GENETIC RESOURCES OF AMARANTHS

Cover photograph: A single plant of *Amaranthus cruentus* in a vegetable grower's field being used for seed production.

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INTERNATIONAL BOARD FOR PLANT GENETIC RESOURCES

GENETIC RESOURCES OF AMARANTHS

- a global plan of action -

by

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The International Board for Plant Genetic Resources (IBPGR) is an autonomous, international, scientific organization under the aegis of the Consultative Group on International Agricultural Research (CGIAR). The IBPGR, which was established by the CGIAR in 1974, is composed of its Chairman and 15 members; its Executive Secretariat is provided by the Food and Agriculture Organization of the United Nations. The basic function of the IBPGR, as defined by the Consultative Group, is to promote an international network of genetic resources centres to further the collection, conservation, documentation, evaluation and use of plant germplasm and thereby contribute to raising the standard of living and welfare of people throughout the world. The Consultative Group mobilizes financial support from its members to meet the budgetary requirements of the Board.

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Preface

When the International Board for Plant Genetic Resources (IBPGR) decided its priorities for action on crops, it was agreed that further study was required for vegetables. As a result, in 1976, the IBPGR commissioned the Royal Tropical Institute of the Netherlands (RTI) to produce a consultant's report on vegetable germplasm with special reference to those grown in the tropics. The report (AGPE:IBPGR/77/23) was published in 1977. It included a summary of information available on genetic erosion and the priority requirements for collection and conservation of germplasm.

When the IBPGR discussed the report, it concluded that more information was required; thereafter an expert consultation was convened 24 - 25 January 1979 at the National Vegetable Research Station (NVRS), Wellesbourne, U.K. At this meeting (see AGPE:IBPGR/79/3), tropical leaf vegetable amaranth was proposed as a first priority vegetable because of its economic importance, the high nutritional value and the low present level of knowledge. The risk of overall genetic erosion in amaranths was considered to be low, since only a small number of commercial cultivars had been developed. The IBPGR agreed in principle with these considerations and requested the Royal Tropical Institute (RTI) to formulate a global plan of action report for leafy amaranths taking into account:

(i) the compilation of data on amaranth germplasm;
(ii) the convening of an ad hoc meeting during the Second Amaranth Conference held in September 1979 at Kutztown, USA;
(iii) possible collaboration for collection and conservation with the National Horticultural Research Institute (NIHORT) in Ibadan, Nigeria and institutions in India (National Bureau of Plant Genetic Resources, New Delhi and Tamil Nadu University, Coimbatore);

and finally to present a report to the IBPGR which should embody the proposed global plan of action. Dr. G.J.H. Grubben, senior agronomist at the RTI, was charged with this assignment.

A report of the ad hoc meeting on amaranth genetic resources, convened during the Second Amaranth Conference, 13 and 14 September 1979 at Kutztown, USA, was submitted to the IBPGR (AGP:IBPGR/79/62) and important parts have been included in this report.

Dr. L. Denton of NIHORT participated in the meeting on amaranth germplasm and provided information on the Nigerian germplasm collection and conservation programme. NIHORT agreed to cooperate in an international network for the genetic resources of amaranth.

The National Bureau of Plant Genetic Resources (NBPGR, New Delhi, India) and the Tamil Nadu University (Coimbatore, India), were visited during November 1980 and a summary of the discussions is incorporated in this report.

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1. SUMMARY AND CONCLUSIONS

The Second Amaranth Conference was organized by Rodale Press Co., Emmaus, Pa., USA, 13-14 September 1979, at the Organic Gardening and Farming Research Center (OGFRC), Kutztown. Apart from participants from the USA, there were researchers from Mexico, Peru, Nigeria, Sweden and a representative of the IBPGR. An ad hoc meeting was convened during the Conference to discuss international cooperation between curators of collections and the users of amaranth germplasm. Most of the conclusions and recommendations of this meeting were incorporated into the draft plan of action report of the RTI. The final conclusions of the report were endorsed by the IBPGR at its seventh meeting in Rome, 4-7 March 1980. The major conclusions are outlined below:

(1) It was decided to treat the grain and vegetable amaranths as a single subject of study and to include the genus *Celosia* in any action plan. Adequate description of any sample will determine the use of the sample whether for a vegetable, grain, or both.

(2) The OGFRC has built up a wide working collection of amaranths (ca. 650 accessions in 1980). The collection is well maintained and registered. Duplicates are deposited for long-term conservation in the National Seed Storage Laboratory, Fort Collins, Colorado, USA. In addition the Second Amaranth Conference recognized other important collections of amaranths in India, Nigeria and Taiwan.

(3) High priority should be given to collecting missions in India, Nepal, Bangladesh and Africa. Also material needs to be collected in North Mexico, Central America (Guatemala), the Andes, Southeast Asia (e.g. Thailand and Indonesia - in particular Irian Jaya) and China.

(4) Amaranth germplasm should be stored, evaluated and maintained in the following four centres:

(i) The National Seed Storage Laboratory (NSSL), Fort Collins, Colorado, USA
The NSSL has agreed to hold a global base collection as part of the IBPGR global network. For evaluation of this collection, several institutes in the USA will cooperate. The suggested procedures to be followed with regard to the global base collection of amaranth are outlined in para 7.2;

(ii) The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India
The NBPGR will be invited by the IBPGR to hold a base collection of Asian material, as soon as long-term storage facilities are functional;

(iii) The National Horticultural Research Institute (NIHORT), Ibadan, Nigeria
NIHORT will be invited by the IBPGR to hold a base collection of African material, as soon as long-term storage facilities are available;

(iv) Instituto Nacional de Investigaciones Agrícolas (INIA), Mexico
INIA will be invited by the IBPGR to hold a base collection of New World material, as soon as long-term storage facilities are available.

(5) A provisional list of descriptors had been prepared by Dr. S.K. Jain, Agronomy and Range Science Department, University of California, USA, upon the request of the IBPGR. The authors of this report have revised and finalized this descriptor list in consultation with Dr. Jain. The comments of Dr. N.R. Bhagat and Mr. M. Kader Mohideen are greatly appreciated and have been incorporated into the final list (Appendix I).

(6) A taxonomic key for the identification of cultivated grain and vegetable species of *Amaranthus* and *Celosia* has been published in the Proceedings of the Second Amaranth Conference. Permission has been granted to include this key (Appendix II) in this report. It is recommended for use in order to clarify current confusion.

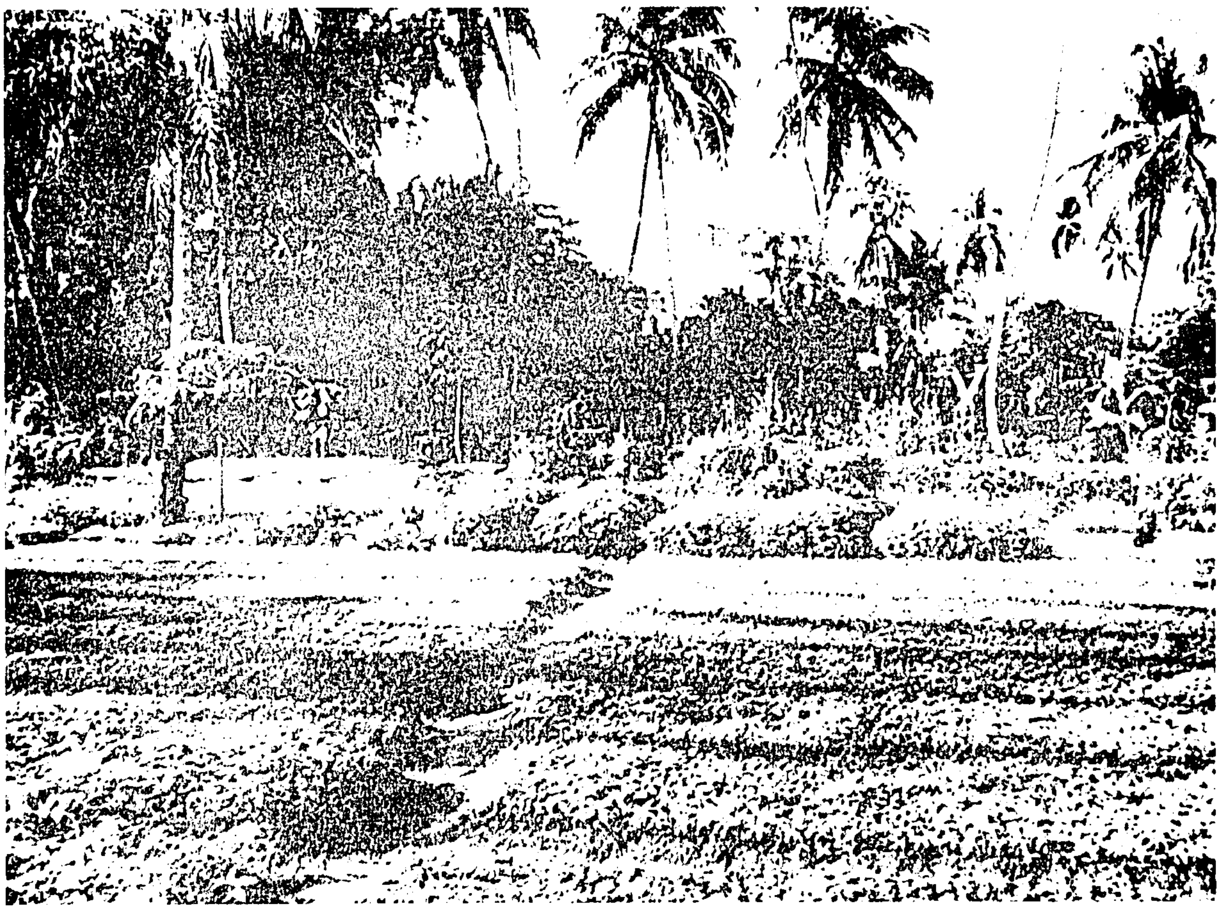

Figure 1. Raised bed method of cultivation of vegetable amaranth (*Amaranthus cruentus*) in West Africa

2. CONSUMPTION LEVELS, ECONOMIC AND NUTRITIONAL IMPORTANCE

2.1 Vegetable amaranth

Amaranthus is one of the main species of the large and taxonomically diverse group of tropical leaf vegetables. In the IBPGR report "Tropical Vegetables and their Genetic Resources" the daily intake of leafy vegetables per head, based on data from nutritional surveys, was estimated as 5 g for Latin America, 15 g for Southeast Asia and 21 g for Africa.

Celosia argentea L. is another species of the Amaranthaceae which is as important as *Amaranthus* sp. in Central and West Africa. It is extremely popular in Nigeria where it is known as sokoyokoto. Growth habit, cultivation practices, and the diseases and pests are very similar to those of *Amaranthus*. As a result, *Celosia* sp. should be collected and described together with *Amaranthus* sp. The same list of descriptors may be used as far as practicable.

Since leafy vegetables are mostly recorded in production statistics and nutritional surveys without any further distinction, and since the vegetables are mainly grown as a non-commercial crop for home consumption, little detailed information can be obtained. Some data about the market production of leafy vegetables for the city Porto-Novo in Benin (80,000 inhabitants) illustrating the popularity of *Amaranthus* and *Celosia* in West Africa are presented in Table 1.

Table 1. Average daily supply of vegetables to Porto-Novo (1972-1973; 80,000 inhabitants) Benin, West Africa[1/]

	g/person/day	%
Non-leafy vegetables: Total	64.9	100
Tomato	24.8	38
Hot pepper	14.1	22
Okra	13.3	20
Onion	10.3	16
Pumpkin, eggplant, etc.	2.4	4
Leafy vegetables: Total	56.9	100
Amaranthus cruentus	18.8	33
Celosia argentea	15.4	27
Corchorus olitorius	10.8	19
Vernonia amygdalina	6.8	12
Solanum aethiopicum	2.9	5
Basella, *Talinum*, cowpea, etc.	2.3	4

1/ Source: Vermeulen H. 1974. La Commercialisation des légumes au Dahomey. Royal Tropical Institute, Amsterdam.

