10 Cultivation of Amaranths

10.1 General

Amaranths are a type of crop that can be grown on any type of soil even in marginal areas in the wild as an escape from cultivation; they need no special agricultural attention and can tolerate environmental stress. Collection and preservation of seeds are the primary aspect of cultivation. Seeds should be dried below 12 % moisture content to store for at least 2 years before regeneration. Common amaranth seeds remain dormant when shed; dormancy is lost after 2–3 months of storage in dry condition. Recommended temperature for germination is 20°–30°, while germination is poor below 20° temperature. Temperature above 25° is optimum for growth, but growth ceases at temperature below 18°. Lower temperature and short-day length favours flowering. Seeds of grain amaranths deteriorate significantly after 1 year of storage. Germination in field depends upon age of seed and depth of sowing. Leafy amaranths are warm-season crop adapted to hot and humid climate, whereas grain amaranths are grown in tropical lowland to an altitude of 3500 mt. Amaranths can be grown on various types of well-drained soil. Grain amaranths are drought-tolerant plant, but leafy amaranths require frequent irrigation to keep soil moist. Most of the amaranths are day neutral but differ in their day-length requirement and respond differently to changes in photo- and thermoperiodism. Seeds are broadcasted on farm but well-pulverised seedbed; germination takes place within 4–5 days after sowing. Amaranths do not require high amount of nitrogen like maize but respond well to fertilisers. There are a number of obstacles in the breeding of amaranth – like nonavailability of improved variety, heavy lodging and seed shattering and lack of information about agrotechniques. Few attributes related with higher seed production were evaluated like mixed cropping, spacing and population trials, transplantation versus direct sowing, etc., with positive result. Vegetable amaranths are harvested by uprooting or repeated clipping. In multicut method, the first cutting is done 25–35 days after sowing; subsequent cutting is done with an interval of 7–10 days. Quality and yield get deteriorated after flowering. For greater nutritional value, amaranth leaves are to be harvested at a young stage (20 days after sowing). On average grain amaranths have longer growth period than weedy species. In grain species, terminal inflorescences are cut when the plants are still green, sundried for 6–7 days in thrashing yard and thrashed by biting to collect the grains.

Amaranths are a crop of marginal areas that require no special agricultural requirement. Being a pseudocereal they are adapted to fragile environmental condition and can tolerate difficult condition and environmental stress, specially the vegetable amaranths. They can grow in the wild, also as an escape from cultivation. Vegetable amaranth species are reported to be tolerant to adverse environmental effects (Dieleman et al. 1996; Ghorbani et al. 1999). Amaranths are being

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cultivated from prehistoric period till now in almost all environmental conditions ranging from the true tropics to semiarid regions and also in few highest farms in the world. Ecotypes having the ability to withstand alkaline sandy soils with pH as high as 8.5, as well as the acidic clays of hillside slash-and-burn fields of the tropics, have been evolved. Although traditionally amaranths are cultivated within 30° latitude of the equator, it can be grown in higher latitudes using strains that flower in spite of the longer-day length (photoperiod) than that of the tropics. Most of the grain amaranths have been concentrated in highland valleys, such as the Sierra Madre, Andes and Himalayas. Compared to the cereals, the yield of grain amaranths has been very low, and the difference continues to widen. Factors responsible for the low grain production in the Himalayas are many. The available varieties of these crops in this region are the mixture of landraces, the crop takes a long time to mature, and their growing season overlaps with that of the cereals. High degree of seed shattering and lodging of plants at maturity makes it less productive. Other factors responsible for the poor yields are: (1) crops are generally grown in lands of marginal productivity without applying adequate amount of fertilisers and pesticides, and (2) there is lack of information on scientific cultural practices for this crop to take maximum advantages of its yield potential.

10.2 Seed Dormancy and Seed Viability of *Amaranthus*

Cultivation of any crop plants and preservation of germplasm require a profound knowledge about seed dormancy and viability. The primary objective of storing seeds is to maintain the genetic integrity of the preserved accessions as long as possible. Deterioration of seeds in storage may cause low vigour, reduced number of viable seeds and genetic drift. The precise guideline is required to protect or reduce the decline in viability of conserved germplasms. This would help gene-bank personnels to frame the viability testing and estimate regeneration intervals on stored germplasm and to increase quality and retain the genetic integrity of the germplasm. The viability of seeds in storage condition is a good indicator of seed quality and vigour in many crops. Seeds may be stored for a short period as required for carry-over seeds or for considerably longer period as in the case of germplasm accessions and high-value seed stocks. One can get full benefit from storage system only when the seeds have high-initial quality. Therefore in germplasm preservation, maximum seed quality and vigour are of paramount importance. Amaranth seeds start losing genetic integrity when germination capacity is below 40 %. Under ambient condition storage period should not exceed 3 months for best performance of amaranth seeds. Seed preservation is the most common method of ex situ maintenance of genetic resources of about 70 % of the Earth's plant species. A variety of problems has been encountered to be associated with ex situ conservation strategies, one of which is the problem of genetic changes in storage due to ageing and/or field rejuvenation (Roberts 1988). Chromosomal aberrations occur during seed ageing in storage.

