# 7 Distribution and Maintenance of Amaranth Germplasm Worldwide

## 7.1 General

Amaranths show a wide geographical distribution, evolution of landraces and domestication in widely spaced areas. To carry out research on genetic improvement of the crop, proper collection, maintenance and periodical evaluation of germplasm are a prerequisite. There are quite a few amaranth research centres and germplasm collections all over the world which are maintaining a working germplasm collection. The germplasm collections are maintained in at least 61 collection centres. Prominent among them are Rodale Research Center, Pennsylvania; USDA Plant Introduction Center at Ames, Iowa; National Bureau of Plant Genetic Resources (NBPGR), New Delhi; etc. Amaranth genome may serve as a model system to study weediness. A bacterial artificial chromosome (BAC) library was constructed from *A. hypochondriacus* containing about 37,000 clones and an anticipated genome coverage of more than tenfold. Microsatellite markers developed from *A. hypochondriacus* and *A. tuberculatus* would be valuable for more detailed study on phylogeny and breeding efforts. These markers were shown transferrable to other cultivated as well as weedy amaranth species. Besides, shotgun sequence data from *A. tuberculatus* and collection of recombinant lines (RIL) derived from initial weed-crop cross between *A. hypochondriacus* and *A. hybridus* can also be very useful for the development of amaranth genetic map.

## 7.2 Germplasm Collection Centres in the World

The amaranths are characterised with wide geographical distribution that has resulted in the evolution of many landraces in widely separated areas. The wide gene pool of amaranths is to be assessed and characterised for future development of the crop. This needs systematic collection and maintenance of germplasm worldwide. Amaranth germplasm is catalogued and stored in germplasm banks in 11 countries (Toll and van Slotten 1982). A descriptive taxonomic key for all the cultivated species of the genus *Amaranthus* was developed by Feine-Dudley (Grubben and van Slotten 1981). Since 1977, Rodale Research Center (RRC) Pennsylvania, USA, is maintaining a working germplasm collection. The 1400 accessions in the amaranth germplasm collection include representatives from 12 amaranth species. The collection includes germplasm from banks in other countries, material from germplasm collection trips and materials which have been donated by collaborating researchers. The germplasm is catalogued according to 'grain type'. The grain type categories may actually be a regrouping of the germplasm according to landrace. The grain type categories have proven to be useful to manage the huge amount of variability that exists within each species. Descriptions of all species and the grain types can be found in the RRC germplasm catalogue (Kauffman and Reider 1986). To meet the problem of genetic



S. Das, Amaranthus*: A Promising Crop of Future*, DOI 10.1007/978-981-10-1469-7_7

erosion, *Amaranthus* germplasm has been collected for ex situ conservation (Grubben and Van Sloten 1981). Field studies have been conducted by Kauffman during 1978 and 1979. In 1978 yields were tested on 23 of the newly selected lines. Most of the lines were selected from the Mexican lines. The yield levels ranged from 5.8 to 18.8 q/ha. In California Davis Jain et al. (1984) reported grain yield of some selection as high as 36 q/ha (National Research Council 1984). Jorge Mario and Bressani (1987) while testing eight grain amaranth selections reported a grain-yield range from 20.3 to 38.q/ha in Guatemala. The highest grain yields were recorded in 20-USA (Rodale Selection of *A. cruentus*) followed by 28-USA (Rodale Selection). In China and Mongolia, maximum grain yields have been reported to be 5500 kg/ha and 3400 kg/ha, respectively. Four amaranth cultivars have been registered in the USA – 'Montana 3' (MT-3), 'Montata 5' (MT– 5), 'Amont' and 'Plainsman' (Schulz-Schaffer et al. 1991; Baltensperger et al. 1992). Several lines have been developed by the RRC, Nu-World Amaranth and American Amaranth that have been widely distributed and evaluated but never registered. All registered cultivars were developed by the RRC; 'MT-3' was a selection from RRC 1041, 'MT-5' was selected from RRC 425 and 'Amont' was a selection from 'MT-3'. 'Plainsman' was a selection from the cross RRC 1024 x RRC 1004 and widely distributed and treated as 'K 343' prior to release. Plainsman has become the most widely grown amaranth cultivar in the USA due to its relatively high yield potential, lodging resistance, limited seed shattering, seed colour and maturity range. Yield variation was high with Plainsman ranging from 2500 kg/ha in Colorado in 1991 down to 220 kg/ha in Missouri in 1990, typically in the range of 700 kg/ha to 1700 kg/ha considering all the entries over the year and locations tested. Several cultivars have been developed through the world including Russian, 'Pastevny 1', 'Turkestan' and 'Ural', and South America's *A. cruentus* genotype 'Anden' (Kaul et al. 1996). None of these cultivars have been widely tested in the USA. The main cultivars in China are five RRC lines (Corke et al. 1997) especially RRC 1011 (Yue and Sun 1993), but later three new lines have been developed in China (Wu 1998). Three cultivar lines, namely, 'Vietmeyer', 'Oscar Blanco' and 'Alan Garcia', were released through selection in Peru (Summar et al. 1992). Covas (1991) developed five cultivars in Argentina. Bansal (1996) described several cultivars in India, where 'Plainsman' replaced 'Annapurna' as the top yielding line.