Amaranths are excellent vegetables for the following reasons:

(i) they are very fast growing crops with an extremely high yield potential; in hot climates the yield of leaves may amount to 30 tons of fresh matter or 4.5 tons of dry matter per ha in 4 weeks from direct sowing;

(ii) amaranths are less susceptible to soil-borne diseases than most other vegetables, they are moreover easy-to-cultivate and appropriate to both homegardening and commercial cultivation;

(iii) they are suitable for crop rotation with any other vegetable crop;

(iv) to compensate for the high mineral uptake, which is inherent to a high yield and a good nutritional composition, amaranths react favourable to fertilizers and to organic manure; they perform well on land fertilized with fresh or partly decomposed town refuse.

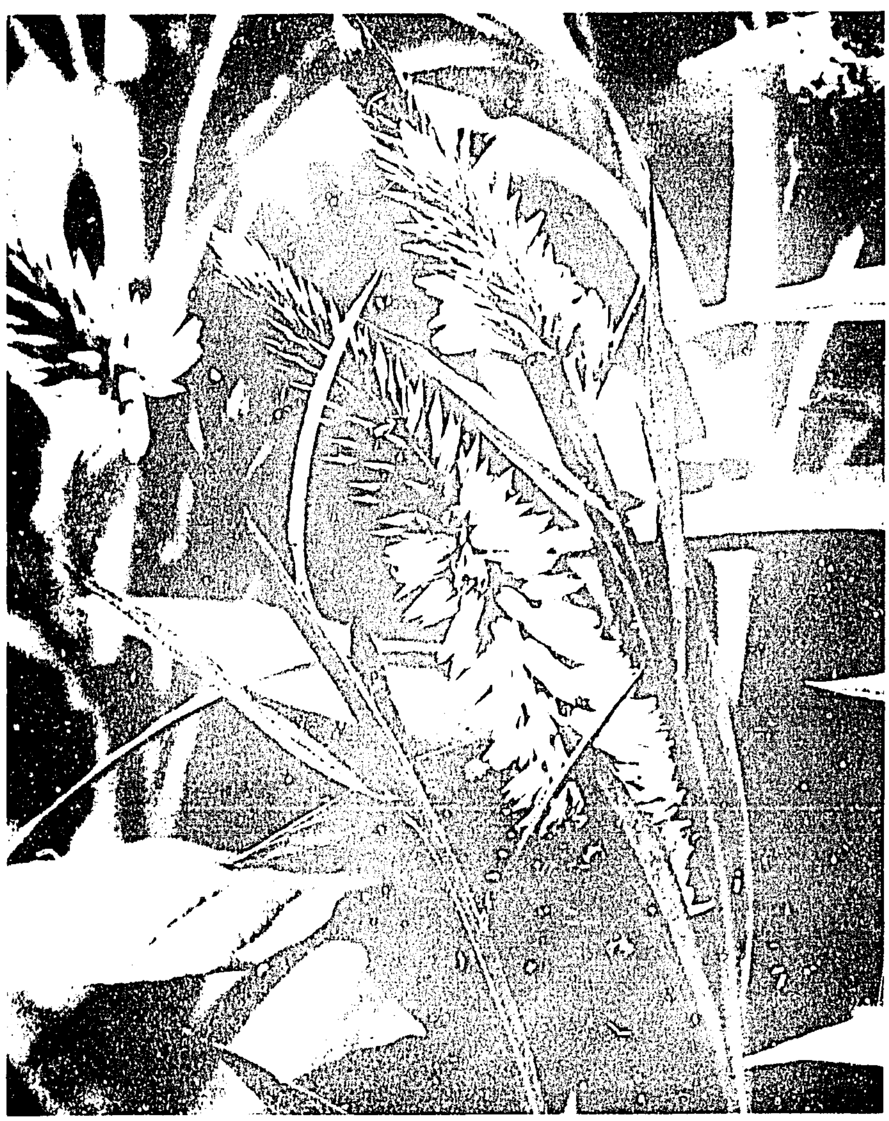

Figure 2. Inflorescence of sokoyokoto (*Celosia argentea*) in West Africa

Because of low production costs and high yield, amaranth is one of the cheapest dark-green leafy vegetables in tropical markets and is often described as a poor man's vegetable. The nutritional value of this cheap product is excellent, because of its high content of essential micro-nutrients. Amaranth leaves are a good source of carotene (of use against xerophthalmia), of iron (of use against anaemia), of calcium, vitamin C, folic acid and other micro-nutrients. Their protein is a valuable contribution to the diet when protein intake is marginal. This is illustrated in Tables 2a and 2b.

Amaranth leaves have nitrate and oxalate levels similar to other green leaf vegetables (spinach, spinach beet and *Basella*). Adverse nutritional effects are not to be feared with a consumption of 100 to 200 grammes per day.

Table 2a. Content of essential nutrients per 100 grammes of edible product of tomato, cucumber and amaranth leaves 1/ ; and total annual nutrient production in Kg/ha, based on 80 tons/ha of edible product per year

	Tomato		Cucumber		Amaranth	
	Content	Kg/ha	Content	Kg/ha	Content	Kg/ha
Dry matter	6.5 g	5200	4.9 g	3920	16.0 g	12800
Carotene	0.5 mg	0.4	trace	trace	5.7 mg	4.6
Iron	0.6 mg	0.5	0.5 mg	0.4	8.9 mg	7.1
Calcium	10 mg	8	13 mg	10	410 mg	330
Vitamin C	26 mg	21	16 mg	13	64 mg	51
Protein	1.0 g	800	0.8 g	640	4.6 g	3680

Table 2b. Number of consumers whose nutrient requirements contributed by the vegetable part of the diet may be satisfied with one hectare of vegetable cropping during one year

	FAO/WHO requirements 2/		Contribution of vegetables	Number of consumers/ ha/year		
	per day	per year	per year	tomato	cucumber	amaranth
Carotene	1.5 mg	0.5 g	0.5 g	800	100	9200
Iron	9 mg	3.3 g	1.7 g	290	240	4180
Calcium	500 mg	183 g	61.0 g	130	160	5410
Vitamin C	30 mg	11.0 g	11.0 g	1910	1180	4640
Protein	37 g	13.5 kg	2.7 kg	300	240	1360

1/ FAO 1968. Food Composition Table for Use in Africa.

2/ Reference man 65 kg.

2.2 Grain amaranth

The seed of *Amaranthus* sp. was once an important food for the inhabitants of the Americas in pre-Colombian times. Since then, it has declined to the state of a minor crop. Recently the high nutritional value of the seed has been recognized, and this has led to a renewed interest in grain amaranths (also called cereal amaranths) in the USA, Mexico and elsewhere in Central and South America. Grain amaranth is also a minor crop of increasing importance in Asia, especially in Nepal and in mountainous areas of North and South India. Pale-seeded types of several *Amaranthus* species are cultivated in mixed croppings for the harvest of the seed, while young plants of the same type are used as a leafy vegetable.

The largest constraint in handling amaranths is the small size of the seed: the 1000-seed weight is only about 0.6 grammes (range 0.3-1.0). In the hill areas of South India, grain amaranth is likely to gain in popularity, since the farmers are used to small grains, their main cereal crops all being small-sized cereals e.g. *Paspalum*, *Setaria*, *Panicum* and *Eleusine*. Commercial cultivation in monoculture fields in Southeast Asia and Latin America will increase if the crop will give a higher profit than the traditional cereals.

In monoculture, grain amaranth may produce 2-3 tons of seed per hectare in a cropping period of 3-4 months. The overall content of nutrients (calories, proteins, vitamins, minerals) in amaranth seed is within the high range of these nutrients in cereals such as wheat. The protein content is 15-16 percent. The special value of grain amaranth, apart from the good baking and organoleptic quality, is the favourable amino-acid composition. The lysine level scores high (5.0 percent) and so do sulphur-containing amino-acids (4.4 percent). Leucine is the limiting amino-acid; the protein score of amaranth seed is 67. Amaranth proteins complement other cereals in lysine content, while these cereals complement amaranth in leucine. A combination of amaranth seed with other grains gives an excellent protein.

3. CULTIVATION PRACTICES

3.1 Introduction

Typical vegetable amaranths e.g. *A. tricolor* and *A. dubius* are characterized by a succulent spinach-like nature; young plants have short tender stems and broad leaves with a high moisture content. The inflorescences are relatively small, and so is the seed production (200-500 kg/ha). *A. blitum* and some other weedy species which are cultivated as leafy vegetables and are popular in India, have small leaves and a strong branching habit. The habit of *Celosia argentea* is very similar to *A. dubius*.

Typical grain amaranths e.g. *A. hypochondriacus*, *A. cruentus* and *A. caudatus* are more sturdy plants with erect habit, well developed main stems and large terminal inflorescences. The leaf/stem ratio is generally smaller than for vegetable types, the dry matter content is higher and the seed production at least five times as high (2000-3000 kg/ha). Typical grain types are pale or white seeded, although blackseeded types do occur. Young plants of all these grain types are used as a leafy vegetable. In spite of its grain habit, *A. cruentus* is popular as a vegetable amaranth in Africa. Grain amaranths are not cultivated in this continent, except probably some cultivation of *A. caudatus* in Ethiopia and some cultivation of *A. cruentus* and *A. hypochondriacus* by Indian immigrants in East Africa.

Figure 3. A flowering plant of an Indonesian cultivar of *Amaranthus tricolor*

3.2 Cultivation of vegetable amaranth

The main cultivation methods of vegetable amaranths are:

(1) direct sowing, in rows:

(i) one single harvest by uprooting or cutting at ground level;

(ii) 2-4 successive harvests by cutting (ratooning).

(2) direct sowing, broadcast:

(i) one single harvest by uprooting or cutting at ground level;

(ii) 2-3 successive harvests by selective uprooting;

(iii) 2-8 harvests by repeated cuttings (the first harvest being thinning out by uprooting).

(3) transplanting:

(i) one single harvest by uprooting or cutting at ground level (planting with a narrow spacing of 10 x 10 cm);

(ii) 2-5 harvests by repeated cuttings (wide spacing of 20 x 20 cm).

The advantages of transplanting over direct sowing are the small amount of seed required, the short occupation of the whole field, a very uniform crop and no competition from weeds. Nonetheless transplanting is less practised than direct sowing since it is very laborious.

Figure 4. Regrowth of an amaranth plot (*Amaranthus cruentus*) after cutting

On fertile soil, with sufficient water and a high light intensity, the first harvest of young plants may be carried out 3 weeks after transplanting or four weeks after sowing. A yield of 2 kg/m^2 with a leaf/stem ratio of 1 to 1.3 is considered reasonable. If the harvest is delayed one-two weeks, the yield will be higher and the product less tender. Later harvesting is practised in India and Bangladesh in order to obtain a larger proportion of stems. These are used for curry.

Amaranth is a hot-season vegetable in the sub-tropical zones and it is cultivated throughout the year in the tropics. Since no serious soil-borne diseases are known, no crop rotation is necessary. Continuous cropping of amaranth may give up to 12 harvests/year, yielding 300 tons of greens/ha.

3.3 Cultivation of grain amaranth

Grain amaranth is mostly cultivated as a secondary crop in mixed croppings with maize, sorghum, millet, castor, hyacinth bean, eggplant, hot peppers or other food crops. It is reported from Mexico as a main crop with pulses or cucurbits as secondary crops. The most popular combination is maize-amaranth. In most areas, farmers spread the seed in between the other crop and spare the desired number of plants during the first weeding. In other areas, small plants are pricked out between the food crop.