Seed viability equation developed by Ellis and Roberts (1980) can be used as a valuable guideline for estimating deterioration of seeds in storage especially when initial viability levels are high (Mead and Gray 1999). The following equation reflects seed longevity over a range of storage temperature and moisture content:

$$V = K_i - P / 10^{\mathrm{KL}} - C_1 m - C_2 t$$

This equation relates probit percentage viability (V) at any time (P), to any combination of moisture content (m) and temperature (t). Once the values of the species' constants $\mathrm{K_L}$, C_1 and C_2 are known, longevity of seeds of that species can be calculated for specific storage condition with certain temperature and seed moisture content. The initial viability of individual seed lot is represented by their K_i value which is dependent on the genotype, the prestorage environment and their interactions (Ellis and Roberts 1980). The equation enables to predict percent viability expected after any given period under different combinations of storage temperature and moisture content within medium-term gene-bank storage. It has been shown that usefulness of this equation regarding storage behaviour persists as long as initial viability is high. Longevity difference has been found in seeds of various species during storage at comparable temperature and moisture content. It has been suggested that the differences between the seed chemical compositions affect longevity by influencing the water-binding capacity and chemical activity in seeds, hence the rate of deterioration (Walters 1998).

Seed collectors should dry amaranth seeds during prolonged collection mission to avoid probable high rate of deterioration. The seeds should be dried below 12 % moisture content to store for at least 2 years before regeneration. Normal storage by the farmers for over a year is possible for seeds of amaranths without major viability loss, at temperature ≤20 °C in any combination with ≤12 % moisture content. The species constants obtained can be used to give an estimate of anticipated longevity of seeds for the species during storage within short- to medium-term storage condition.

Seeds in the state of rest do not germinate, in spite of potentially favourable conditions for germination, known as seed dormancy. Three types of seed dormancy are distinguished: (1) resulting from the external determinants of germination (2) determined by physical and biochemical factors occurring inside the seeds, but provoked by external factors, and (3) resulting from internal physiological state of the germ, independent on the surrounding conditions. Seed dormancy of most species can be primary (inborn) or secondary. Primary dormancy is associated with natural maturing of seeds. In many species such a state is induced by the germination temperature that is improper for them, or not meeting the light conditions creating favourable conditions for germination. Inborn dormancy may be of physical and mechanical nature, associated mainly with the hardness of the seed cover. Secondary dormancy occurs in nongerminating seeds, in which the stage of absolute dormancy has already been passed and the seeds are able to germinate.

Wild species and few vegetable accessions of *Amaranthus* have seed dormancy. The cultivated and especially white-seeded grain types lack seed dormancy and will germinate in 3–4 days at 21 °C or above (Myers 1996). Kigel (1994) reviewed the seed dormancy; Deno (1993) wrote about cool-moist treatment to overcome seed dormancy of many plant species having the kind of dormancy like amaranths. A month or more of moist stratification at approximately 2–5 °C will be enough to overcome seed dormancy for many accessions. Years of dry storage and many chemical and scarification options can abolish dormancy (Kigel 1994), but the cool-moist treatment is recommended because it is safe and reliable. Germination can be achieved on blotter or sand (Baskin and Baskin 1998). After stratification efficient seed germination will takes place with 20 °C (night) and 30–35 °C (day) temperature. Attempts to explain the reasons for low germinating capacity of amaranth seeds were made based on studies on different species comprising grain amaranths and different vegetable amaranths. To combat the unevenness in germination, a number of methods for presowing seed processing have been employed. The lack of readiness of seeds to germinate leads to unevenness of emergences, and a number of methods for presowing seed processing were developed in order to stimulate them for better germination and emergence of seedlings in the shortest period of time possible under a wide range of environmental conditions (Jisha et al. 2013).

From the biological point of view, the seeds of amaranth are fruits and small nuts, in which the proper seed is surrounded with the hard pericarp. Such structure of fruits favours durability of seeds. In their natural environment, plants sometimes have to wait for a long time for suitable subsoil moisture to germinate. Even when the climatic conditions and habitat are similar to that required by amaranth, still plant emergences sometimes become difficult, although seed germination proceeds very fast – only in a few days. Amaranth seedlings are very small and the soil moisture in the surface layer determines their survival. Almost all the methods known from agricultural practice were used in experiments to increase the germinating capacity of seeds of amaranths, viz. treatments affecting an increase in permeability of the seed cover and soaking seeds in water (Musa et al. 2014), in the alcohol solution of $CaCl_2$ (Colmenarez de Ruiz and Bressani 1990) and in the sulphuric acid solution (Soomarin et al. 2010), by cooling (Zharare 2012) and by the action of alternating magnetic field to seeds (Dziwulska-Hunek and Kornarzyński 2009). Most of the above-mentioned methods as presowing treatment of amaranth seeds achieved the expected results. The most spectacular effects were given by the use of various treatments to seeds stored for several years, overwintered in soil and exposed to the salt stress, for those which have naturally weakened germination capacity (Moscova 2012). In laboratory conditions, the germination energy and capacity of amaranth seeds of the cultivar Rawa much more depend on the germination temperature than on the kind of preparation in which seeds are soaked. Germination capacity at 25 °C can be regarded as satisfactory, irrespective of the method for seed material treatment. Effective stimulation of amaranth seed germination at 15 °C is induced by soaking them for 8 h in 0.03 % water solution of Pol-Gibrescol, as well as in a mixture of 0.03 % Pol-Gibrescol and 2 % Betokson 025 Super SL.