The germplasm collections are maintained in at least 61 collections (IPGRI 1999). The collections are gradually becoming more and more important because of their accessibility and documentation through the Internet. Most collections have less than 100 accessions except six collections which are maintaining quite a large number of accessions (Table 7.1). *Amaranthus* is well adjusted to *ex situ* conservation due to their small and long-lived seeds (Kigel 1994). Brenner and Widrlechinar (1998) described an efficient protocol for regenerating seeds of *Amaranthus* germplasm and maintenance of its genetic integrity in ex situ situation.

A majority of the accessions in the RRC germplasm collection were collected as mass selections or single plant selections of cultivated landraces of those species which are commonly grown for their light-coloured seed. Many selections have been made from the segregating accessions in an effort to create uniform lines. Seed from the amaranth accessions has been distributed to thousands of researchers and farmers around the world. The germplasm collection is the backbone of the varietal improvement programme which is aimed at developing agronomically acceptable lines using classical plant breeding and selection methods.

Germplasm characterisation is being conducted at a number of locations around the world. Extensive, well-documented amaranth germplasm characterisation has been conducted by organisations in India, Peru and Mexico. Since 1982, the staff at RRC has collaborated with researchers who are conducting observations on 14 selected grain amaranth accessions (representing grain types from the species *A. hypochondriacus* L., *A. cruentus* L., *A. caudatus* L. and *A. hybridus* L.) to collect information on their

**Table 7.1** Six largest ex situ *Amaranthus* germplasm collections in the world

| | Institute | No. of accessions | Year updated | References |
|---|---|---|---|---|
| 1. | Institute of Crop Germplasm Resources (CAAS)Beijing, China | 438 | 1996 | IPGRI (1999) |
| 2. | Universidad Nacional del Altiplano Puno, Peru | 440 | 1990 | IPGRI (1999) |
| 3. | Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP) | 495 | 1993 | IPGRI (1999) |
| 4. | Univ. Nacional San Antonio Abad del Cusco (UNSAAC/CICA) | 740 | 1990 | IPGRI (1999) |
| 5. | National Bureau of Plant Genetic Resources | 3000 | 1995 | Joshi (1985) |
| 6. | North Central Regional Plant Introduction Station (NCRPIS), Ames, Iowa, USA | 3380 | 1999 | USDA, ARS (1999) |

performance at distinctly different climates and latitudes (Bressani et al. 1987; Senthong 1986; Gupta 1986; Duriyaprapan 1986; Espitia 1986). Information generated at each location serves as a starting point to help determine which sources of germplasm should be exploited to develop improved lines of grain amaranth for any given area. Similar observations have also been made to characterise germplasm which was collected throughout India (Joshi 1986). Populations of landraces which were collected from Mexico to Argentina have been observed for their genetic structure (Hauptli and Jain 1984).

Germplasm enhancement is being conducted at RRC since 1977 using recurrent single plant selection and mass selection with an intention to develop ideotypes which would meet the needs of modern agriculture.

The USDA Plant Introduction Center at Ames, Iowa, has been working to characterise germplasms and to determine the amount of outcrossing that has occurred. This Plant Introduction Center is of great significance in maintaining a large number of amaranth germplasm collected from all over the world and their distribution to promote amaranth research (Tables 7.2 and 7.3). USDA, Ames, Iowa, USA, also published an amaranth catalogue of 2783 collections with origin and grouped them under respective species of the genus *Amaranthus* (Brenner 1990).