Figure 5. Mr. M. Kader Mohideen, researcher at Tamil Nadu Agricultural University, India, observing *A. hypochondriacus* in a mixed cropping with hyacinth bean

Only 1-2 kg of seed/ha is required for a pure crop, giving a grain yield of about 1.5 tons (maximum 3 tons). Rodale Organic Gardening and Farming Research Center in USA is working out improved cultivation practices for mechanized cultivation in the USA. High density planting, of 60,000 to 120,000 plants/ha , gives the advantage of a more uniform ripening of all inflorescences because of the suppression of lateral shoots. With a dense planting, the plant habit is short and lodging and seed shattering occurs less. Both mechanized sowing in line, and hand or mechanized planting are possible (see the recent publications mentioned in Appendix IV for more detailed instructions, especially Rodale Research Report 80-1 of April 1980. This report describes also the mechanized harvesting, threshing and cleaning of the seed.)

3.4 Pests and diseases

The main diseases and pests of vegetable and grain amaranths are:

(1) *Pythium aphanidermatum* (Ed.) Fitzp. causing damping-off. Some types/species are more susceptible than others.

(2) *Choanephora cucurbitarum* (Berk. et Lav.) Thaxter causing wet-rot. The most troublesome disease of amaranth in Africa. Some cultivars show partial resistance. *A. cruentus* is more susceptible than other species.

(3) *Albugo bliti* (Biv.) Kuntze causing white rust is a serious disease in Southeast Asia. *A. tricolor* especially is very susceptible.

(4) *Hymenia recurvalis* F. and other caterpillars are serious pests of amaranths. Differences in susceptibility are not know. Commercial growers use pesticides for control.

(5) *Lixus truncatulus* F. a stemborer, is a troublesome pest in Africa and Asia for vegetable crops harvested by repeated cuttings and for grain amaranth.

(6) *Cletus* sp., *Aspavia* sp. and *Lygus lineolarus* cause some damage to the leaves. They are serious pests for grain amaranths causing abortion of the seed. Some types, notably the African *A. cruentus* show partial resistance.

(7) *Meloidogyne incognita* Chitwood. Root-knot nematodes are a serious pest of *Celosia*, but most *Amaranthus* species are not or only slightly affected.

4. CENTRES OF ORIGIN AND DIVERSITY

The origin of the various species of cultivated amaranths is not easy to trace because the wild ancestors are pantropical cosmopolitan weeds. *Amaranthus spinosus*, *A. hybridus* and *A. dubius* are typical tropical types, *A. retroflexus*, *A. viridis*, *A. lividus* and *A. graecizans* are more temperate hot-season weeds. Probably all the grain amaranths originated from Central and South America, whereas the main vegetable type, *A. tricolor*, originated somewhere in South or Southeast Asia. Since then, several secondary centres of diversity have developed in the main production areas. Many wild amaranths, often known as pig-weed, are collected for use as potherb and are sometimes cultivated (see Fig. 6).

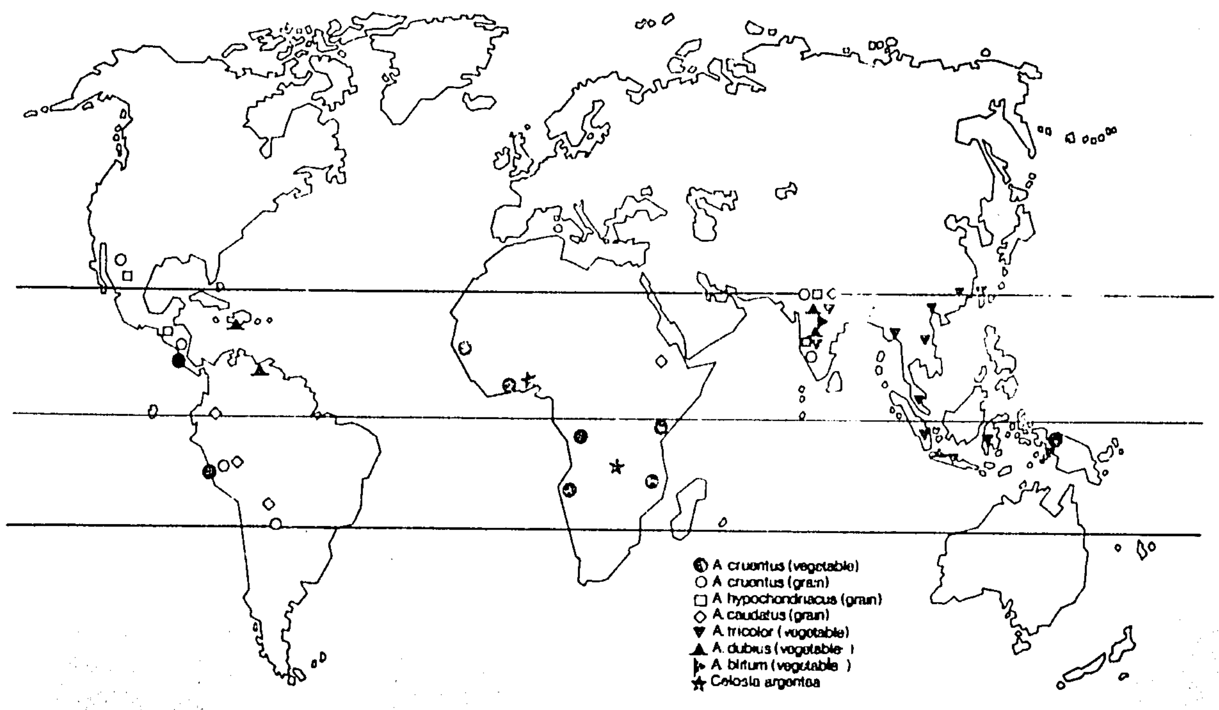

Figure 6. Centres of diversity of amaranths (*Amaranthus* and *Celosia*)

A. tricolor might have originated in India and have spread to neighbouring countries by traders, Buddhist monks and Moslem invaders. Cultivars from Indonesia look similar to those of remote areas in India. The Indonesian name for amaranth "bayam" could be derived from "bhaji", which means greens in South India. Also South China could be the origin. Particular cultivars with long slender leaves or tiger-striped leaves occur in Malaysia, Taiwan, Indo-China, Hong Kong and Southern China. *A. dubius* shows diversity in Central America (where it might have originated), in Indonesia, India and to a limited extent in Africa. *A. lividus* seems to have been a popular vegetable in Southern and Central Europe. It is related to *A. blitum* which is cultivated only in India. The African leaf vegetable *A. cruentus* is a grain type which was probably introduced from Central America centuries ago. *Celosia argentea* is very popular in Nigeria; its origin might have been in the Hindustani centre, where the genus *Celosia* shows much diversity.

The most important grain species *A. cruentus* originates from Central America, probably from Guatemala, where it is cultivated as a cereal and as a vegetable in the lowlands. It has spread to South America, to Africa as a vegetable, and to South and Southeast Asia as a grain crop. *A. hypochondriacus* is a grain amaranth from South America (Argentina, Peru) which is now cultivated in the Himalayas and in South India. *A. caudatus* has somewhat different ecological requirements. It is a short-day plant and more adapted to cold conditions than the other species. It is cultivated in Nepal to an altitude of 3000 m. It might have originated from the high Andes and spread to East Africa and the Himalayas as a grain amaranth. Ornamental types are popular in temperate and subtropical areas. The Hindustani subcontinent has become an important secondary centre of diversity for the grain amaranths.

5. GERMPLASM COLLECTIONS, BREEDING AND RESEARCH

There are presently three focal points for amaranth germplasm collection, breeding and research.

(1) USA: Rodale Organic Gardening and Farming Research Centre, Kutztown, and the National Seed Storage Laboratory, Fort Collins, Colorado, USA.

(2) India: National Bureau of Plant Genetic Resources, New Delhi and Tamil Nadu Agricultural University, Coimbatore.

(3) Nigeria: National Horticultural Research Institute and other institutions at Ibadan.

5.1 USA

The Organic Gardening and Farming Research Center (OGFRC) of Rodale Press at Kutztown, USA, started research on grain amaranth, a traditional food of the American Indians, in 1975. The first results are reported in the proceedings of the First Amaranth Conference, held at Kutztown in 1977. Over 650 accessions of cereal and vegetable types of amaranths were collected through trips to Mexico, Guatemala and other Latin American countries and to India. University students were given grants for research in order to popularize the cultivation and consumption of amaranths as new health foods in the USA. Data are published in the proceedings of the Second Amaranth Conference.

The Rodale collection comprises many cereal types (mainly *A. hypochondriacus* and *A. cruentus*) collected in Southwestern United States and in Central and South America on collection trips by collaborators of the Rodale amaranth programme (Mrs. Hauptli, Mr. Nabhan, Mrs. Feine and in India by Dr. S.K. Jain). It also includes duplicates of the leaf types collected by Deutsch at AVRDC, the African leaf types used by Grubben at the Agricultural University in Wageningen (Netherlands), and many other accessions from diverse origins. Simple techniques for micro-propagation and crossing in the glasshouse without the need for isolation have been worked out (see Fig. 7).

Breeding work with this material has the following objectives: short plant habit, early maturity, potentially high yield, resistance to insects, tendency to dry down, no seed shattering and white and large sized seed.

The Rodale collection is described and listed in Rodale Research Report 80-2 by C.S. Kauffman and P. Haas, 1980. It catalogues 648 accessions. The most promising 42 accessions, called "R series" have been multiplied for wider distribution. Seed quantities of many other accessions are limited. Seed samples are distributed free of charge as a public service. Requests are normally limited to ten samples, unless the request is for a specific research programme needing broad diversity. Samples from either the "R series" or the germplasm collection can be obtained from OGFRC, Rd. 1, Box 323, Kutztown PA 19530, USA.

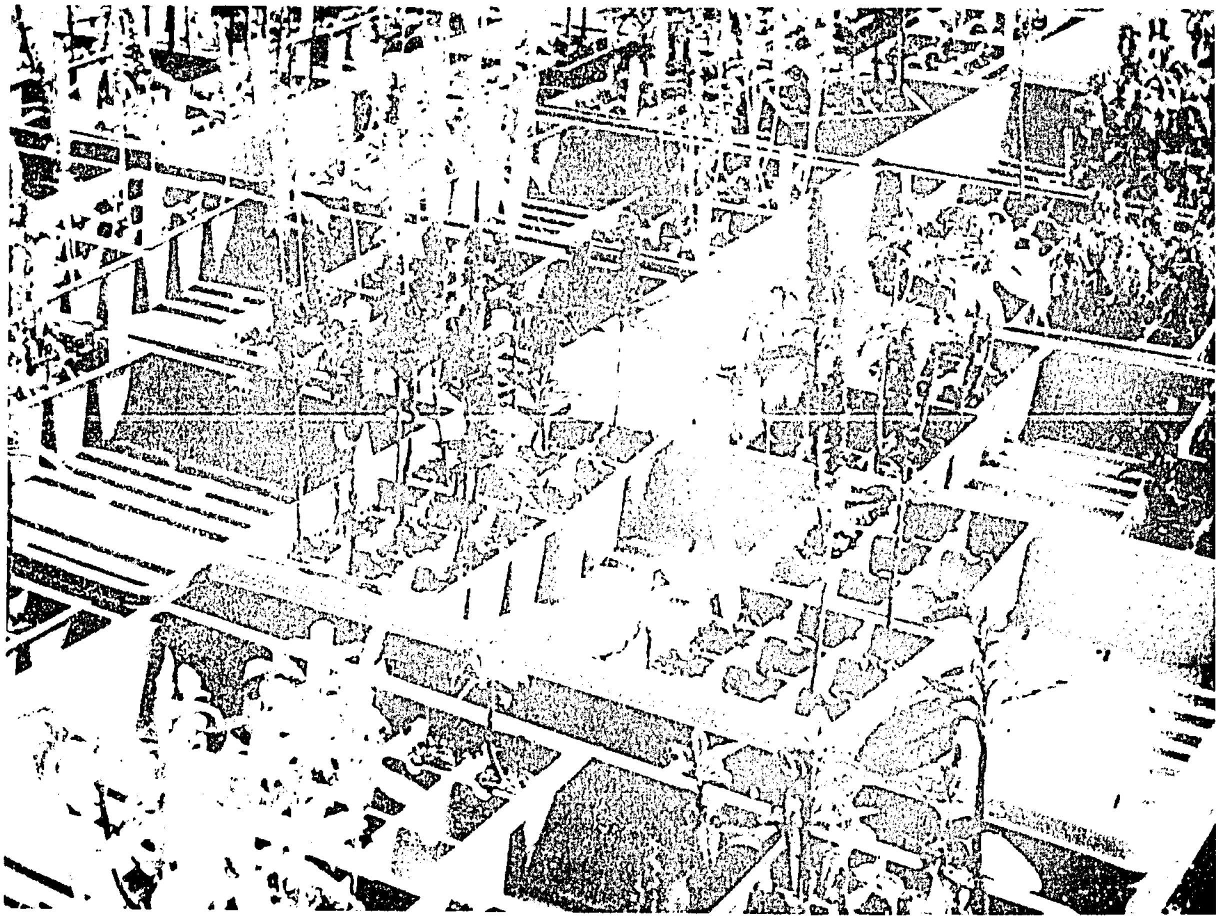

Figure 7. Economical micro-plant propagation of amaranth in a glasshouse. Each plant produces several hundred seeds

5.2 India

In India, where both grain and vegetable amaranths are of great importance, a large amaranth collection has been gathered by the National Bureau of Plant Genetic Resources (NBPGR). The collection is kept at the hill station at Simla in Northern India and at Akola. It comprises about 1400 accessions, 450 of which are vegetable amaranths. The NBPGR intends to complete the Indian collection in collaboration with the 24 agricultural universities, as part of the all-India programme. Dr. N.R. Bhagat (National Bureau of Plant Genetic Resources, IARI, New Delhi 110012, India) has been designated as coordinator and contact person for national collections and international research.