Although ISTA (1985) recommended germination at either 20 °C or 20/30 °C for *Amaranthus* sp., Grubben (1976) suggested that 20 °C was approaching a germination temperature boundary, and germination was poor at temperatures lower than 20 °C, particularly in the presence of white light. Germination of *Amaranthus* seed is photo inhibited. In the dark, germination is independent of temperature, but in the light, germination at constant temperature increases with increasing temperature. In *A. cruentus* germination was usually greater at 20/30 °C than at 20 °C. Seed dormancy in *Amaranthus* spp. is a type of relative secondary dormancy, a photo dormancy (Kendrick and Frankland 1969) induced by prolonged exposure of seeds to white and far-red light. It can be broken by exposure to red light, but the more conventional seed testing methods of prechilling and KNO_3 (ISTA 1985) proved adequate for *A. cruentus*.

Aufhammer et al. (1998) conducted an experiment in incubator to find out the effects of several factors on the germination of two amaranth cultivars. The factors considered in the experiment were year of harvest, crop type of the mother plant, seed position on the mother plant, stage of maturity, temperature, light and seed dressing. In the experiment percentage germination and germination speed were also recorded. Most effects appeared in interaction with cultivars. Germination percentage was above 80 % when the temperature was higher than 16 °C. The germination speed showed close relationship with temperature, and speed decreased with decrease in temperature. Light or even a short illumination inhibited germination and slowed it down at temperatures below 25 °C, while presoaking of seeds accelerated germination. Seed stored for more than 1 year showed decreased germination percentage. An early harvest of homogenous and dense amaranth crops is recommended for amaranth seed production. More research regarding presowing treatment of amaranth seeds is required.

Seeds of grain amaranths are considered among the most sensitive seeds susceptible to significant deterioration after storage of 1 year. Seeds are required to be preserved in safe storage since they are harvested in the preceding season and generally used for sowing in the next season often after a time gap of 6 months or more. Seeds gradually lose their vigour and germinability and ultimately become less viable during the ageing process in storage (Maity et al. 2000). Losses in seed quality also occur during field weathering, harvesting and storage. Several intrinsic and extrinsic factors influence the viability of seeds during storage. Among intrinsic and extrinsic factors, seed moisture content, relative humidity, temperature of storage, pests and diseases and oxygen availability are more important. Storage of seeds wrapped in polyethylene and aluminium foil was found effective in preventing moisture uptake and maintaining seed viability, while storage of seeds in paper and cloth-made containers were found least effective (Wilson and McDonald

1992). Seed deterioration is an inexorable and an irreversible event. One of the symptoms of seed deterioration is membrane deterioration (Copeland and McDonald 1995). Seed deterioration alters the semi-permeability properties of the membrane and membrane integrity (Berjack and Villiers 1972). Electrical conductivity of seed leachate increased gradually over period of storage. With increase in storage period, the germination capacity, vigour and protein content decrease, while the electrical conductivity increases irrespective of treatments and storage containers. This may be probably due to increased moisture content of the seeds.

Weed species which form persistent seed banks are of concern for future weed management (Egley and Chandler 1983). In the absence of viable seed production, a decline in amaranth seed bank might be due to seed mortality through physiological age and herbivory or microbial decay (Egley and Williams 1990; Buhler and Hartzler 2001). Persistent seed bank of a few *Amaranthus* species has been investigated earlier (Steckel et al. 2007). Palmer amaranth (*A. palmeri* S. Watson) is known as prolific seed producer, a single female plant may produce up to 600,000 seeds (Keeley et al. 1987). Investigation on seed persistence of palmer amaranth is lacking. It shows seasonal seed dormancy and an extended emergence period, resulting in a season-long interference and severe yield reductions in several crop plants. *Amaranthus* species have low persistence in soil seed banks (Steckel et al. 2007). The redroot pigweed (*A. graecizans*) exhibits a sharp decline in the viable seed bank within 2 years of burial, with no viable seeds remaining in the upper 0–15 cm depth of soil after the third year (Egley and Williams 1990). Several studies on natural and artificial seed banks reported that the rapid decline of *Amaranthus* seed bank within a year of burial might be due to physiological death of seeds, fatal germination, seed herbivory or microbial seed deterioration in the soil (Cardina et al. 1996; Kremer 1993).

Generally common amaranth seed remain dormant when shed. The time of emergence and the growing conditions experienced by the parent plant have a definite effect on the level of dormancy. Fresh seed collected from distinct populations of common amaranth may show difference in their germination behaviour, but such differences are reduced during dry storage. The tough seed coat does not rupture easily and, while water uptake is not prevented, seed germination is prohibited by it. In laboratory studies, the minimum temperature for germination was 10 °C (Wiese and Binning 1987; Ghorbani et al. 1999), while maximum germination occurred at 35–40 °C. The ripe seeds soon after harvest showed some germination when incubated at temperature of 40 °C. Nitrogen is suggested to promote germination, but the effect of light on germination is yet to be documented conclusively.

Seed of common amaranth showed 50 % less germination at 15 °C than at 25 °C (Chakraborty 1977). In laboratory experiment, when dry-stored seeds are sown on moist paper or soil in the light at a constant temperature of 18–20 °C, 70 % germination was achieved (Cross 1930–1933). Germination was nearly 90 % when the seeds were incubated at alternating temperatures of 0/30 °C or 8/20/30 °C. In other experiments, little difference was observed between germinations under diffuse light or light filtered through a leaf canopy to reduce the red light ratio compared with the far-red light (Taylorson and Borthwick 1969).