In India initial efforts to study grain amaranths were made in the 1960s by the Division of Plant Introduction, Indian Agricultural Research Institute, New Delhi (now National Bureau of Plant Genetic Resources or NBPGR), which then held a small germplasm collection (less than 50) at Shimla Station, assembled from indigenous sources as well as from a few foreign countries, viz. Nepal and the USA. It was only in 1978 onwards when more efforts were directed towards germplasm collection and evaluation of the existing genetic resources to enrich these collections and to analyse and study the potential of this dual-purpose crop (Joshi and Rana 1991). A great deal of variability was observed, especially in inflorescence, leaf and stem colour; inflorescence size and shape; inflorescence and stem branching pattern; axillary inflorescence branching pattern; plant height, spiny/glabrous nature of the bracts; seed colour, size, weight and transparency; terminal inflorescence length and shape; and maturity. The collected amaranth germplasm includes nearly 2722 indigenous accessions and 293 exotic accessions. Now the total amaranth germplasm collection of Shimla Regional Station is 3081 comprising mainly of grain amaranth (Table 7.4). Apart from exchange of germplasm within India, exchange of seeds under physiosanity vigilance between India and other countries are being encouraged by NBPGR making exchange links with about 70 different countries. It is linked with several international institutes like IRRI, ICARDA, IITA, CIAT, AVRDC, CSIRO, USDA and IBPGR.

**Table 7.2** Various accessions of *Amaranthus* maintained at Plant Introduction Center at Ames, Iowa

| Sl. no. | *Amaranthus* species | Number of accessions |
|---|---|---|
| 1 | *Amaranthus* spp. NC7-amaranth | 41 |
| 2 | *Amaranthus albus* NC7-amaranth | 7 |
| 3 | *Amaranthus hybridus* NC7-amaranth | 154 |
| 4 | *Amaranthus blitum* NC7-amaranth | 10 |
| 5 | *Amaranthus dubius* NC7-amaranth | 43 |
| 6 | *Amaranthus crispus* NC7-amaranth | 1 |
| 7 | *Amaranthus greggii* NC7-amaranth | 2 |
| 8 | *Amaranthus palmeri* NC7-amaranth | 15 |
| 9 | *Amaranthus pumilus* NC7-amaranth | 7 |
| 10 | *Amaranthus torreyi* NC7-amaranth | 1 |
| 11 | *Amaranthus viridis* NC7-amaranth | 18 |
| 12 | *Amaranthus caudatus* NC7-amaranth | 557 |
| 13 | *Amaranthus cruentus* NC7-amaranth | 365 |
| 14 | *Amaranthus deflexus* NC7-amaranth | 5 |
| 15 | *Amaranthus hybridus* NC7-amaranth | 191 |
| 16 | *Amaranthus powellii* NC7-amaranth | 18 |
| 17 | *Amaranthus spinosus* NC7-amaranth | 24 |
| 18 | *Amaranthus tricolor* NC7-amaranth | 182 |
| 19 | *Amaranthus watsonii* NC7-amaranth | 1 |
| 20 | *Amaranthus wrightii* NC7-amaranth | 2 |
| 21 | *Amaranthus arenicola* NC7-amaranth | 7 |
| 22 | *Amaranthus asplundii* NC7-amaranth | 1 |
| 23 | *Amaranthus australis* NC7-amaranth | 2 |
| 24 | *Amaranthus blitoides* NC7-amaranth | 7 |
| 25 | *Amaranthus crassipes* NC7-amaranth | 2 |
| 26 | *Amaranthus muricatus* NC7-amaranth | 1 |
| 27 | *Amaranthus quitensis* NC7-amaranth | 51 |
| 28 | *Amaranthus acutilobus* NC7-amaranth | 2 |
| 29 | *Amaranthus cannabinus* NC7-amaranth | 3 |
| 30 | *Amaranthus fimbriatus* NC7-amaranth | 4 |
| 31 | *Amaranthus floridanus* NC7-amaranth | 1 |
| 32 | *Amaranthus graecizans* NC7-amaranth | 14 |
| 33 | *Amaranthus* retroflexus NC7-amaranth | 24 |
| 34 | *Amaranthus tenuifolius* NC7-amaranth | 1 |
| 35 | *Amaranthus tucsonensis* NC7-amaranth | 1 |
| 36 | *Amaranthus californicus* NC7-amaranth | 1 |
| 37 | *Amaranthus polygonoides* NC7-amaranth | 1 |
| 38 | *Amaranthus standleyanus* NC7-amaranth | 2 |
| 39 | *Amaranthus tuberculatus* NC7-amaranth | 51 |
| 40 | *Amaranthus acanthochiton* NC7-amaranth | 2 |
| 41 | *Amaranthus tamaulipensis* NC7-amaranth | 1 |
| 42 | *Amaranthus hypochondriacus* NC7-amaranth | 1523 |