Over the past twenty years, a number of publications on research into breeding and cultivation methods for vegetable amaranth have appeared from the Tamil Nadu Agricultural University, Coimbatore, India. Productive cultivars were selected from local material, viz. Co. 1 (*Amaranthus dubius*) and Co. 2 (*A. tricolor*), which are now cultivated and commercially available in South India. A new cultivar, Co. 3 (*A. tricolor*) will be released soon, which is specially suitable for ratooning. The present research programme includes intervarietal hybridization, mutation breeding and polyploidy and cultivation of grain amaranths. Researchers involved in the amaranth programme are M. Kader Mohideen (assistant professor), Dr. K.C. Shanmugavelu, head of the Department of Olericulture, and Dr. C.R. Muthukrishnan, Dean of the Faculty of Horticulture.

A large working collection (450, mostly local, accessions) is available through NBPGR. Part of this material is already included in the Rodale collection. Correspondence should be directed to Dr. C.R. Muthukrishnan, Faculty of Horticulture, Tamil Nadu Agricultural University, Coimbatore 641003, Tamil Nadu, India.

Figure 8. Mr. M. Kader Mohideen, with breeding lines of vegetable amaranths (*A. dubius*, *A. blitum* and *A. tricolor*)

5.3 Nigeria

The most important centre for work on vegetable amaranths in Africa is the National Horticultural Research Institute, Ibadan, Nigeria. Some research has also been undertaken at the University of Ife, at the International Institute for Tropical Agriculture (IITA) and at Moor Plantation. Collection trips by Dr. Prem Nath (FAO) and Dr. Lanre Denton produced about 60 local cultivars of *Amaranthus* and *Celosia*. A medium-term storage room is under construction to establish a genebank for local Nigerian vegetables. The most urgent research topic is breeding for resistance to wet-rot caused by *Choanephora cucurbitarum*.

5.4 Other countries

In addition to the above focal points for amaranth germplasm collection, breeding and research, research activities have also been reported in Brazil, Kenya, Ghana, Indonesia, Puerto Rico, Taiwan, Thailand, the Netherlands, Uganda, United Kingdom and Zambia. Most of the researchers have small working collections of local varieties. Seed samples may also be ordered from commercial seed companies. In Appendix III, a list is provided of institutes with working collections of amaranths and suppliers of commercial seed. Further details of existing collections will be published at a later date when the IBPGR produces a Directory of Vegetable Germplasm Collections.

Research work on amaranth is still relatively scarce. During 1978 the Abstracts on Tropical Agriculture noted only 3 publications on vegetable amaranth, published in the Netherlands, the USA and India. In comparison in the same year, 75 publications were noted on tomato and 24 on onion cultivation in the tropics. It is relatively easy for new researchers to gain access to the literature on amaranth by means of the abstracting journals, literature reviews and recent publications listed in Appendix IV. In addition an alphabetical list of researchers who have published on amaranth or have shown interest in amaranth germplasm is supplied in Appendix V.

6. PRIORITIES FOR COLLECTING

The ad hoc meeting on amaranth germplasm, Kutztown, USA, recognized that it would be difficult and impractical to separate grain (cereal) amaranths from vegetable amaranths. In Latin America (Guatemala), India and Nepal, the young plants of cereal amaranths are frequently used as greens. One of the main vegetable amaranths, *A. cruentus*, is also an important cereal amaranth. *A. dubius* and *A. tricolor* are unique vegetable types, but exchange of genes by interspecific crossing is within reach. The meeting decided that grain and vegetable amaranth should be collected as one entity and the main use will appear from the description. In addition the meeting recommended the collection and description of *Celosia* sp. together with *Amaranthus* sp. (see para 2.1)

Gaps in the actual collections were noted for North Mexico, Central America (Guatamala), the Andes, for East and West Africa, Nepal, India, Bangladesh, China, Indonesia (especially Irian Jaya) and Thailand.

Danger of erosion was mentioned for the American grain types, in the traditional growing areas of Central and South America. Mrs. Hauptli reported a great variability of local grain types which are also used as greens in Guatemala, and pointed out the danger of loss of these old landraces. Danger of erosion for vegetable types is present in Asian countries (India, China etc.) where commercial seed of improved cultivars is becoming popular.

Although no immediate danger of genetic erosion was reported, except for the American grain types and the Asian vegetable types, collecting work should be promoted for the supply of material to plant breeders and researchers and to safeguard local cultivars for future use. A priority list for collecting is shown in Table 3. An estimate of a complete collection of amaranths covering the existing genetic variability would be 4000-6000 accessions.

Table 3. Priorities for collecting

Priority	Region/Country	Crop type
1	India, Nepal, Bangladesh	grain and vegetable types
	East and West Africa	vegetable types including *Celosia* sp.
2	North Mexico	grain types
	Central America (Guatemala)	grain & vegetable types
	Andean zone	grain types
3	Indonesia (Irian Jaya)	vegetable types
	China	vegetable types
	Thailand	vegetable types

7. BASE AND ACTIVE COLLECTION CENTRES

7.1 Base collection centres

Amaranth germplasm should be stored, evaluated and maintained in the following centres:

(i) The National Seed Storage Laboratory (NSSL), Fort Collins, Colorado, USA
The NSSL has agreed with the IBPGR to hold a global base collection for amaranths. For evaluation and maintenance of this collection, several institutes in the USA will cooperate (for procedures see para 7.2);

(ii) The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India
The NBPGR will be invited by the IBPGR to hold a base collection of Asian material, as soon as a long-term storage faciltity is functional;

(iii) The National Horticultural Research Institute (NIHORT), Ibadan, Nigeria
NIHORT will be invited by the IBPGR to hold a base collection of African material, as soon as long-term storage facilities are available;

(iv) Instituto Nacional de Investigaciones Agrícolas (INIA), Mexico
INIA will be invited by the IBPGR to hold a base collection of New World material, as soon as long-term storage facilities are available.

7.2 Procedures for the global collection of amaranth

The following recommendations resulted from discussions with Dr. G.A. White, USDA Plant Introduction Officer and Dr. W.M. Porter, Computer Specialist, USDA, Beltsville Agricultural Research Center:

(i) seed from each accession should be sent to Beltsville so that a Plant Introduction number can be assigned:

Plant Germplasm Quarantine Center
Building 320, BARC - East
Beltsville, Maryland 20705
USA
Attn: H.R. Hanes

(ii) the seed would then be sent to the Regional Plant Introduction Station, Ames, Iowa, for medium-term storage, multiplication and preliminary evaluation;

(iii) seed (minimum of 10 000 seeds, or 3-9 grammes per accession) would be forwarded to NSSL, Fort Collins for long-term storage;

(iv) germplasm should also be maintained at other stations (Rodale Collection, India, Nigeria, Mexico) to back-up the Ames collection and to help retain the original genotypes;

(v) a computer storage and retrieval system should be set up according to the guidelines used at Beltsville;

(vi) it is advisable to catalogue the introductions, to keep the Rodale Press collection up-to-date for immediate exchange and to facilitate the task of USDA by sending them new accessions with a maximum of information.

7.3 International contact persons for amaranth germplasm collections

The suggested international contact persons for Amaranth germplasm collections are:

- for North, Central and South America:
  Dr. S.K. Jain, Agronomy & Range Science Dept., University of California, Davis, CA 95616, USA

- for Africa:
  Dr. L. Denton, National Horticultural Research Institute, P.M.B. 5432, Idi-Ishin, Ibadan, Nigeria

- for Asia:
  Dr. N.R. Bhagat, National Bureau of Plant Genetic Resources, IARI, New Delhi 110012, India

- for general information:
  Ir. D.H. van Sloten, Genetic Resources Officer, Secretariat of the International Board for Plant Genetic Resources, FAO, Via delle Terme di Caracalla, Rome 00100, Italy.

Figure 9. Characterization and evaluation of amaranth

8. DESCRIPTORS

A provisional list of descriptors was prepared by Dr. S.K. Jain, Agronomy and Range Science Department, University of California, USA, upon the request of the IBPGR. The authors of this report have finalized the descriptor list in consultation with Dr. Jain. The comments of Dr. N.R. Bhagat and Mr. M. Kader Mohideen are greatly appreciated and have been incorporated into the final list (Appendix I).

Figure 10. Mrs. Laurie Feine-Dudley during her taxonomic study

9. TAXONOMIC CLASSIFICATION AND DESCRIPTION

The taxonomy of the amaranths is still confused. Synonomy is a basic problem. A provisional key for edible species of the genera *Amaranthus* and *Celosia* based on a study of plants grown at OGFRC, and information compiled from floras and monographs, has been worked out by Mrs. Laurie B. Feine-Dudley and her colleagues. This work makes no attempt to revise the genera *Amaranthus* or *Celosia* but instead is a compilation of information that is difficult to find.

This key, with the list of relevant floras and monographs, as well as the detailed descriptions of the species, has been appended with the permission of the author (Appendix II).

The botanical drawings of some major species, made by Miss H.G.D. Zewald and Miss F.M. Gillot of the Laboratory for Plant Taxonomy and Geography, Agricultural University, Wageningen, the Netherlands and originally published in "The Cultivation of Amaranth as a Tropical Leaf Vegetable", Communication 67, Department of Agricultural Research, RTI, Amsterdam, are used to illustrate the text and to facilitate the determination.

APPENDIX I

AMAPANTH DESCRIPTOR LIST

The IBPGR now uses the following definitions in genetic resources documentation.

(i) passport data (accession identifiers and information recorded by collectors);

(ii) characterization (consists of recording those characters which are highly heritable, can be easily seen by the eye and are expressed in all environments);

(iii) preliminary evaluation (consists of recording a limited number of additional traits thought desirable by a consensus of users of the particular crop).

Characterization and preliminary evaluation will be the responsibility of the curators, while further evaluation, which often requires designed experiments, should be carried out by plant breeders and other users of the material. The data from further evaluation should be sent to the curators who will maintain data files.

Many descriptors which are continuously variable are recorded on a 1-9 scale. The authors of this list have sometimes described only a selection of the states, e.g. 3, 5 and 7 for such descriptors. Where this has occurred the full range of codes is available for use by extension of the codes given or by interpolation between them - e.g. Leaf pubescence (4.1.11) could also be coded as 1 Extremely low or 5 Intermediate.