The optimum depth of seedling emergence is a crucial factor that varies from 0.6 to 1.3 cm depending on temperature (Mohler 1993). In the laboratory condition best seed germination was observed between 5 and 30 mm deep in soil (Ghorbani et al. 1999). Germination was found better in clay soil than in sandy soil. Below the depth of 40 mm and on the soil surface, seed germination in both the cases was much less. However, when seeds are sown in trays of field soil subjected to different cultural treatments, the highest germination was achieved from seeds left on the soil surface (Chepil 1946). Seedling emergence decreased with increasing burial depth, and cultivation increases seedling emergence by bringing seeds into the upper soil layers, but fatal germination did not occur and a greater number of seeds simply remained nongerminated. Seedling emergence was less in untilled soil than in tilled soil even when seeds were maintained at the same depth (Mohler and Galford 1997). Few of the seeds sown in a 7.5 cm layer of soil in open cylinders in the field and stirred periodically seedlings emerged soon after sowing in autumn (Roberts 1986). In the following year, the seedlings emerged from May to August. Germination appeared to require a high temperature. A gradually reducing number of seedlings emerged in subsequent years, but some viable seeds still remained after 5 years.

Common amaranth seeds spread in moist soil, persist and can remain viable but dormant for over 30 years (Crocker 1916). However, other investigations reported just 1 % seed viability after 5.5 years in soil (Egley and Chandler 1983). In an experiment to study the relationship between burial depth and germination percentage, it was found that seed buried at 20, 56 and 107 cm showed 9, 11 and 18 % germination, respectively, after 1 year; 11, 36 and 48 % after 10 years; and none after 16 years (Toole 1946; Goss 1924). After a dry storage at low temperature for 30 months, seeds retained full viability, but after burial in field soil for the same period, viability was less than 13 % (Egley and Chandler 1978). Common amaranth seeds sown in the field and followed by cultivation of wheat in winter and barley in spring over a 5-year period showed an annual decline in germination of around 40 % (Barralis et al. 1988). Emerging seedlings represented only 8 % of the seed bank. The viability of seeds recovered from 10 cm deep in soil declined from 98 % to 90 % in a 12-month time period, while the viability of seeds recovered from the soil surface declined from 93 % to 62 % over the same time period (Omami et al. 1999). Soil solarisation is the main factor for speedy decline in germinability and viability, and common amaranth seeds are very sensitive to soil solarisation. When the seeds were sown in pots of moist soil and treated with worm air for 6 h, germination was reduced by 30 % at 47 °C, 60 % at 52 °C and 80 % at 54 °C (Laude 1957).

If germination is slow, soil surface needs to be lightly stirred; amaranth seeds require some sunlight after a period of darkness for germination. This trait helps them to adapt in disturbed or overturned soil. The weedy amaranths are often called ‘pigweed’ because they would germinate in hordes in an area after pigs had passed and turned the soil, exposing their seeds to the light so they could germinate. Amaranth seeds can be stored safely for up to 3 years at a temperature below 8 °C and at 10 % relative humidity in a tightly closed moisture-resistant container (Hartmann et al. 2011). Ideal containers are airtight such as a sealed glass jars, metal cans or foil envelopes as they maintain seed water content best. Seed in containers should be stored in a cool, shady and dry place to extend seed shelf life (Hartmann et al. 2011).

Seeds from different crops can be stored for different periods of time after harvesting. Seed viability at the end of the storage period is determined by the initial viability at harvest and the rate of deterioration during storage. Deterioration differs with seed species as well as the storage conditions including temperature and relative humidity (Muyonga et al. 2008). Seeds can be classified as either recalcitrant or orthodox based on their genetic potential to tolerate storage. Recalcitrant seed are those that do not tolerate seed moisture below 25 % after seed maturation, while orthodox seeds can tolerate drying from 10 % down to 4 % moisture content after seed development, and these differ in the length of time they can tolerate storage (Barker and Duarte 1998). According to Hartmann et al. (2011), orthodox seeds can be further divided into medium-lived and long-lived categories. Medium-lived seeds can remain viable for periods of 2–5 years provided that seeds are stored at relative low humidity and temperature. Seeds of most vegetables, flowers and grain crops belong to this group. It is important for seed storage to be designed in such a way that it should not create conditions that will negatively affect seed and/or seedling vigour. During seed deterioration the seed first loses vigour or the ability to germinate when environmental conditions are not favourable. Seed deterioration during storage is stimulated by high respiration and other metabolic rates which injure the embryo (Hartmann et al. 2011).

Moisture content in seeds is the most important factor in seed longevity and, therefore, is important to consider during storage (Baskin and Baskin 1998). For example, seed having orthodox characteristics can be best stored at a non-fluctuating low moisture level as they can tolerate low moisture content. Seed moisture content of about 4–6 % is suitable for prolonged storage of seed from many vegetable species. However, many storage problems may arise when seed moisture content is elevated during storage (Baskin and Baskin 1998): (1) at about 8–10 % moisture content, several insects are active and can reproduce; (2) above 12 % seed moisture content, fungi are active and can multiply to produce spores; and (3) at the higher seed moisture content levels, respiration, germination and disease activity are stimulated leading to reduced seed viability (Barker and Duarte 1998). On the other hand, too low water content in some seeds can have a reducing effect on seed viability and germination rate (Abdullah et al. 2011). For this reason, hydration is necessary for seeds stored at a humidity atmosphere below 2 %, to avoid seed injury, as this can influence the moisture content of the stored seed. Conversely, in the case of some species, dry climate increases seed longevity, while high relative humidity (RH) results in shorter seed life (Barker and Duarte 1998). Amaranth seeds can be preserved safely for up to 3 years at a temperature below 8 °C and at 10 % RH in a tightly closed moisture-resistant container (Hartmann et al. 2011). Ideal containers are airtight such as sealed glass jars, metal cans or foil envelopes as they best maintain seed water content. Seed in containers should be stored in a cool, shady and dry place to extend seed shelf life (Hartmann et al. 2011).

