11 Future Prospects in Amaranth Research

Amaranths especially the grain amaranths are considered as the golden crop of future. Though the cultivation of grain amaranths was initiated in the prehistoric period with a promising note, later it lagged behind conventional crop a lot, because a large section of the people rejected that due to its unpalatability. Later, a number of research works on unique nutritive value of both vegetable and grain amaranths rediscovered the plant and projected the group as useful super crop of future keeping in view its minimum agronomic demand and food security of huge world population. The available literatures on amaranth research reveal that this underutilised crop has not received much attention as it deserves. Most of the research works were concentrated on its nutritive value as human and animal feed, utilisation of starch, basic biology, genetics and breeding practices. A little work has been done on taxonomy, phylogeny and germplasm maintenance and screening and biotechnological approach in breeding programme. Much of the attentions was directed towards grain species of amaranths; vegetable group received very little attention. Weed amaranths too are not evaluated for utilisation in breeding programme. Thus, the area of amaranth research is vast and wide. A multidisciplinary research approach is very much needed to project amaranths as golden super crop of future.

Cultivation of amaranth has gradually crept into a number of countries. Research work on re-evaluation of its significance and importance and contribution towards genetic manipulation of other crops has gained a momentum in recent years. Breeding programme related to genetic improvement has escalated a lot. But still there are few areas which are to be given emphasis. While no fundamental obstacles to the crop's future development are apparent, many technical details remain to be explored. Agencies funding agricultural research for developing countries should consider supporting amaranth research and testing. Some of the thrust areas for recommendations and research needs are listed here:

1. *Collection and screening of germplasm*: Amaranth offers more genetic diversity in its present undeveloped state than do many conventional crops. The broad geographic spread of the genus has resulted in the evolution of many landraces in widely separated areas. Several features of their highly variable breeding system and overall reproductive biology provide ample choice of breeding methods. This huge gene pool will be very important to the future development of the crop. Further systematic collections of amaranth germplasm should be made in Latin America, the Caribbean, India, Nepal, China and the Pacific. These collections should be coordinated with the International Board on Plant Genetic Resources (IBPGR), which is starting germplasm collections in Southeast Asia and has recently completed one in Peru. Proper screening of germplasm

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collection is necessary for the future development of the crop.

There is a need to develop an international cooperation network to enrich the germplasm collection with exotic elite lines or cultivars also to test elite lines and germplasms of amaranths in as many locations as possible under various agroclimatic conditions.

2. *Adaptability trials*: Selection and standardisation of uniform high-yielding lines for multilocation yield trials are essential to fish out types with desirable features like wide adaptability in the hill. Studies on inheritance and combining ability, correlation and genetic divergence need due emphasis for varietal improvement. The varieties selected for adaptability trials should include a range of species and morphological types that have agronomic potential. This would be an excellent way to obtain indications of the geographical areas where given types will grow best. It would be the first step towards developing 'zones' for amaranth adaptability, similar to those used for soybeans. Larger trials, involving perhaps 100–500 varieties, should also be undertaken by geneticists and screening nurseries. Demonstration trials under farm conditions are also recommended.
3. *Ethnobotanical aspects of the crop*: Studies of the ways people grow and use grain amaranths in Central and South America and the Himalayas, as well as those methods employed to grow and use vegetable amaranths elsewhere, could be very informative. Data could be collected about the most favourable environments within which the various species can be grown and much useful information could be collected by documenting the rainfall, temperature, day length and soil conditions of these areas. This would enable to target new areas for amaranth cultivation. It would also demonstrate soil requirements, crop ecology and social aspects of amaranth cultivation and use. Such studies will not only benefit those wanting to grow amaranth for the first time but will also assist people who traditionally cultivate the crop.
4. *Role of weedy amaranths*: From agronomic point of view, amaranth, specially the weedy members, is interesting for their drought tolerance, low susceptibility to disease and pest (Barba de la Rosa et al. 2009) and environmental plasticity, i.e. ability to grow in areas where traditional crops fail to adapt (Brenner et al. 2000). Amaranths are leading the modern weed science research and have played as a model system for the study of weedy nature of plants (Basu et al. 2004).