APPENDIX I
(Continued)

PASSPORT DATA

1. ACCESSION DATA

1.1 ACCESSION NUMBER

This number serves as a unique identifier for accessions and is assigned by the curator when an accession is entered into his collection. Once assigned this number should never be reassigned to another accession in the collection. Even when an accession is lost, its assigned number is still not available for re-use. Letters occur before the number to identify the genebank.

1.2 SCIENTIFIC NAME

1.2.1 Genus

1.2.2 Species

1.3 DONOR NAME

Name of donating institute or person

1.4 DONOR NUMBER

Number given by the donor to the accession including pedigree information

1.5 ANY OTHER NAMES OR NUMBERS ASSOCIATED WITH THE ACCESSION

e.g. USDA Plant Introduction number, common name etc. (Not collection number see 2.2)

2. COLLECTION DATA

2.1 COLLECTING INSTITUTE

Institute or person collecting the original sample

2.2 ORIGINAL NUMBER ASSIGNED BY COLLECTOR OF THE SAMPLE

2.3 DATE OF COLLECTION OF ORIGINAL SAMPLE

Expressed as day/month/year, e.g. 15 March 1981 as 150381

2.4 COUNTRY OF COLLECTION

Use the three letter abbreviations supported by the Statistical Office of the United Nations. Copies of these abbreviations are available from the IBPGR Secretariat

2.5 LATITUDE OF COLLECTION SITE

Degrees and minutes suffixed by N or S, e.g. 1235 N

APPENDIX I
(Continued)

2.6 LONGITUDE OF COLLECTION SITE

Degrees and minutes suffixed by E or W, e.g. 7740 E

2.7 LOCATION OF COLLECTION SITE

Number of kilometres and direction from nearest town, village or map reference point

2.8 ALTITUDE OF COLLECTION SITE

Elevation above sea level, in m

2.9 SOURCE OF COLLECTION

The place where the original collection was made

1 Roadside, wild vegetation
2 Shifting cultivation
3 Farmland
4 Backyard
5 Market
6 Farm store
7 Agricultural instit
8 Seed company
9 Other (specify)

2.10 POPULATION STRUCTURE

1 Continuous
2 Subdivided

2.11 DENSITY OF THE STAND

3 Sparse
7 Dense

2.12 AREA OF THE STAND

1 small $< 10\ m^2$
2 medium $10-100\ m^2$
3 large $> 100\ m^2$

2.13 STATUS OF SAMPLE

1 Wild
2 Weedy
3 Primitive cultivar
4 Advanced cultivar

2.14 LOCAL CULTIVAR NAME

Romanized local name of the cultivar used by the people of the region where the sample was collected

APPENDIX I
(Continued)

2.15 PRIMARY USE

1 Vegetable
2 Grain
3 Ornamental
4 Medicinal
5 Other (specify)

2.16 SECONDARY USE

1 Vegetable
2 Grain
3 Ornamental
4 Medicinal
5 Other (specify)

2.17 OTHER NOTES FROM COLLECTOR

Some collectors will record ecological and soil information, whether a cultivated crop was irrigated, season of sowing, topography of land, associated crops or wild plants, etc.

CHARACTERIZATION AND PRELIMINARY EVALUATION

3. GENERAL

3.1 SITE OF CHARACTERIZATION AND PRELIMINARY EVALUATION

3.2 YEAR OF CHARACTERIZATION AND PRELIMINARY EVALUATION

3.3 EVALUATOR(S) NAME AND ADDRESS

3.4 DATE OF SOWING

Expressed as day/month/year, e.g. 7 April 1981 as 070481

4. CHARACTERIZATION

4.1 PLANT, STEM, LEAF AND ROOT CHARACTERS

4.1.1 Growth habit

1 Erect
2 Prostrate

4.1.2 Plant height at flowering, in cm

4.1.3 Branching index (score if erect growth habit)

1 No branches
2 Few branches, all near the base of the stem
3 Many branches, all near the base of the stem
4 Branches all along the stem

APPENDIX I
(Continued)

4.1.4 Mean length of basal lateral branches, in cm

4.1.5 Mean length of top lateral branches, in cm

4.1.6 Stem pubescence

0 None
3 Low
7 Conspicuous

4.1.7 Stem pigmentation

1 Green
2 Purple or pink

4.1.8 Spines in leaf axils

0 Absent
+ Present

4.1.9 Leaf length

Measured in cm on 6th or 8th leaf

4.1.10 Leaf width

Measured in cm on 6th or 8th leaf

4.1.11 Leaf pubescence

0 None
3 Low
7 Conspicuous

4.1.12 Leaf pigmentation

1 Entire lamina purple or pink
2 Basal area pigmented
3 Central spot
4 Two stripes (V-shaped)
5 One stripe (V-shaped)
6 Margin and vein pigmented
7 One pale green or chlorotic stripe on normal green
8 Normal green
9 Dark green
10 Other (specify)

4.1.13 Leaf shape (see Fig.11)

1 Lanceolate
2 Elliptical
3 Cuneate
4 Obovate
5 Ovatainate
6 Rhombic
7 Oval
8 Other (specify)

APPENDIX I
(Continued)

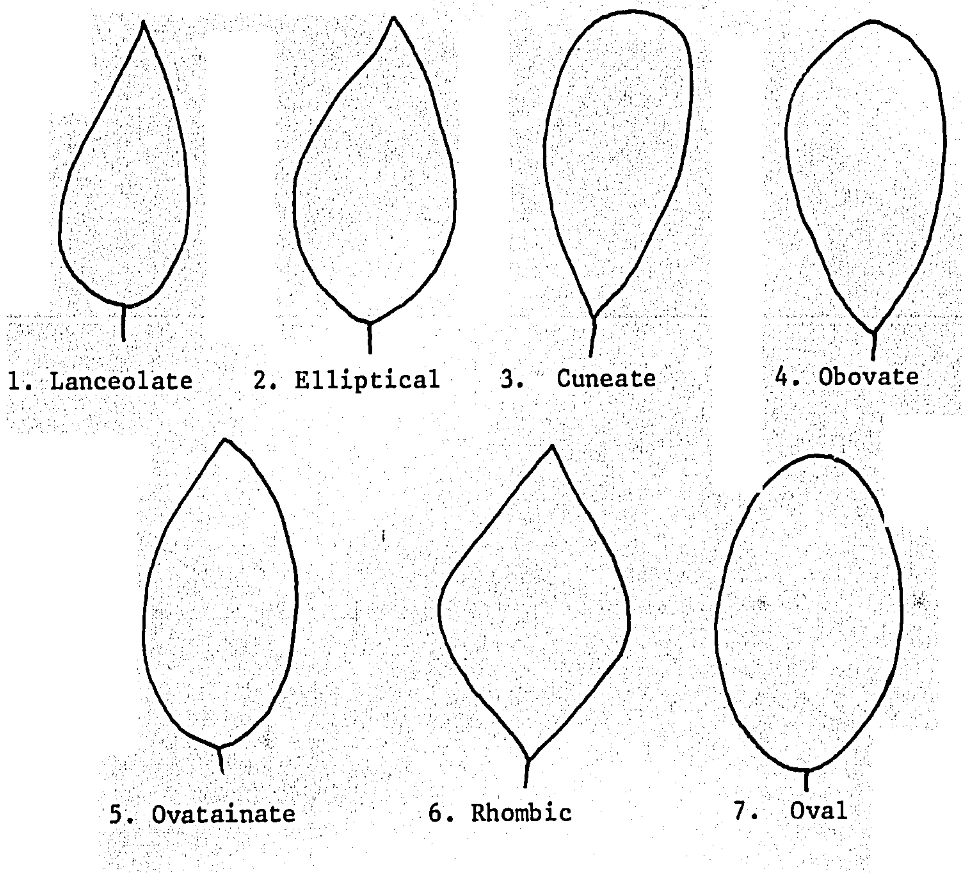

Figure 11. Leaf shape

4.1.14 Leaf margin (see Fig. 12)

1 Entire
2 Crenate
3 Undulate
4 Other (specify)

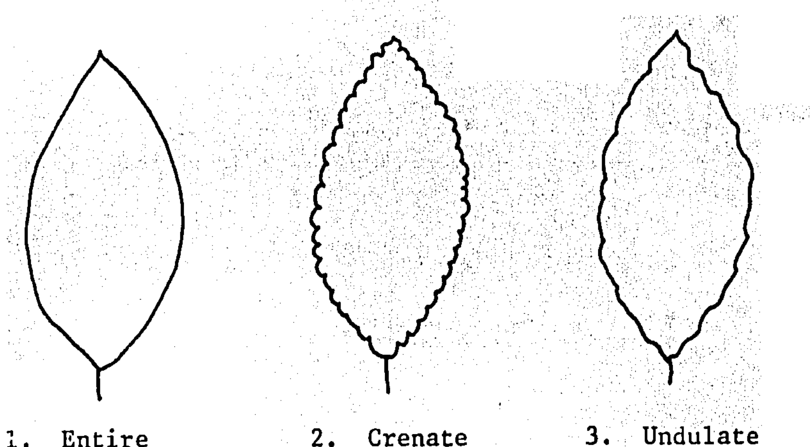

Figure 12. Leaf margin

4.1.15 Prominence of leaf veins

1 Smooth
2 Rugose (veins prominent)

4.1.16 Petiole pigmentation

1 Green
2 Dark green
3 Purple
4 Dark purple

4.1.17 Root type

1 Tap root
2 Fleshy root

4.2 INFLORESCENCE CHARACTERS

4.2.1 Terminal inflorescence stalk length, in cm

4.2.2 Terminal inflorescence laterals length, in cm

4.2.3 Terminal inflorescence shape

1 Spike (dense)
2 Panicle with short branches
3 Panicle with long branches
4 Club-shaped at tips
5 Other (specify)

4.2.4 Terminal inflorescence attitude

1 Erect
2 Drooping

4.2.5 Presence of Axillary inflorescence

0 Absent
+ Present

4.2.6 Length of axillary inflorescence, in cm

4.2.7 Sex type

1 Monoecious
2 Dioecious
3 Polygamous

4.2.8 Inflorescence density index

3 Lax
5 Intermediate
7 Dense

APPENDIX I
(Continued)

4.2.9 Inflorescence colour

1 Yellow
2 Green
3 Pink
4 Red
5 Other (specify)

4.3 SEED CHARACTERS

4.3.1 Seed colour

1 Pale yellow
2 Pink
3 Red
4 Brown
5 Black

4.3.2 Seed coat type

1 Translucent
2 Opaque

4.3.3 Seed shape

1 Round
2 Ellipsoid or Ovoid

5. PRELIMINARY EVALUATION

5.1 GERMINATION RATE

1 Rapid (< 2 days)
2 Slow (2 - 7 days)
3 Very slow (> 7 days)
4 Irregular

5.2 DAYS TO FLOWERING

Number of days from sowing till appearance of 50% plants with inflorescence

5.3 SEED SHATTERING IN THE FIELD

1 Low (< 10%)
2 Intermediate (10 - 50%)
3 High (> 50%)

FURTHER EVALUATION

6. FURTHER AGRONOMIC EVALUATION

6.1 SEEDLING GROWTH RATE

Estimated by biomass output at 4-week age, using plants grown at 25 x 25 cm spacing. The average weight of 10 seedlings in grammes

APPENDIX I
(Continued)

6.2 LEAF YIELD

In gramme/plant at six weeks after sowing

6.3 LEAF DRY MATTER PERCENTAGE

6.4 LEAF/STEM YIELD RATIO

6.5 REGROWTH

After first harvest by cutting at two internodes (for vegetable types)

3 Poor
5 Moderate
7 Good

6.6 SEED YIELD PER PLANT in gramme

6.7 1000 - SEED WEIGHT in gramme

6.8 LODGING AT MATURITY

0 None
3 Low
5 Moderate
7 High

6.9 PERCENTAGE OUTCROSSINGS

6.10 PHOTOPERIOD SENSITIVITY

1 Short-day
2 Day-neutral

6.11 POPPING ABILITY OF SEED

Estimated by percent popped seed and relative increase in volume

3 Poor
5 Medium
7 Good

6.12 PERCENTAGE PROTEIN CONTENT OF SEED

6.13 PERCENTAGE MINERAL CONTENT OF DRY LEAF MATTER

6.14 PERCENTAGE OXALATE CONTENT OF DRY LEAF MATTER

6.15 NUTRITIONAL VALUE OF LEAVES

A separate descriptor is needed for carotene, vitamin C, iron, calcium, folic acid, protein etc.