**Table 7.3** Various accessions of *Amaranthus* available at Plant Introduction Center at Ames, Iowa for distribution

| Sl. no. | *Amaranthus* species | Number of accessions |
|---|---|---|
| 1 | *Amaranthus albus* NC7-amaranth 7 | 7 |
| 2 | *Amaranthus hybridus* NC7-amaranth 153 | 153 |
| 3 | *Amaranthus blitum* NC7-amaranth 10 | 10 |
| 4 | *Amaranthus dubius* NC7-amaranth 31 | 31 |
| 5 | *Amaranthus crispus* NC7-amaranth 1 | 1 |
| 6 | *Amaranthus greggii* NC7-amaranth 2 | 2 |
| 7 | *Amaranthus palmeri* NC7-amaranth 15 | 15 |
| 8 | *Amaranthus viridis* NC7-amaranth 17 | 17 |
| 9 | *Amaranthus caudatus* NC7-amaranth 543 | 543 |
| 10 | *Amaranthus cruentus* NC7-amaranth 335 | 335 |
| 11 | *Amaranthus deflexus* NC7-amaranth 5 | 5 |
| 12 | *Amaranthus hybridus* NC7-amaranth 184 | 184 |
| 13 | *Amaranthus powellii* NC7-amaranth 16 | 16 |
| 14 | *Amaranthus spinosus* NC7-amaranth 23 | 23 |

(continued)

**Table 7.3** (continued)

| Sl. no. | *Amaranthus* species | Number of accessions |
|---|---|---|
| 15 | *Amaranthus tricolor* NC7-amaranth 181 | 181 |
| 16 | *Amaranthus watsonii* NC7-amaranth 1 | 1 |
| 17 | *Amaranthus wrightii* NC7-amaranth 2 | 2 |
| 18 | *Amaranthus arenicola* NC7-amaranth 6 | 6 |
| 19 | *Amaranthus asplundii* NC7-amaranth 1 | 1 |
| 20 | *Amaranthus australis* NC7-amaranth 2 | 2 |
| 21 | *Amaranthus blitoides* NC7-amaranth 7 | 7 |
| 22 | *Amaranthus crassipes* NC7-amaranth 2 | 2 |
| 23 | *Amaranthus muricatus* NC7-amaranth 1 | 1 |
| 24 | *Amaranthus quitensis* NC7-amaranth 49 | 49 |
| 25 | *Amaranthus acutilobus* NC7-amaranth 2 | 2 |
| 26 | *Amaranthus cannabinus* NC7-amaranth 2 | 2 |
| 27 | *Amaranthus fimbriatus* NC7-amaranth 4 | 4 |
| 28 | *Amaranthus floridanus* NC7-amaranth 1 | 1 |
| 29 | *Amaranthus graecizans* NC7-amaranth 14 | 14 |
| 30 | *Amaranthus retroflexus* NC7-amaranth 24 | 24 |
| 31 | *Amaranthus tucsonensis* NC7-amaranth 1 | 1 |
| 32 | *Amaranthus californicus* NC7-amaranth 1 | 1 |
| 33 | *Amaranthus polygonoides* NC7-amaranth 1 | 1 |
| 34 | *Amaranthus standleyanus* NC7-amaranth 2 | 2 |
| 35 | *Amaranthus tuberculatus* NC7-amaranth 50 | 50 |
| 36 | *Amaranthus acanthochiton* NC7-amaranth 2 | 2 |
| 37 | *Amaranthus tamaulipensis* NC7-amaranth 1 | 1 |
| 38 | *Amaranthus hypochondriacus* NC7-amaranth | 1497 |

**Table 7.4** Germplasm of amaranths maintained at Regional Station Shimla, NBPGR

| Sl. no. | Species of *Amaranthus* | No. of accessions |
|---|---|---|
| 1. | *Amaranthus hypochondriacus* | 2452 |
| 2. | *A. cruentus* | 556 |
| 3. | *A caudatus* | 27 |
| 4. | *A. edulis* | 08 |
| 5. | *A. dubius* | 10 |
| 6. | *A. hybridus* | 09 |
| 7. | *A. viridis* | 05 |
| 8. | *A. retroflexus* | 07 |
| 9. | *A. lividus* | 03 |
| 10. | *A. tricolor* | 04 |

