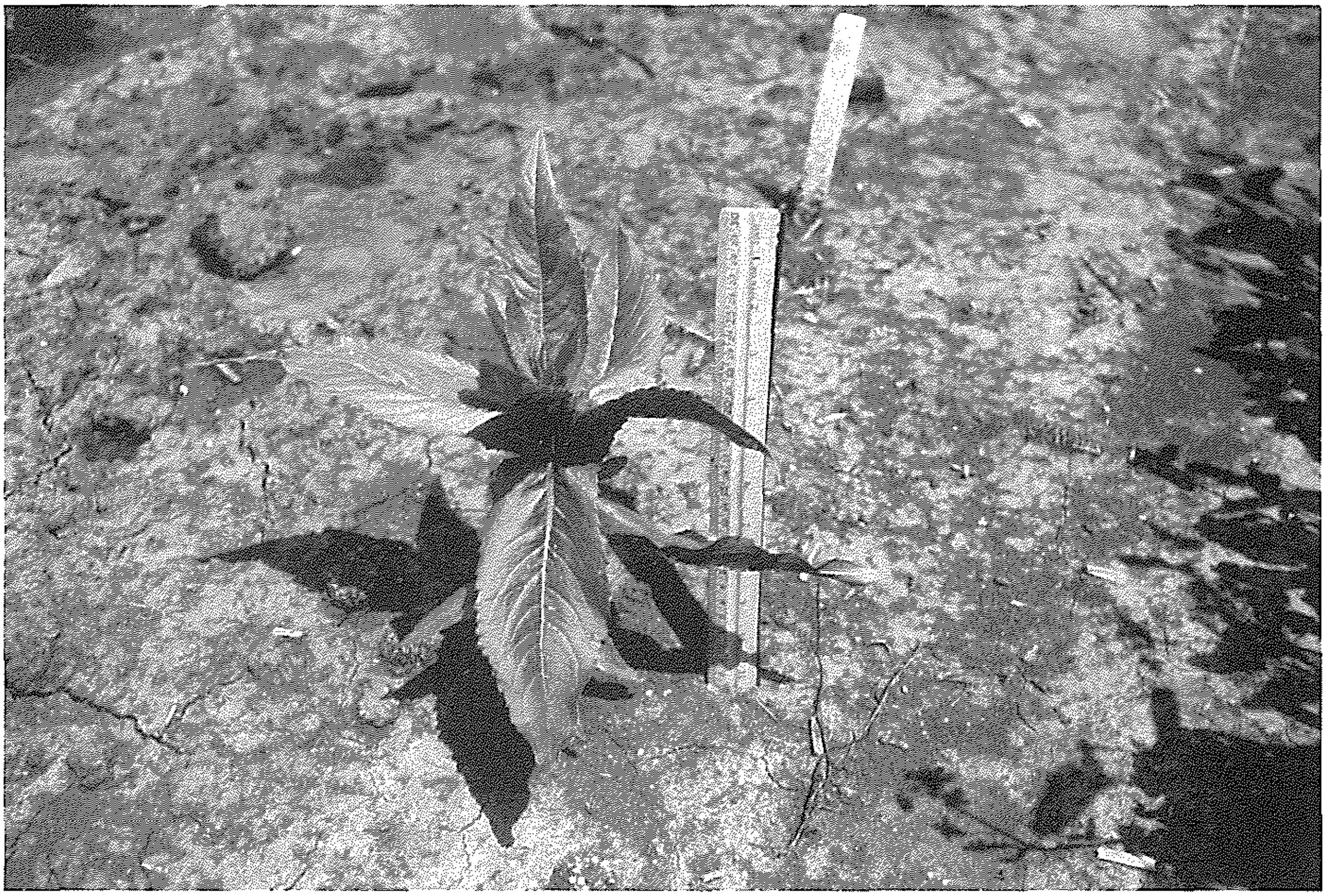


Figure 10. Niger on July 5. It was planted May 5 and will grow rapidly in July and August.

Oil concentration in niger seed is about like that of sunflower, 40 to 45 percent, and the oil is used primarily for food. It can be used in soap, paint, oil lamps, and other nonfood uses. Niger oil characteristics of potential value for cosmetics are its lack of odor and its capacity for absorbing fragrances of flowers. The meal remaining after oil extraction is about 37 percent protein.

Introductions from Ethiopia and India have been grown in research plots at Rosemount. Production practices were similar to those used for sunflower. Planting dates ranged from late April to June 1 and it required 2.5 weeks to emerge. Trifluralin (Treflan 4E) at 1 quart/acre preplant incorporated and cultivation controlled weeds. Row spacing was 30 inches, and plants grew 3 to 4 feet high by

September (Figure 11). In only 1 of 3 years did the plants bloom before frost, and the yellow flowers, 1.25 inches in diameter, failed to produce mature seed. Yields of about 375 pounds per acre are reported in Ethiopia.

Figure 11. Niger with a few flowers in September.

Since niger is an annual and did not produce seed, it should not become a weed in Minnesota despite its wide distribution in birdfeed. However, weed regulatory personnel in some states have been alerted to this hypothetical problem.

Niger seed could be produced in states with longer growing seasons. It has produced seed at Lincoln, Neb. Seed production in the United States to replace imports would reduce the foreign trade deficit by millions of dollars. However, potential yields and economics of production in the United States are unknown. Variability in maturity was evident at Rosemount indicating that varieties differing in maturity might be developed for south and central United States. Niger flowers are cross-pollinated by insects so isolation is needed for pure seed production.

The five crops discussed in this report are examples of many potential field crops evaluated by the University of Minnesota Department of Agronomy and Plant Genetics. The research started in 1948, and publications on some of the crops are available in agricultural libraries and county extension offices. New and uncommon field crops are of current interest as potential future alternatives to continued surplus production of the major field crops.

Alternative crops researched were sunflower, safflower, fieldbean, fieldpea, chickpea, grasspea, cowpea, tangierpea, sainfoin, lupine, peanut, fababean, adzuki, lentil, crownvetch, vetch, teparybean, mungbean, fenugreek, hyacinth bean, berseem, guar, sunn hemp, hemp, kenaf, rye, annual canarygrass, sorghum, broomcorn, millet, buckwheat, castorbean, naked-seeded pumpkin, crambe, rape, canola, mustard, tyfon, kale, comfrey, flax, sesame, fodder beet, anise, coriander, and about 200 other uncommon crops. Most alternative crops have genetic or production deficiencies or very limited usage. Consequently research is needed to develop better varieties, better production practices, or expanded usage.