APPENDIX I
(Continued)

7. STRESS DESCRIPTORS

These are all expressed on a 1-9 scale where:

1 Very resistant
3 Resistant
5 Intermediate
7 Susceptible
9 Very susceptible

7.1 REACTION TO DISEASES

A separate descriptor is needed for each disease (e.g. stem rot, wilt, *Pythium* damping-off, leaf rust, *Choanephora* wet rot, etc.)

7.2 REACTION TO INSECT PESTS

A separate descriptor is needed for each insect pest (e.g. bugs, caterpillars, leafhopper, stalkborer, aphids, cucumber beetle, etc.)

7.3 REACTION TO NEMATODES

A separate descriptor is needed for each nematode

7.4 REACTION TO DROUGHT

7.5 REACTION TO SALINITY

7.6 REACTION TO LOW TEMPERATURE

APPENDIX II

A PROVISIONAL KEY TO SOME EDIBLE SPECIES OF THE FAMILY AMARANTHACEAE

Laurie B. Feine-Dudley[1/]

A Flowers unisexual

B Tepals 3

C Tepals equal to or longer than utricle; utricle circumscissile .... 1. *Amaranthus tricolor.*

C Tepals shorter than utricle; utricle indehiscent.

D Utricle smooth .... 2. *A. blitum.*

D Utricle rugose .... 3. *A. viridis.*

B Tepals 5

E Tepals approximately equal in length and incurved against utricle

F Plants armed; inflorescence with upper cymes staminate and lower cymes pistillate .... 4. *A. spinosus.*

F Plants unarmed; cymes with initial flower staminate and remainder pistillate .... 5. *A. dubius.*

E Inner tepals shorter than outer, tepals straight or recurved from utricle

G Bracts exceeding style branches; inflorescence either short and thick or moderately developed; always dark seeded

H Tepals longer than utricle, inner tepals with apex obtuse or emarginate; utricle not forming tower; inflorescence short and thick .... 6. *A. retroflexus.*

H Tepals shorter than utricle, inner tepals with apex acute; utricle narrowing into tower at apex; inflorescence moderately developed .... 7. *A. hybridus.*

G Bracts not exceeding style branches; inflorescence fully developed, enormous (domesticated species); seeds usually light, sometimes dark.

I Bracts equalling style branches; inflorescence stiff; style branches forming sharp cleft at base; tepals with apex acuminate .... 8. *A. hypochondriacus.*

I Bracts shorter than style branches; inflorescence lax

J Utricle narrowing into tower at apex; style branches erect; tepals with apex acute .... 9. *A. cruentus.*

J Utricle not forming tower; style branches spreading, meeting in saddle at base; tepals broad, often overlapping, inner tepals with apex obtuse .... 10. *A. caudatus.*

A Flowers perfect

K Flowers broadening into crest at apex, resembling a cock's comb .... 11. *Celosia cristata.*

K Flowers forming simple spikes .... 12. *C. argentea.*

1/ 426 Marlborough St., Apt., 3. Boston, Massachusetts 02115, USA

APPENDIX II
(Continued)

Figure 13. *Amaranthus tricolor* L. 1. branch with flowers (2/3 x); 2. male flower (4 x); 3. female flower (4 x); 4. fruit with dehiscing cap (6 x); 5. fruit without cap (6 x); 6. seed, lateral view (6 x); 7. scheme of glomerules

1. *Amaranthus tricolor* L. Sp. Pl. 989. 1753.
(see Fig. 13)

Amaranthus melancholicus L. Sp. Pl. 989. 1753.
Amaranthus tristis L. Sp. Pl. 989. 1753.
Amaranthus mangostanus L. Cent. I. 32. 1755.
Amaranthus gangeticus L. Syst. Veg. ed. X. 1268. 1759.

Erect annual herb, usually branched, to 1.5 m tall. Leaves extremely variable, broad-ovate, elliptic, deltoid, or lanceolate, apex acuminate, acute, retuse, or rounded, base acute, truncate, or cuneate. Inflorescence variable, usually a globose axillary cluster, if a terminal spike, usually reduced, occasionally well developed. Bracts lanceolate, as long as perianth or slightly shorter. Tepals 3, oblong or lanceolate, apex acuminate, equal to or longer than utricle. Utricle circumscissile and membranous, its cap narrowing into tower, style branches long and erect or reflexed. Seeds dark.

Cultivated as vegetable or as an ornamental.

2 *Amaranthus blitum* L. Sp. Pl. 990. 1753. (wild)

Amaranthus blitum L. var. *oleraceus* (L.) J.D. Hooker Flora Brit. India 4:721. 1885. (cultivated)

Amaranthus lividus L. Sp. Pl. 990. 1753.

Decumbent or ascending branched annual herb to 75 cm. Leaves variable, ovate, oblong-rhomboid, or obovate, apex obtuse, emarginate, or muchronate, base cuneate, acute, or obtuse. Inflorescence usually small axillary glomerules, occasionally a reduced terminal spike. Bracts much shorter than perianth. Tepals 3, ovate-oblong or obtuse, apex acuminate, 1/2 - 2/3 as long as utricle. Utricle smooth or slightly wrinkled, indehiscent or dehiscent with short style branches. Seeds dark.

Weed and cultivated forms.

APPENDIX II
(Continued)

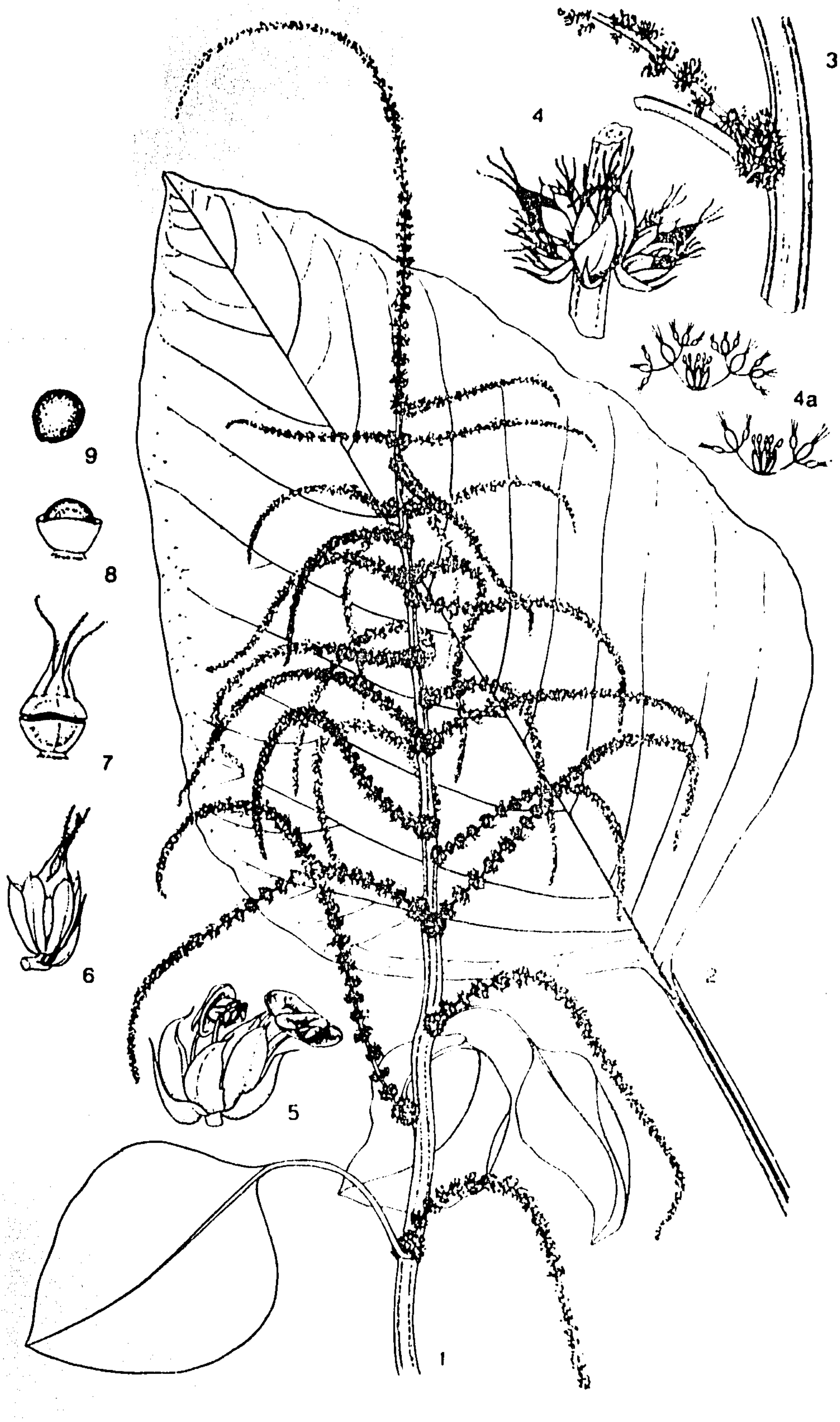

Figure 14. *Amaranthus dubius* Mart. ex Thell. 1. inflorescence (1/3 x); 2. adult leaf (2/3 x); 3. detail of inflorescence, petiole excised (2/3 x); 4. glomerule (6 x); 4A. scheme of glomerules; 5. male flower (6 x); 6. female flower (6 x); 7. fruit with dehiscing cap (6 x); 8. fruit without cap (6 x); 9. seed, lateral view (6 x)

APPENDIX II
(Continued)

Amaranthus viridis L. Sp. Pl. ed. 2. 1405. 1763.

Amaranthus gracilis Desf. Tabl. Bot. 43. 1804.

Annual herb to 80 cm, erect or ascending, branching from base or higher. Leaves variable, deltoid to rhombic-ovate, apex rounded, emarginate, or mucronate, base truncate or subacute. Inflorescence of small slender spikes, terminal spike often forming loose panicle. Bracts minute. Tepals 3, linear, oblong, to obovate, apex acuminate or acute, much shorter than utricle. Utricle indehiscent, strongly rugose, style branches short. Seeds dark.

Weed sometimes cultivated.

4. *Amaranthus spinosus* L. Sp. Pl. 991. 1753.

Armed annual herb, erect or ascending, to 1.5 m, with paired spines at most nodes. Leaves ovate, ovate-oblong, or oblong-rhomboid, apex obtuse, rounded, or retuse, base cuneate or obtuse. Terminal inflorescence lax and slender, upper portion staminate, lower portion pistillate; axillary inflorescences pistillate. Bracts lanceolate, often spine-like, equalling or slightly shorter than tepals. Tepals 5, oblong-ovate, equal in length, apex acute or acuminate, incurved against utricle. Utricle indehiscent or bursting irregularly. Seeds dark.

Weed.

5. *Amaranthus dubius* Mart. ex Thellung Fl. Adv. Montpellier 203. 1912. (see Fig. 14)

Erect annual herb, to 2 m, often branched. Leaves much larger in cultivated than weedy forms, deltoid, rhombic-ovate to lanceolate, apex obtuse or rounded, base cuneate or rounded. Inflorescence of long, slender, and lax spikes or panicles, often with many sterile flowers. Bracts shorter than tepals, ovate with slender midribs extending beyond laminas in points. Tepals 5, equal in length, shorter than and incurved against utricle, oblong lanceolate, or obovate, apices acute or mucronate. Utricle circumscissile, narrowing into tower at apex. Style branches erect and long. Seeds dark.

Weed or cultivated forms.

6. *Amaranthus retroflexus* L. Sp. Pl. 991. 1753.