Apart from NBPGR, Regional Station Shimla, collections have also been made by the Vivekananda Parvatiya Krishi Anusandhan Shala (VPKAS) Almora, GB Pant Agricultural University, Ranichauri, Tehri Garhwal, North Eastern Hill Complex, Shillong, Maharashtra and Gujarat State in India. Collection activities have also been reported for grain amaranth germplasm including IBPGR (1984)-supported explorations in Nepal, Bhutan, Thailand, Indonesia, Ethiopia, Zambia, Nigeria, Kenya, Argentina, Bolivia, Ecuador, Mexico, Guatemala and Peru. The global germplasm collections have been stored in the National Seed Storage Laboratory, Fort Collins, Colorado, USA, where IBPGR has designated NBPGR as a regional base centre for amaranth germplasm collection in view of pioneering work done on this crop by this station. The evaluation of indigenous and exotic germplasm collections of grain amaranths over several years led to the identification of strains/accessions which offer good opportunities for its utilisation and improvement (Annual Report 1981 to 1988, NBPGR, Regional Station, Phagli, Shimla). These have been multiplied and maintained separately for distribution to the persons involved in crop improvement and those who are interested to take up inheritance studies. The most promising genotypes in indigenous and exotic material of interest to breeders include IC-38541, IC-38577, EC-170304 and EC-169626 (dwarf types, 68–81 cm); IC-38137, EC-38323 and EC-151544 (high number of spikelets, 65–95); IC-38052, IC-38508 and EC-157415 (high inflorescence length, 78–95 cm); IC-5626, IC-7934 and IC-38 136 (hard threshability); IC-38133, EC-157413 andBDJ86–329 (early flowering 40–52 days); IC-38133, IC-38422 and EC-1574 17 (early maturing 100–110 days); IC-38131, IC-386 11, IC-38665 and BDJ-86–259 (bold seeded 1000 grain weight more than 1 gramme); and IC-38269, IC-38280, IC-42258–1, VL-21 and BDJ86–129 (high grain yield per plant). A very high yielding variety of grain amaranth *A. hypochondriacus* named 'Annapurna' was developed in the National Bureau of Plant Genetic Resources (NBPGR) Regional Station, Shimla, through screening germplasms of 2700 collections and multilocation trials after a continuous research of 14 years (Joshi et al. 1983). It has given an average grain yield of 22.3 q/ha. and 34 q/ha of seed yield in Shimla condition. The variety has few distinguishing features like tall habit, medium or late maturing, dark-green broad leaves, yellowish-green inflorescence with long terminal and lateral spikelet, about 74 cm long and creamish-white seed with 14.5 % protein content. The popping quality of the seeds is excellent, about six times of the seed size. The other significant varieties of grain amaranth like R 104, 20 USA, Jumla, VL-21 and S.K. Nagar have also been developed and employed in cultivation in different parts of the world. The variety 'Annapurna' has a wide adaptability and can be grown in rain-fed land in the hills as well as in the drought-prone areas and also under Himalayan watershed. It has given 68.9 % higher increase in grain yield over VL-21, another promising selection from Almora, Uttarakhand. All India Coordinated Research Project has recommended it as a national check (Joshi and Rana 1991). Nine promising varieties selected from landraces of grain amaranths were evaluated by repeated trials at Shimla and Almora during 1986. The highest grain yield (34.8 q/ha) was recorded for 'Annapurna' followed by VL-21 (32.5 q/ha) and IC-42290–17 (30.9 q/ha). Multilocation trials of 14 promising varieties were conducted at eight centres during 1988–1989. The varieties that appeared to be significant were S.K. Nagar, 'Annapurna', 'Akola local', *A. edulis* (ex Taiwan), IC-5564, etc. with varying yield amounts at different locations.

**Table 7.5a** Amaranth germplasm collection at Tamil Nadu Agricultural University, Coimbatore

| Sl. no | Species of *Amaranthus* | No. of accessions maintained |
|---|---|---|
| 1 | *Amaranthus dubius* | 18 |
| 2 | *Amaranthus tricolor* | 22 |
| 3 | *Amaranthus tristis* | 6 |
| 4 | *Amaranthus hypochondriacus* | 14 |
| 5 | *Amaranthus cruentus* | 19 |
| 6 | *Amaranthus paniculatus* | 18 |
| | Total | 97 |

In South India, Tamil Nadu Agricultural University, Coimbatore, is a prominent centre of amaranth germplasm collections, specially vegetable amaranths (Tables 7.5a and 7.5b), which released few improved varieties of vegetable amaranths.