As mentioned earlier, germination of all seed is affected by the viability of the seeds, seed dormancy and adequate environmental factors. If one of the three aspects is not sufficiently considered, germination can be severely delayed or inhibited, leading to secondary dormancy (Tucker 1986). Seed viability represents the ability of nondormant seeds to germinate, and viability testing is essential in determining seed quality. Seed dormancy is the condition whereby seeds do not germinate even if they are subjected to favourable conditions that are normally beneficial for germination (Mayer and Mayber 1995). Essentially, dormancy is an adaptation mechanism that prevents seeds from germinating after it has been dispersed by mother plants and that only permits germination when environmental conditions are favourable (Baskin and Baskin 1998). Dormancy in amaranth seed is reported to be high at the time seeds are detached from mother plants, but decline as seed water content decreases (Baskin and Baskin 1998). Generally, dormancy is at its peak within 2–3 months after seed harvesting. In amaranth seed dormancy after ripening is associated with naturally occurring compounds present in the seed at maturity, and oven drying or naturally air-drying can help to reduce amaranth seed dormancy (Hartmann et al. 2011).

10.3 Agroclimatic Condition for Cultivation of Amaranths

10.3.1 Climate

Leafy amaranths or vegetable amaranths are a warm-season crop adapted to hot-humid climatic conditions. It is grown throughout the year in tropics and in autumn, spring and summer seasons in temperate regions. Amaranth can tolerate full sun, drought conditions and high temperatures. Grain amaranths are grown in wide geographic areas ranging from tropical lowlands to 3500 m in the Himalayas. Altitudes above 1000 m in the tropics are considered best for grain amaranth cultivation though they are tolerant to drought condition and low soil fertility. It performs much better under conditions that are considered ideal for maize (corn). It can be intercropped with maize, beans, peppers or squash. In the Andes region, it is often intercropped with quinoa (*Chenopodium quinoa*) and other pseudocereals by the local farmers. For grain amaranth cultivation, altitude is not a severe limiting factor. Amaranths can grow satisfactorily from sea level to above 3000 m; the only exception is *A. caudatus* which is known to grow at an altitude of 3000 m in the Andean region and

Himalayas. Some of the grain species of *Amaranthus* are sensitive to day length. Some accessions of *A. hypochondriacus* will not set flower in summer; however they do mature in the greenhouse during short-day situation in winter. Some strains of *A. cruentus* remain vegetative for a long time in its equatorial house. However, it starts to set seed very early when introduced into the long-day conditions. *A. caudatus* thrives well in high hills and is familiar as a short-day species. It generally flowers and sets seed only when day length is less than 8 h. Amaranth population are easily miniaturised, and their flowering cycle can be accelerated by controlling the environment (Brenner and Widrlechner 1998). *Amaranthus* production guide (Sooby et al. 1998) is a useful reference for field management of amaranth.

10.3.2 Soil

Amaranths can be grown on various types of soil including marginal soil. Amaranth comes up well in well-drained loamy soil rich in organic matter. The ideal pH is 5.5–7.5, but there are types which can come up in soils with pH as high as 10.0. It can be grown on marginal areas with little soil management. It is evident from the field observations that amaranth can grow well on soil containing variable amount of soil nutrients. Initial studies at Rodale Research Centre (RRC) in Pennsylvania showed that young grain amaranth plants grow taller with fertiliser but with little improvement in grain yield. On the other hand, vegetable amaranth needs high soil fertility, particularly potassium and nitrogen. Grain amaranths prefer well-drained cultivation field with neutral or basic soils (pH values above 6). However, this aspect has not been studied carefully considering the wealth of amaranth germplasm variability that exists. It is most likely that types that can tolerate acidic condition can be identified for cultivation in tropical lowlands where acid soils are common. The genus is not known for high salt tolerance, but they have the ability to withstand mild salinity and alkalinity as apparent in some species of amaranth. Moreover, *A. tricolor* has demonstrated (Foy and Campbell 1984) tolerance for soil with high aluminium levels. Cultivation practices differ according to the methods of harvest, duration, growth pattern of variety, etc. Land is prepared to a fine tilth by thorough ploughing and harrowing. Well-decomposed and powdered organic matter at 20–25 t/ha is incorporated with the soil at the time of final ploughing. The poor amaranth stands in field can be attributed to various reasons like soil crusting, low soil moisture, poor seed-to-soil contact, uneven planting depth and wind erosion in some areas. Proper addressing of such primary reasons will result in a good stand of amaranths (Sooby et al. 1998).