Erect to ascending annual herb, usually much branched, sometimes simple, to 1.5 m. Leaves broad-ovate to elliptic, apex acute or apiculate, base cuneate. Inflorescence stiff, thick, and erect, of short panicles or spikes. Bracts twice as long as calyx, with heavy midribs and points extending well beyond laminas, giving the inflorescence a prickly look and feel. Tepals 5, longer than and recurved from utricle, oblong or oblanceolate, apex truncate, obtuse, or emarginate, inner tepals shorter than outer. Utricle circumscissile, more or less rugulose on upper half. Style branches erect or only slightly recurved, forming shallow cleft at thick bases. Seeds dark.

Weed.

7. *Amaranthus hybridus* L. Sp. Pl. 990. 1753.

Erect annual herb, usually branched, to 2 m. Leaves variable, broadly ovate, lanceolate, elliptic, ovate, oblong, or rhomboid, apex acute, acuminate or obtuse, base broad or narrow. Inflorescence moderately developed, lax terminal panicle with many lateral spikes. Bracts twice as long as tepals, exceeding style branches, with midrib extending beyond laminas. Tepals 5, shorter than utricle and slightly recurved. Inner tepals shorter than outer, slightly obovate, apex acute, outer tepals oblong, apex acute. Utricle circumscissile, narrowing into tower at apex, slightly rugose. Style branches erect; meeting in shallow cleft at base. Seeds dark.

Weed.

8. *Amaranthus hypochondriacus* L. Sp. Pl. 991. 1753.

Amaranthus flavus L. Syst. Nat. ed. 10. 2:1269 1759.
Amaranthus leucocarpus S. Wats. Proc. Amer. Acad. 10:347. 1875.

Variable annual herb, simple or branched, to 3 m. Leaves elliptic or ovate-oblong, apex acute or acuminate, base cuneate or acute. Inflorescence enormous, of terminal and lateral panicles or spikes, thick and erect, prickly and stiff. Bracts large, as long as style branches, long-pointed, giving the inflorescence a prickly look and feel. Tepals 5, slightly recurved, longer than tepals of other grain species, apices acuminate, inner tepals shorter than outer. Utricle circumscissile with large cap. Style branches recurved, meeting in a sharp cleft at thick bases. Seeds white, gold, brown, or black. Light coloured seed most commonly used for grain.

Cultivated for grain and as an ornamental.

APPENDIX II
(Continued)

9. *Amaranthus cruentus* L. Syst. Veg. ed. 10. 1269 1759. (see Fig. 15)

Amaranthus paniculatus L. Sp. Pl. ed. 2. 2:1406. 1763.

Erect annual herb to 2 m high, generally smaller than *A. hypochondriacus*, simple or branched habit. Leaves elliptic, rhombic-ovate to ovate-lanceolate, apex acute, obtuse, or acuminate, base cuneate or acute. Inflorescence fully developed, lower inflorescence forming lax and soft spikes, higher forming panicles. Bracts small, with slender points extending beyond laminas, never as long as style branches, sometimes exceeding tepals. Tepals 5, straight, oblong or oblong-obovate, apices acute, inner tepals shorter than outer. Utricle circumscissile, narrowing into tower at apex. Style branches slender and erect. Seeds black, brown, white, or yellow. Grain forms generally light seeded, vegetable forms dark seeded.

Cultivated for grain, as a vegetable, and as an ornamental.

10. *Amaranthus caudatus* L. Sp. Pl. 990. 1753 (see Fig. 16)

Amaranthus mantegazzianus Passerini, Ind. Sem. Hort. Parma 4. 1865.
Amaranthus edulis Spegazzini, Physis 3:163. 1917.

Erect annual herb, sparsely branched, to 2 m. Leaves variable, elliptic, ovate, lanceolate, or rhombic-ovate, apex acute to obtuse, base cuneate. Inflorescence usually of lax, extremely long drooping spikes or panicles, with distinctly knobby appearance due to large glomerules spaced relatively far apart, occasionally similiar to *A. cruentus*. Bracts short, not as long as style branches, with broad laminas and slender midribs. Tepals 5, broad, often overlapping, strongly recurved. Outer tepals obovate, longer than inner, inner spatulate, apices mucronate or obtuse. Utricle circumscissile, not forming tower. Style branches spreading, meeting in saddle at base. Seeds white, white with pink rim, or dark.

Cultivated for grain or as an ornamental.

APPENDIX II
(Continued)

Figure 15. *Amaranthus cruentus* L. 1. inflorescence (2/3 x); 2. big leaf (2/3 x); 3. branch with axilla (2/3 x); 4. male flower, one tepal removed (7 x); 5. female flower with dehiscing cap (7 x); 6. glomerule (7 x); 6A. scheme of glomerules; 7. seed, lateral view (7 x); 8. anther (7 x)

APPENDIX II
(Continued)

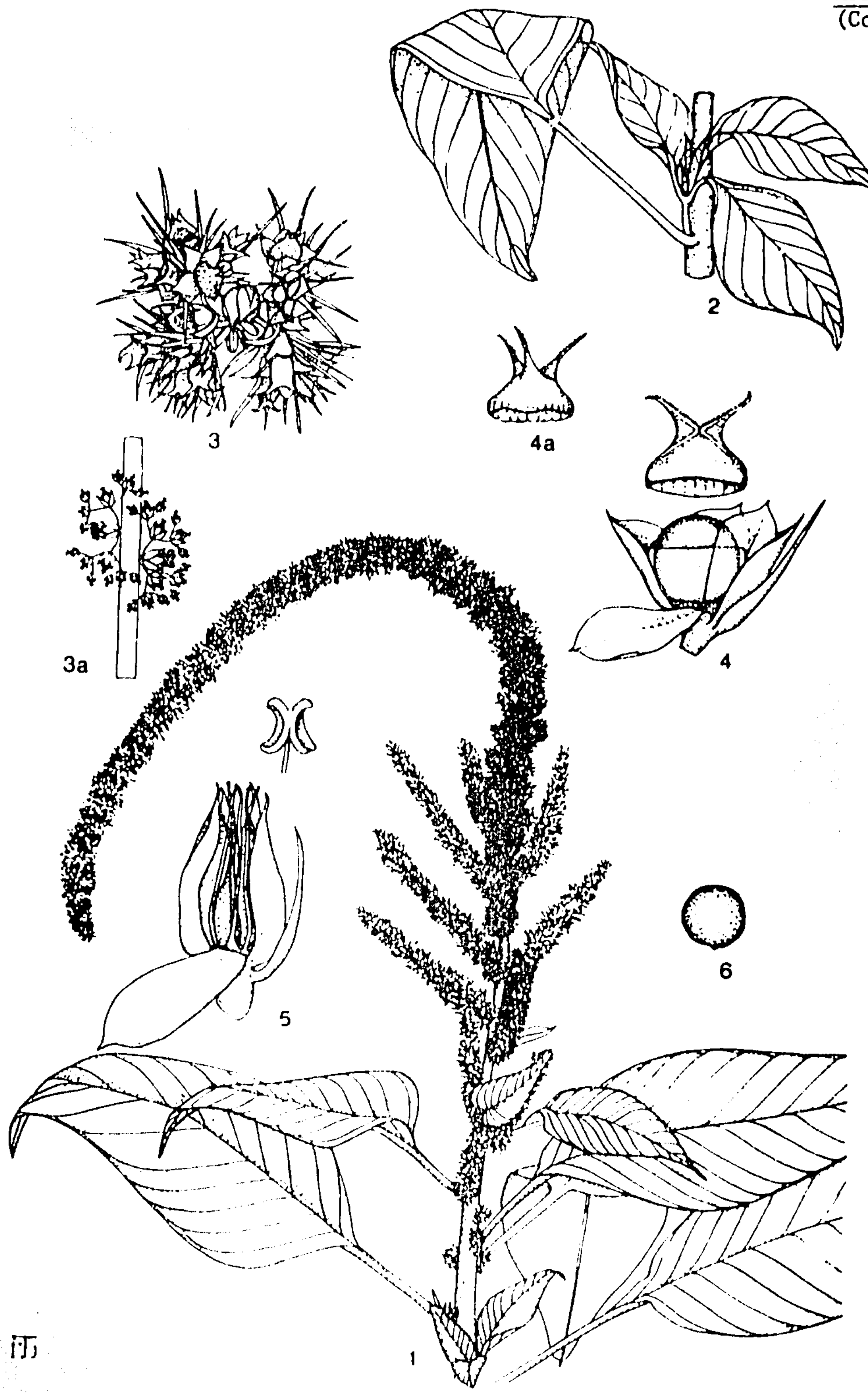

Figure 16. *Amaranthus caudatus* L. 1. branch with inflorescence (2/3 x); 2. detail, axilla (2/3 x); 3. front view of two glomerules (4 x); 3A. scheme of glomerules; 4. adult female flower with dehiscent cap (8 x); 4A. cap with three stigmata (8 x); 5. male flower (8 x); 5A. anther (8 x); 6. seed, lateral view (6 x)

APPENDIX II
(Continued)

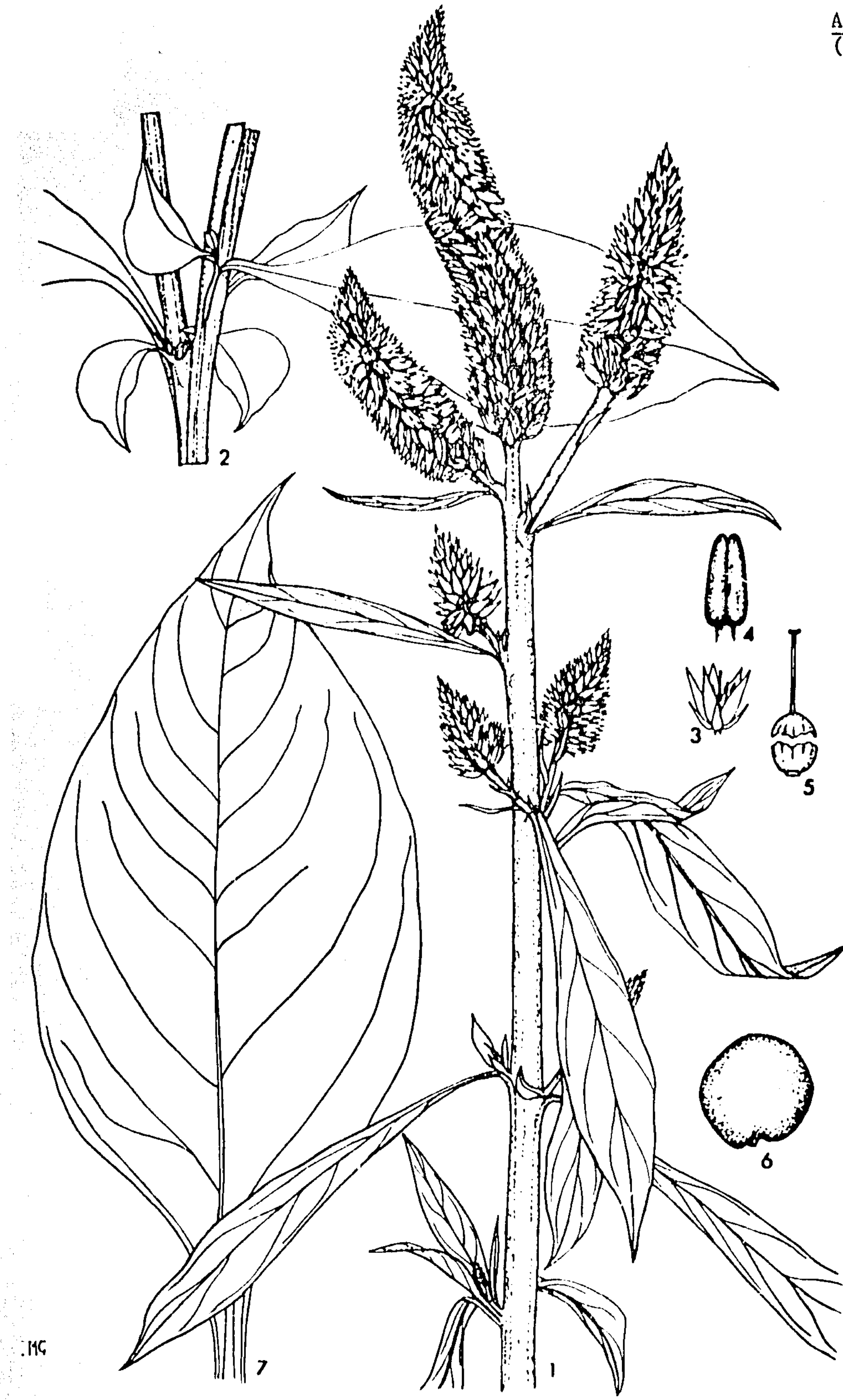

Figure 17. *Celosia argentea* L. 1. flowering branch (2/3 x); 2. detail, axilla (2/3 x); 3. flower (1.5 x); 4. anther (9 x); 5. fruit with dehiscing cap (8 x); 6. seed, lateral view (10 x); 7. adult leaf (2/3 x)

11. *Celosia cristata* L. Sp. Pl. 205. 1753.