Many amaranth species have developed unique resistance to few herbicides, recommended for the control of annual dicot weed. Heap (2002) reported about six amaranth species among 25 worst resistant weeds in the world. Amaranth weeds provide valuable genomic resources that can be utilised for improving important agronomic crop trait, like potentiality to generate herbicide resistance. Genome analysis of resistant species can be helpful to explore the evolution of herbicide resistance in plants as well as the possibility to transfer the resistant trait from weed to crop.

Seeds of the shattering, weedy amaranth species (e.g. *Amaranthus hybridus*, *Amaranthus palmeri*, *Amaranthus retroflexus* and *Amaranthus spinosus*) should not be distributed for cultivation. Nevertheless, these weeds can be useful to the amaranth breeder. *Amaranthus hybridus* is the wild progenitor species of present-day cultivated *Amaranthus hypochondriacus* and easily exchanges genes with it. For introducing desirable traits like faster maturation, disease resistance and wider adaptability in the cultivated forms, the role of *Amaranthus hybridus* could be invaluable. *Amaranthus spinosus* (a diploid), sometimes a troublesome weed, can be utilised in raising hybrids (F_1 triploids) with *Amaranthus dubius* (a tetraploid) on a commercial scale for forage. This is made possible by the peculiar distribution of male and female flowers in *Amaranthus spinosus*. The hybrids are fast-growing and sterile and have very soft spines. Feeding trials and nutritional studies are, however, a prerequisite before using such hybrids for forage.

5. *Taxonomic delimitation in amaranths*: Taxonomic disputes in amaranths are still not clearly resolved. The presence of a large number of morphotypes, landraces and overlapping morphological features and frequent misapplication of names and a large number of synonyms have made taxonomic delimitation in amaranths much complicated. Subcategorisation in grain amaranth and its derivation from weed amaranths almost unequivocally resolved applying both morphological and molecular parameters. Weedy and grain amaranths are phylogenetically and historically linked inseparably. Disputes regarding taxonomic segregation in vegetable amaranth are still awaiting proper attention. From Lower Gangetic Plain of West Bengal, India, few new species and varieties of vegetable amaranths have been identified having specific morphological and reproductive identity. The plains of India and other Southeast Asian countries are rich source of vegetable amaranth germplasm with unique diversity. This diversity should be explored to broaden the vegetable list of nutritive potential.

   It is assumed that both the grain and vegetable amaranths have originated from their respective weed progenitors at different locale of the globe. But unlike grain amaranth, we don't have any concrete idea about the putative progenitor of vegetable amaranth and phylogenetic linkage among them as well. Information on genetic diversity and relationship within and among crop species and their wild relatives is essential for the fruitful utilisation of the Plant Genetic Resources. It is of common consensus that the monoecious grain and vegetable amaranths form two distinct groups. The subgenus *Acnida* represents dioecious weedy amaranths. Its relation with grain amaranths is yet to be explored conclusively which is very important for their utilisation in any breeding programme.

6. *Biotechnological approach in genetic improvement of amaranth*: Previously the genetic improvement of amaranths has been done by conventional selection method and hybridisation. But recently biotechnological procedures have been applied and found to be very effective. A novel protein *AmA1* has been isolated from the seeds of *Amaranthus hypochondriacus* and subsequently purified and characterised; its cDNA was cloned, and through transformation, transgenic potato and wheat plant has been raised. This has opened a new avenue to improve the nutritive value of several other crops through introduction of *AmA1* protein gene by *Agrobacterium*-mediated transformation.

   Much of the research activities done on amaranths has focussed on its exceptional nutritive value. The main reason could be the content of protein, fat and active substance with antidiabetic, anti-hyperlipidemic, spermatogenic and anticholesterolemic effects (Sangameswaran and Jayakar 2008; Girija et al. 2011) and antioxidant and antimicrobial activities (Alvarez-Jubete et al. 2010; Tironi and Aron 2010). Additional interest is generated by the oil and carbohydrate profile of amaranth seeds which offers scope for various industrial applications. Nutritive value of vegetable amaranths is somewhat degraded by the presence of some antinutrients like oxalic acid and nitrates. The presence of saponin and phenolic compounds in grains is responsible for its unpalatability. Decarboxylative degradation of oxalic acid is catalysed by enzyme oxalate decarboxylase. A full-length cDNA for oxalate decarboxylase was cloned and characterised, and transgenic tomato plant was raised showing oxalate decarboxylase activity. This approach is very promising for vegetable amaranths to reduce oxalate problem and make it more acceptable. A protocol for *Agrobacterium*-mediated transformation of *Amaranthus tricolor* has already been developed and standardised. This could be utilised to produce transgenic amaranth with oxalate decarboxylase activity.