10.3.3 Temperature

Temperature is an important parameter for seed germination, growth, emergence of inflorescence, etc. Grain amaranths grow best when the daily high temperature is at least 21 °C. Various accessions of grain amaranths have shown optimal germination at temperature range of 16–35 °C. The speed of emergence is encouraged at the higher end of the temperature range. The grain species *A. hypochondriacus* and *A. cruentus* are not frost hardy and can withstand high temperature. Growth of the plant stops at about 8 °C and below 4 °C the plants get injured. However, *A. caudatus* being native to Andes and high Himalayas is more resistant to chilling than the other two grain species. The optimum germination temperature for amaranth has been reported to be between 20 and 30 °C (ISTA 2010). The best temperature for germination and early seedling growth ranges between 25–30 °C for *A. cruentus* and 25–35 °C for *A. hybridus*, respectively. Amaranth seeds require soil-temperature range of 18–25 °C for germination and an air temperature above 25 °C for optimum growth. The growth ceases at temperatures below 18 °C. Lower temperatures associated with shorter-day length will induce flowering with a subsequent reduction in leaf yield. As the crop grows during summer with the onset of the rains, frost damage should not be a problem. However, harvesting of the crop may be effected by frost. As amaranth is an annual crop, it does not mature completely in areas having a short growing season. Frost is necessary to terminate the crop's growth.

10.3.4 Rainfall

Grain amaranths are drought-tolerant crops, but vegetable amaranths require frequent irrigation to keep soil moist. Frequency of irrigation depends on soil. Seeds of amaranths require well-moistened soil to germinate and establish roots, but once seedlings are established, grain amaranths perform well with limited water; in fact they grow best under dry, warm conditions. Vegetable amaranths, on the other hand, require moisture throughout the growing season. Grain amaranths have been grown in dry agricultural areas that receive as little as 200 mm of annual precipitation, while vegetable amaranths are routinely grown in areas receiving 3000 mm of annual rainfall.

10.3.5 Day Length

Most of the vegetable amaranths are day neutral in habit but differ in their day-length requirements and respond differently to changes in photo- and thermoperiodism. Grain types, *A. caudatus*, *A. cruentus* and *A. edulis*, are short-day species, while *A. hypochondriacus* is day neutral. Many of the amaranths are sensitive to day length. For example, accessions of *Amaranthus hypochondriacus* from the south of Mexico will not flower in the summer in Pennsylvania. However they will flower in the greenhouse during the short-day conditions in winter. The reverse happens with *Amaranthus cruentus* from Nigeria. It remains vegetative for a long period in its equatorial home. However, it sets seed very early when placed under the long-day conditions in Pennsylvania and can be used to breed for early-maturing traits. *Amaranthus caudatus*, on the other hand, is known to be a short-day species. It usually flowers and sets seed only when day length is less than 8 h. However, some accessions of *Amaranthus caudatus*, such as the ornamental 'love-lies-bleeding', will set seed when the day length is longer (El-Sharkawy et al. 1968).

10.4 Cultivation Practices

10.4.1 Sowing of Seeds

The field must be well levelled and two to three ploughings are sufficient for sowing of amaranth seed. To initiate amaranth cultivation, a well-worked, firm and moist seedbed is required. It is necessary to firm the soil over the seed to make good contact between the seed and the soil. A loose (but firmly packed), friable soil is preferred in seedbed. Amaranth seeds are very small in size, and the weight of 1000 seeds is varying from 0.7 to 0.9 grammes. It has been found that the largest amaranth seeds are only 1/16 in., and some varieties have seed as small as 1/23 in. in diameter. As per the recommendation, 1.2–3.5 kg seed/ha is to be planted to an average depth of 1.3 cm (Webb et al. 1987). According to the authors, planting depth needs to be monitored carefully as the deeper range might delay and decrease seedling emergence. On the other hand, shallower planting depth is also believed to decrease seed-soil contact, exposes the seeds to pests and increases the risk of being washed away by water (Stallknecht and Schulz-Schaeffer 1993). Further, amaranth seed requires a firm moist seedbed with a soil temperature above 15 °C to ensure proper seedling emergence and good plant establishment. Consequently, drying of the top soil during the germination process can reduce seed germination and subsequently seedling establishment. Therefore, amaranth seed germination depends mostly on moisture and temperature, with an optimal temperature range between 16 and 35 °C (Muthomi and Musyimi 2009). As is the case with all crops, amaranth also experiences harsh abiotic and biotic stress conditions when planted in the field. Water-deficit stress and other environmental factors, like stress of unfavourable temperature, have been shown to reduce seed germination and seedling development.

Seeds may be planted in a nursery bed for subsequent transplanting in cultivation field or sown directly in the field. Transplanting ensures a very efficient use of seeds and the growing area to be weed free just before the seedlings are transplanted. If direct seeding is practised, sowing in rows is recommended. Seed sown at a depth of 1.3 cm (0.5 in) or less in soil with temperature of 15 °C will establish a good plant stand. Seed will germinate within 3–4 days with soil temperature of 20 °C (68 °F). Before sowing, application of 50 quintals of farmyard manure per hectare has been found to be good to enhance yield. Plant density, i.e. spacing between plants, has a great impact on yield and harvesting specially in the case of vegetable amaranths. One common practice is to grow plants at a spacing of 5–10 cm (2–4 in) and harvest by uprooting when the plants are 5–7 weeks old. Another common method is to sow seed less densely at a spacing of 15–30 cm (6–12 in) and harvest by cutting the stem tips and tender leaves periodically starting from 4 to 6 weeks when the plants are about 15 cm tall. The crop is generally sown in the first or second week of June just after the first monsoon shower. However, amaranth can be propagated from seed in the early summer (Muyonga et al. 2008). Traditionally, the seeds are broadcast, but better crop stand is achieved if seeding is done in rows. The depth of sowing should be less than 2 cm in view of very small grain size, with 50 cm spacing between rows and between plants. On a large scale, grain amaranth is directly seeded into the field at a seed rate of 1–1/2 kg to 2 kg/ha for good grain yield. Amaranth is harvested by pulling out and by frequent clippings (multicut).