Celosia argentea L. var. *cristata* (L.) Kuntze, Reviso Generum Plantarum 2:541. 1891.

Erect annual herb, simple or branched, to 90 cm. Leaves ovate, oblong, or ovate-lanceolate, apex acute or acuminate, base rounded, truncate, or cuneate. Inflorescence of shortly peduncled spikes, broadening into crest resembling a cock's comb. Bracts oblong-lanceolate, apex acute, half as long as perianth. Flowers perfect. Tepals 5, ovate or ovate-oblong, apex acute or acuminate. Stamens 5, united into short cup. Ovary globose, with single long style and capitate stigma. Capsule circumscissile. Two or more dark seeds per capsule.

Cultivated as an ornamental.

12. *Celosia argentea* L. Sp. Pl. 205. 1753 (see Fig. 17)

Annual erect herb, branched, to 2 m. Leaves elliptic, lanceolate, ovate, linear-lanceolate, rhombic, apex acute or acuminate, base cuneate. Inflorescence of several simple spikes. Bracts ovate-oblong, apex acute, shorter than tepals. Flowers perfect. Tepals 5, ovate or ovate-oblong, often longer than style branches. Stamens united into membranous cup. Ovary globose, style single and elongated with capitate stigma. Capsule circumscissile. Two or more dark seeds per capsule.

Weed or cultivated forms.

APPENDIX II
(Continued)

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APPENDIX III

INSTITUTIONS WITH GERMPLASM COLLECTIONS AND COMMERCIAL SEED SUPPLIERS

BENIN - Centre de Formation Horticole et Nutritionnelle, B.P. 13, Ouando, Porto-Novo (commercial seed 2 amaranth and 2 celosia cvs).

CHINA - Asian Vegetable Research & Development Center, P.O. Box 42, Shanhua, Taiwan 741 (genebank + 100 accessions, local & introduced; duplicated in OGFRC and partly in NIHORT).

CHINA - Hsing Nong Seed Co., 188 sec. 4 Chung Hsin Road, P.O. Box San Chung no. 2 San Chung, Taipei, Taiwan (several commercial cvs.).

CHINA - Taipei District Agricultural Improvement Station, Chin Chun, Taipei, Taiwan (working collection).

CHINA - Taiwan Seed Service, Shin-Shieh, Taichung, Taiwan (several commercial cvs.).

FRANCE - Institut National de Recherches Agronomiques, Petit-Bourg, Guadeloupe (working collection local cvs.).

GHANA - Department of Horticulture, University Science and Technology, Kumasi (working collection).

HONGKONG - Wong Yukhop Seed Co., 20 Pei Ho Street, Shumshuipo, Kowloon (2 commercial cvs.).

INDIA - Pocha's Seeds, P.O. Box 55, Poona 411001 Maharashtra (3 commercial cvs.).

INDIA - Division of Vegetable Crops and Floriculture, Indian Agric. Res. Institute (IARI), New Delhi 110012 (working collection).

INDIA - National Bureau of Plant Genetic Resources, IARI Campus, New Delhi 110012 (genebank 1400 accessions).

INDIA - Division of Vegetable Crops, Institute of Horticultural Research, 225 Upper Palace Orchards, Bangalore (working collection).

INDIA - Kerala Agricultural University, College of Horticulture, P.O. Vellanikkara 680651, Trichur Kerala (working collection).

INDIA - Faculty of Horticulture, Tamil Nadu Agric. University, Coimbatore 641003, India (working collection; 3 improved cvs.).

INDIA - National Botanical Gardens, Lucknow, UP. (working collection).

INDIA - Suttons Seeds, P.O. Box 9010, Calcutta-16, (4 commercial cvs.).

JAPAN - T. Sakata, CPO Box Yokohama 11, Yokohama, Japan 220-91 (1 commercial cv.).

NETHERLANDS - Dept. Tropical Crops, Agricultural University, Ritzema Bosweg 32, Wageningen (working collection ± 20 accessions).

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NIGERIA -	International Institute for Tropical Agriculture (IITA), P.M.B. 5320, Ibadan (working collection amaranth and celosia ± 60 accessions; TLV8 = new cv celosia from Benin).
NIGERIA -	Plant Science Dept., University of Ife, Ile-Ife (working collection).
NIGERIA -	National Horticultural Research Institute, P.M.B. 5432, Ibadan (genebank for vegetables; in 1979 138 acc. viz. amaranth 48 local cvs: 2 cereal types via FAO, 4 India, 78 AVRDC Collection; 6 celosia).
THAILAND -	Chia Tai Seeds & Agricultural Co., Ltd., 295-303 Songsawad Road, Bangkok (2 commercial cvs.).
USA -	Tsang & Ma International, P.O. Box 294, Belmont CA 94002 (1 commercial cv.).
USA -	Germplasm Resources Laboratory, Beltsville Agricultural Research Center, Beltsville MD 20705 (genebank, plant introduction fo. long-term storage).
USA -	Thompson & Morgan, P.O. Box 100, Farmingdale, N.Y. 07727 (1 commercial cv; Hinn Choy).
USA -	Burpee Co., Philadelphia 47, PA (1 commercial cv; Tampala).
USA -	Rodale Press, Organic Gardening & Farming Research Center, Rd 1, P.O. Box 323, Kutztown PA 19530 (± 650 accessions cereal + vegetable + wild species).
USA -	Park Seed Co., P.O. Box 31, Greenwood SC 29647, (1 commercial cv; Tampala).
ZAMBIA -	Crop Science Department, University of Zambia, Lusaka (collection 100 local cvs, Indian cereal & vegetable types from Tamil Nadu).

APPENDIX IV

BIBLIOGRAPHIES AND RECENT PUBLICATIONS

Abstract journals and bibliographies

ABSTRACTS ON TROPICAL AGRICULTURE. Department of Agricultural Research, Royal Tropical Institute, Amsterdam, The Netherlands.

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SELECTED AMARANTH BIBLIOGRAPHY (144 titles). Rodale Press, Kutztown: 9 p.

Reviews of current research

ANON, 1977. Proceedings of the First Amaranth Seminar, held at Kutztown, USA, July 29, 1977. Rodale Press, Emmaus: 132 p. (10 papers, review of research in USA 1975-1977 mainly on cereal amaranths).

ANON, 1979. Proceedings of the Second Amaranth Conference, held at Kutztown, USA, September 13-14, 1979. Rodale Press Inc., Emmaus, USA: 184 p. (Papers on nutrition, cultivation, assembly and handling of germplasm).

COLE, J.N. 1979. Amaranth from the past for the future. Rodale Press, Emmaus, USA: 311 p. (Including bibliography of 120 publications).

FEINE, L.B., HARWOOD, R.R., KAUFFMAN, C.S. and SENFT, J.P. 1979. Amaranth: gentle giant of the past and the future. In, Ritchie G.A. (Ed.), New Agricultural Crops. Westview Press, Boulder, Colorado, USA. AAAS Selected Symposium 38: 41-63 (Including 79 references).

GRUBBEN, G.J.H. 1976. The cultivation of amaranth as a tropical leaf vegetable, with special reference to South-Dahomey. Communication 67, Department of Agricultural Research, Royal Tropical Institute, Amsterdam: 207 p. (Including 197 references).

MARTIN, F. and LEHEL TELEK. 1979. Amaranth and Celosia. Part 6 of Vegetables for the hot, humid tropics. SEA-USDA, New Orleans: 21 p. (Including 15 references).

Recent publications

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DERMARDEROSIAN, A.H. et al., 1980. Nitrate and oxalate content of vegetable amaranth. Rodale Research Report, 80-4 : 25 p.

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HAUPTLI, H. and JAIN, S.K. 1980. Genetic polymorphisms and yield components in a population of amaranth. J. Hered., 71 : 290-292

JAIN, S.K. and HAUPTLI, H. 1980. Grain amaranth: a new crop for California. Agronomy Progress Report, Agricultural Experiment Station, University of California, Davis; No. 107 : 3 p.

APPENDIX IV
(Continued)

JAIN, S.K., WU, L. and VAIDYA, K.R. 1980. Levels of morphological and allozyme variation in Indian amaranths: a striking contrast. J. Hered., 71 : 283-285

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APPENDIX V

LIST OF RESEARCHERS ON AMARANTH

(topic of study is provided in brackets)

ABIDIN, Z.	Lembaga Penelitian Hortikultura, Lembang, Indonesia (cultivation)
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DENTON, L.	National Horticultural Research Institute, Idi-Ishin, P.M.B. 5432, Ibadan, Nigeria (germplasm collection, breeding)
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GILBERT, L.	OGFRC Rodale Press, Emmaus PA 18049, USA (amaranth foods)
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HAN HUANG	Dept. Horticulture, National Taiwan University, Taipei, Taiwan 107 (temperature)
HARI KRISHNA SAIJU	Dept. Medicinal Plants, Thapathali, Kathmandu, Nepal (cereal amaranth germplasm)
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OKE, O.	Chemistry Dept., University Ife, Ile-Ife, Nigeria (nutritional value)
OKIGBO, B.N.	IITA, P.M.B. 5320, Ibadan, Nigeria (farming systems)
OLUFOLAJI, A.O.	Dept. Agricultural Biology, Univ. Ibadan, Ibadan, Nigeria (cultivation, mineral content)
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ONWUEME, I.C.	Dept. Plant Science, University Ile-Ife, Nigeria (temperature stress amaranth and celosia)
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PREM NATH	National Horticultural Research Institute/FAO-UNDP Project NIR/72/007, P.M.B. 5432, Ibadan, Nigeria (germplasm)
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APPENDIX V
(Continued)

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SENFT, J.	Rodale Press OGFRC, Rd 1, P.O. Box 323, Kutztown PA 19530, USA (nitrate and oxalate studies, protein quality)
SHANMUGAVELU, K.G.	Dept. Olericulture, Tamil Nadu Agric. University, Coimbatore 641003, India (breeding)
SIVAKAMI, N.	Division Vegetable Crops & Floriculture, IARI, New Delhi 110012 India (variety testing)
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TAYO, T.O.	Dept. Agricultural Biology, Univ. Ibadan, Ibadan, Nigeria (cultivation, mineral content)
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TIMPO, Gl. M.	Dept. Horticulture, University Science & Technology, Kumasi, Ghana (cultivation amaranth, celosia)
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VAIDYA, K.R.	Dept. Agronomy & Range Science, University of California, Davis CA 95616, USA (genetics)
VIJAYAKUMAR, M.	120 P.G. Hostel, Tamil Nadu Agric. University, Coimbatore 641003, Tamil Nadu, India (cultivation, composition)
VISHAKANTALAH, M.	Dept. Entomology, University Agric. Sciences, Hebbal, Bangalore, India (Plutella caterpillars)
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WILSON, G.F.	IITA, P.M.B. 5320, Ibadan, Nigeria (cultivation)
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