7. *Some specific agronomic requirements*: From agronomic point of view, though amaranth requires little agronomic attention in comparison with other conventional crops, still few steps need to be taken to improve yield. Amaranth cultivation and harvesting practices require several types of research in the following aspects:
   1. Selection of type best adapted to local conditions
   2. Application of mixed cropping system in amaranth cultivation and crop rotation
   3. To learn about the most extreme rainfall, evaporation and soil characteristics under which amaranths grow and produce a reasonable yield
   4. Knowledge about soil requirements, i.e. fertility, tolerance to salinity, need for organic matter and maximum and minimum moisture
   5. Knowledge about the effects of growth conditions on chemical composition and nutritive value
   6. Determination of best planting dates, plant density and weed and pest management
   7. Development or adaptation of machinery, planting implements, thresher, winnower and grain cleaner
   8. Control of diseases and pests causing significant damage of the crop
   9. Proper strategies of seed storage to sustain seed viability for longer period of time

   Future research should be directed towards achieving few breeding objectives which are yet to be achieved. Presently, breeding objectives of grain amaranths prescribe selection for the following traits:
   1. Desirable growth characteristics such as reduced plant size, reduced sensitivity to photoperiod, synchronous flowering, early maturity, reduced lodging and uniform drydown
   2. Environmental adaptations such as drought tolerance, pest and disease resistance, herbicide tolerance and efficient fertiliser utilisation
   3. Food quality such as white seeds, palatability and high levels of protein and essential amino acids
8. *Processing of grain amaranths*: Research is needed on the physiology of postharvest handling, especially on the effect of moisture on grain quality and storage. Studies are also needed on some other agrotechnical aspects:
   1. Grain cleaning
   2. Removal of sand and weed seeds from the grain
   3. Applicability of existing machineries to handle amaranth
   4. Drying and storage of harvested grains
   5. Processing of the whole grain, such as by extrusion cooking, milling whole and popped seed and toasting, rolling, sprouting and popping, to assess any changes in nutritional value or chemical compounds from such processing
   6. Commercial development requirements, such as dry and wet milling and derivatives
   7. Storage and shelf life of products
   8. Value of the grain and crop residues for ensilage and for direct feeding to livestock
9. *The use of grain amaranths as food*: Regarding the use of grain amaranths, research is needed in the following aspects:
   - Basic characteristics of seed starch, protein, bran, germ and oil
   - Uses in products, including breakfast foods and weaning mixtures, as well as recipe development
   - Nutritional testing in humans
   - Amaranth's value as a wheat extender or a supplement for added nutritional value in traditional foods such as chapattis, tortillas, weaning foods, chicha and arepas
   - Its use in infant foods
   - Nutritional availability of minerals, vitamins, proteins and starch
   - Amaranth's functional characteristics (viscosity, density, freeze-thaw stability, heat stability, emulsifying properties) when used in foods, and how grain types differ from one another in those characteristics.
   - Anti-nutritional constituents