## 7.3 Genome Resource Development of *Amaranthus*

Amaranth may serve as one of the best model systems of genome investigation of weediness (Basu et al. 2004; Chao et al. 2005). Amaranth possesses several characteristics which made them a desirable model system:

1. Most species are functional diploid having n = 16 or 17 (exception *A. dubius* is a polyploid with 2n = 64). *Amaranthus* species have detectable genome size 3 to 4 times that of model plant *Arabidopsis thaliana.*
2. *Amaranthus* species are generally easy to culture and manipulate under greenhouse or other experimental condition.

**Table 7.5b** Few new cultivars/varieties of vegetable amaranths were released from vegetable research station, TNAU

| Sl. no | *Amaranthus* species | No. of accessions at VRS, Palur | Remarks |
|---|---|---|---|
| 1. | *Amaranthus polygonoides* | 8 | Called Sirukeerai in Tamil |
| | | | A variety named PLR1 was released in 2013 from this university |
| 2. | *Amaranthus tristis* | 2 | Called Araikeerai in Tamil |
| | | | A variety named CO3 was released in 2013 from this university |
| 3. | *Amaranthus tricolor* | 7 | Called Mulaikeerai/Thandukeerai in Tamil |
| | | | Varieties: CO2 and CO5 |

3. As a typical weed, *Amaranthus* spp. exhibit plasticity in adaptability in diverse environmental condition.
4. The monoecious species are readily self-pollinated but outcross, and F1 hybrids are easily obtainable if selectable (herbicide resistance), detectable or scorable (pigmentation) markers are present in one of the parents.
5. Production of a large number of small seeds.

The first genome-based resource derived specifically from *Amaranthus* species is now available. A bacterial artificial chromosome (BAC) library was constructed from *Amaranthus hypochondriacus* (Maughan et al. 2008). It can be used as a tool for isolation and identification of the full-length gene sequence. This library contains about 37,000 clones and a presumed genome coverage greater than tenfold. Thus any specific DNA sequence of *A. hypochondriacus* has greater than 99 % chance of being represented in this library. A full-length genome sequence for desirable target site of the gene ALS and PPX2 can be obtained. Due to the sequence similarity among the *Amaranthus* species, the BAC library from *A. hypochondriacus* can be utilised for genome-based investigation of other weedy species as for example, transferability between *A. hypochondriacus* and other weed species. The BAC library can be used to generate a physical map of the *Amaranthus* genome, which ultimately can enable map-based cloning of *Amaranthus* genes of interest (Maughan et al. 2008).

The second genome resources available are a set of microsatellite marker. The microsatellite markers are one of the most robust and informative markers to study genetic variability. The microsatellite markers will be of great value to investigate queries related to gene flow, evolution and hybridisation within and among *Amaranthus* weeds. The microsatellite markers can also be used to construct genetic linkage map from mapping populations and for multilocus genome scanning to identify genetic target of selection (Smith and Haigh 1974). Microsatellite markers have been developed from *A. hypochondriacus* (Lee et al. 2008; Mallory et al. 2008), and markers were demonstrated to be transferable to the other cultivated as well as weedy amaranth species. Nearly 400 unique microsatellite markers were obtained primarily from microsatellite-enriched libraries but also from BAC-end sequence data. About 180 of these proved polymorphic among three grain amaranths. Many of these markers are transferable to the dioecious amaranth species as well. A preliminary phylogenetic analysis using some of these markers placed *A. hybridus* within multiple grain amaranth clades, suggesting multiple domestication events from *A. hybridus* (Mallory et al. 2008). Additional microsatellite markers were obtained recently from *A. tuberculatus* (Lee et al. 2009); collectively these microsatellite markers will be valuable for more detailed phylogenetic studies and breeding effects.

The third genome resource obtained recently is shotgun sequence data from *A. tuberculatus* (Lee et al. 2009). Random sequencing was done using massively parallel pyro-sequencing technology (Margulies et al. 2005). From a single pilot sequencing run, approximately 160,000 sequencing reads were obtained within an average read length of about 270 nucleotides, yielding a total of about 43 million nucleotides of *A. tuberculatus* sequence data. The data sheet included nearly a complete sequence of the chloroplast genome and partial sequence of most currently known herbicide target-site genes.

The fourth resource is a collection of recombinant inbreed lines (RILs) derived from an initial crop-wild cross between *A. hypochondriacus* and *A. hybridus*, selected based on herbicide resistance. They can be the useful source to provide ideal populations for development of an amaranth genetic map.