Field studies have shown that amaranth yields remain constant across a range of 0.3–4.5 kg/ha (0.25–4 lbs/a). There are approximately 1000–3000 amaranth seeds per gramme (1,000,000–2,500,000/kg) (Sooby et al. 1998). Plant spacing recommended for grain amaranth varies widely. One recommendation is to maintain a spacing of 23 cm (9 in) between plants and 75 cm (30 in) between rows. This results into a planting density of approximately 38,000 plants per hectare (15,400 per acre). If harvesting is to be done manually, the less dense spacings are advisable. The wider rows gave the highest yields. Amaranth seeds, being small in size, are mixed with fine sand and sown uniformly by broadcasting. The seeds are covered either by raking up soil and by covering with a thin layer of sand or soil. This is followed by a light irrigation. Soil is kept moist by frequent irrigation. Grown-up seedlings are selectively pulled out at 30 days after sowing and marketed in small bundles along with roots.

10.4.2 Seedling Growth and Interculture

Vegetable amaranth species are reported to be tolerant to adverse environmental effects (Dieleman et al. 1996; Ghorbani et al. 1999). They have been growing wild in arid and semi-arid regions, which mean that they could be more tolerant to low-water and high-temperature conditions (Hurro and Cees 1991; Modi 2007). Many African communities believe that because amaranth is found in the wild, there is no need to cultivate these plants (van Rensburg et al. 2007). Seedling growth is highly dependent on both moisture and temperature, with *A. hybridus* being more tolerant to high-temperature and low-moisture conditions than *A. cruentus*.

Seed germinates within 4–5 days after sowing and needs maximum care till it attains a height of about 25–30 cm. In fact this is the most critical stage for obtaining maximum yield potential of the crop. During this phase, it must be properly spaced, made free from weeds and must receive adequate moisture. One more weeding is necessary after 30 days of sowing. At the seedling stage, one spray of some fungicides to check the attack of damping off is necessary. Once the stand is established, then its maintenance is relatively easy. The land, after thorough ploughing and levelling, is made into shallow trenches/basins of 50–60 cm width and convenient length. Well-decomposed farmyard manure is applied in trenches and thoroughly incorporated in soil by digging. Seedlings (20–25 days old) already raised in nursery are transplanted in trenches at 20–25 × 10–15 cm spacing. Seed requirement for transplanted crop is only 500 g/ha. Amaranth is a short-duration and shallow-rooted crop. A light hoeing is needed to prevent soil crust formation after irrigation and to keep soil loose. Field also should be kept weed free, especially during initial stages.

Direct seeding though requires much less labour, but it invites a greater risk of poor stand due to diseases and predators of young seedlings and poor competition with existing weeds in the crucial initial couple of weeks. If direct seeding is practised, sowing should be done in rows to facilitate cultivation. Because of the shallow depth of plantation, special care must be taken to prevent the soil from drying out or soil solarisation until plants are established. Transplanting or thinning is vital, and it may be done within about 2 weeks after sowing when plants are 5–10 cm tall (2–4 in). However, any delay in transplanting has an adverse effect on yield.

10.4.3 Manuring

Amaranth does not require a high amount of nitrogen fertiliser like maize, but responds well to fertilisation. A leguminous cover crop tilled under prior to seeding is enough to provide sufficient nitrogen for amaranth. Animal manure or chemical fertiliser at a rate of 135 kg per hectare (135 lbs/a) is also sufficient. The requirement of chemical fertilisers is less when the cultivation is preceded by a leguminous crop such as beans or soybeans. Singh and Whitehead (1993) studied the growth responses to three different pH levels 6.4, 5.3 and 4.7. Results indicated that pH 6.4 is the best for growth and growth decreases with the increase in soil acidity. Stallknecht and Schulz-Schaeffer (1993) recommended soils with pH above 6.0 suitable for growth. Fertiliser like NPK showed no significant effect on yield, but increased the seed protein content in the two lowest-yielding ecotypes, while effects on seed fat content were inconsistent. Amaranth is not well adapted to soils markedly deficient in available phosphorus; amaranth seedlings have repeatedly failed to establish. In the same trials, cereals such as corn, sorghum, wheat, triticale and even small-seeded millets established satisfactorily. In these situations, satisfactory stands of amaranth were established applying readily soluble phosphorus fertiliser directly below the seeds. Under hilly condition in India, NPK at the rate of 20:30:20 kg/ha is sufficient to meet the full requirements of the crop.

Amaranths are heavy feeder and high-yielding crop; 20–25 tonnes/ha of FYM (farm yard manure) and 50:25:20 kg NPK/ha are recommended as basal dose. Under pulling-out method, 20 kg nitrogen should be top-dressed twice during subsequent pulling-out of seedlings. For clipping varieties, a still higher dose of 75:25:25 is advisable. Nitrogen should be applied after every clipping or cutting. Foliar spray of 1 % urea or diluted cow urine at every harvest is good for promoting further growth and for high yield.

10.4.4 Obstacles in Productivity in Grain Amaranths

The major productivity constraints of the crop identified are:

1. Nonavailability of improved variety for cultivation till recently
2. The lack of information on agrotechniques for high seed production
3. Heavy lodging and seed shattering
4. Little or no use of inorganic fertilisers
5. Little or non-utilisation of seed for various domestic and agroindustrial products by mass consumers
6. The lack of public (consumer) awareness about the organoleptic taste and quality of both grains and greens for production of various domestic, agroindustrial delicious products.