10. *Vegetable amaranths*: Vegetable amaranths have been more thoroughly investigated than the grain amaranths in Asia and more specifically in Southeast Asia. Several important aspects are still left for improvement. Selections have been made by Asian growers for many years; varieties have been identified suitable for widespread culture. Nevertheless, further improvement of the crop could be achieved by studies of the following:
    1. Pest and disease resistance
    2. Nutrient uptake and nutrient content at different stages of harvest or crop growth
    3. Leaf yield
    4. Food quality, including tenderness and storage methods to prolong the life of the harvested produce
    5. The use of amaranth leaves as a remedy for vitamin A deficiency
    6. Anti-nutritional factors and heavy-metal accumulation in response to type and quantity of fertilisers used and type of soil
    7. Production of leaf-nutrient concentrate
    8. Regrowth after harvest
    9. Comparison of yield from clipping versus successive planting
    10. Seed production and farmer-selection techniques
    11. Leaf/stem ratio
    12. Late emergence of inflorescences
    13. Planting and cultural practices for efficient use of land, water and fertiliser
    14. Crop rotation to avoid soil-borne diseases
    15. Proper timing of harvest
    16. Benefits and possible toxic problems of vegetable amaranth as a forage
11. *New uses*: The germs and brans of grain amaranths contain about 20 % oil. There is a need to study and screen the germplasm for edible oil. The amaranth oil is the rich source of squalene (a high-priced material found in amaranth seed but normally obtained from shark livers and used in cosmetics). The industrial application of amaranths is an area which is to be explored in much extensive manner. The nutraceutical activities of amaranths are yet to be explored adequately. There is a need to evaluate the impact of processing and cooking on the nutritional properties of the species. Amaranth can also be a potent source of natural dyes and pharmaceuticals.
12. *Environmental impact*: It is important to study the weediness of the most problematic *Amaranthus* species and the likelihood of their becoming pests. Amaranth pollen and grain may cause allergic reactions in some people, and this needs to be addressed. Both the grain- and vegetable-type amaranths could provide many nutritious foods for the world. The small seed size is a limitation in planting as well as in harvesting, threshing and cleaning the grain. But modern experience in the Northern Indian plains shows that they have a good chance of adapting successfully. They might complement other cereals such as sorghum, millets or barley, thus helping countries that import large amounts of wheat. In addition, they would provide a local source of feed grain for the poultry industries of developing nations. Grain amaranths are the new promising crop for drylands (areas with 600–800 mm of rainfall per year) and for tropical highlands up to extreme elevations (3500 m and above) and as a quick-maturing, dry-season crop for monsoon areas. It would be a daydreaming and too much optimism to expect amaranth to be on dinner plates next year; it took a century for the American people and the farmers to accept the soybean, and it took two centuries for Europeans to give recognition to potato. Comparing with such now-established crops, amaranth has attracted the attention of scientific research or testing though in small scale. With the help of today's communications and technology, the day is not far away when amaranth would find its niche. Within a few years, it seems likely that this ancient grain of the Americas will return to grace in the modem age. Eventually, it may prove to be as a rich leg-

acy of the American Indian as maize and beans.

Despite the growing evidence in amaranth's favour, much research needs to be done before the crop be commercially produced on large scale like conventional cereals and widely accepted. Nevertheless, the researchers are studying the crop's responses to climate, soil conditions, pests and diseases. Also, they are engaged in breeding of short-statured plants of uniform height with sturdy, wind-resistant stalks and high-yielding seedheads that hold their seeds until they are harvested. Much of the amaranth's development has been done in the Rodale Research Centre near Emmaus, Pennsylvania, where more than a thousand different accessions collected from all parts of the world were bred, grown and evaluated. Further collaboration has been initiated with scientists in Africa, Asia and Latin America; as a result, plant lines have been selected to overcome tendencies towards lodging, seed shattering, indeterminate growth, succulence at harvesting time and day-length dependence. This research effort has produced grains with improved baking, milling, popping and taste qualities, as well as machinery adapted to planting, cultivating, harvesting and threshing the crop. Lines of uniform colour and height that bear their seedheads above the leaves, thus making them suitable for mechanical harvest, are now available. The crop can be said to be on the threshold of limited commercial production in the USA. Several companies are testing the grain in their products, and an amaranth-based breakfast cereal is available. Research has mainly emphasised grain amaranths so far, but in 1967 FAO started investigation on vegetable amaranth. The following year it began field experiments in home garden projects in Nigeria and Benin. Later it commissioned germplasm collections. As a result, the vegetable branch of the amaranth family is beginning to attract recognition, and FAO has published a report on these species (Grubben and Van Sloten 1981).

In any country among the crops under cultivation, some may be native, and some may be of non-native origin from other regions. The Plant Genetic Resources for Food and Agriculture (PGRFA) formulated the basis for the establishment of a multilateral system of access and benefit sharing which is applicable to a list of crops under a Standard Material Transfer Agreement (SMTA) for food security and interdependence irrespective of the origin of the crop. Enforcement of the Convention on Biological Diversity (CBD) from 1993 and provisions under trade-related aspects of Intellectual Property Rights (TRIPS) led to the apprehension that exchange of germplasm would get restricted. To increase the food production at global level on sustainable basis, dependence on crop genetic resources that originated from different geographical locations through introduction and exchange is inevitable. This holds good especially in the case of underutilised crop species which have same centre of origin and centre of domestication because domestication process is still in evolutionary phase.