To identify and standardise the attributes for high seed production in grain amaranths, agronomic trials concerning five attributes were conducted at NBPGR, Regional Station, Shimla, with newly released variety Annapurna during 1985 and 1986. The attributes were (1) spacing and population trial, (2) sowing date trial, (3) mixed cropping with French bean, (4) transplanting vs. direct sowing and (5) leaf picking vs. nonpicking.

Plant-to-plant spacing of 20 cm has been observed to be the optimum spacing for obtaining highest grain yield of 34 q/ha. To standardise the optimum time for sowing of seed in the hills and for obtaining highest seed yield, a randomised block-design trial with four sowing dates with an interval of 15 days was conducted. The highest grain yield of 16.1 q/ha was obtained when sowing was done on first date of sowing (June 2) followed by the second date of sowing (June 17), and the last was recorded on the last date of sowing (July 17). The reasons for low yield levels in this trials were due to heavy lodging and seed shattering. The delayed sowing beyond June highly reduced the plant height, inflorescence length and glomerule number per plant. It also induced tenderness to the plants. Early sowing caused a big stem borer problem as compared to late-sown plants which were completely free from this disease. Highest yield of 21 q/ha was obtained under mixed cropping when French bean (viny type) was grown between two rows of amaranth at 25 cm apart. Mixed cropping with French bean not only provided the nitrogenous fertiliser to the amaranth plants but also held them by twining and preventing lodging which is a serious problem in the hills. Highest grain yield of 24.3 q/ha was obtained in the case of direct sowing, and there was a reduction of 7 q/ha under transplanting. Early maturity by a week time and reduction in plant height, inflorescence length and leaf size were observed in the case of transplanted plants. The farmers in the Himalayas generally pluck the leaves of grain amaranth at vegetative stage when the plant is tender for vegetable use and leave the rest for grain yield. There was a reduction of 2.9 q/ha grain yield in the case of leaf-plucked plant than the normal ones, but there was 20 q/ha additional foliage yield for vegetable use. In the case of leaf picking, plant height is reduced and number of branches at the top and number of leaves increased. The size of inflorescence increased, but the number of glomerules decreased. The leaf-plucked plants became stunted and stout and did not lodge which is the most desirable character. Late maturity by a week was observed in the case of leaf picking than the normal ones. Thus leaf picking at the vegetative stage is recommended for taking maximum advantage of the crop in the hills.

10.4.5 Harvesting

Vegetable amaranths are harvested by uprooting tender plant or by repeated clipping or cutting. Harvesting by repeated clippings, with an interval of 2 or 3 weeks is common through the end of the season (usually the short-day length period of the year). Frequent clipping is helpful to increase both the yield and quality of leaves. At the end of vegetative growth, flowering begins, and subsequently harvest becomes inferior both in quality and quantity. Vegetable amaranth is harvested early in the morning by pulling out or by clipping. In the first method, grown-up plants are pulled out at 30, 45 and 55 days after sowing, along with roots, washed and sent to market in small bundles. In multicut method, first clipping or cutting is done 25–35 days after sowing. Subsequent cuttings are made at 7–10-day intervals. Premature flowering or bolting is a serious problem in cultivation of amaranth. Bolting is usually associated with planting of short-day varieties during November to December, deficiency of nitrogen, extreme high temperature and poor soil erosion. Practices like raising of crop at ideal time depending on locality, frequent application of nitrogen fertilisers and manures and keeping soil loose by light hoeing may be some of the preventive measures. Prolonged flowering is a serious problem in cultivation of amaranth. Quality and yield are deteriorated after flowering. Flowering of *Amaranthus* species usually starts 4–8 weeks after showing (Grubben and Denton 2004). However the growth and development pattern are highly variable between species to species and cultivars to cultivars, depending on photoperiodism, altitude and cultivation practices (Wu et al. 2000).

Wild leafy vegetables are harvested from crop fields by rural people at different stages of plant growth. There may be a specific or preferred plant developmental stage when flavour and palatability are most favourable for human consumption. In the case of leafy vegetable, it is not likely that flavour and palatability are influenced by environmental condition. Data on changes in nutritional quality of leaf in response to plant age and environmental condition is scanty. Modi (2007) made an attempt to study the effect of growth temperature on amaranth leaf yield and nutritional value at different stages of plant growth involving five species, viz. *A. hybridus*, *A. hybridus* var. *cruentus*, *A. hypochondriacus*, *A. tricolor* and *A. thunbergii* in South Africa. Vegetable amaranths are the most widely occurring leafy vegetable in South Africa and Africa in general (Modi 2007). Nutritional quality of *Amaranthus* leaves is significantly influenced by growth temperature and developmental stages at which harvesting has been done. It was found that cool environmental condition favours the increase in total protein and amino acid content in leaves. However the amount of mineral element like calcium and iron increased in leaves in response to increase in growth temperature. It was recommended that for greater nutritional value, amaranth leaves should be grown under warm condition and leaves should be harvested at young stage (20 days after sowing). Warm condition was found to be associated with high yield and improved germination capacity.

On an average the three grain types have longer growth period than weedy species. Amaranth grains mature much earlier and the plant dries up quite late. If the heads are allowed to remain till the plant dry up, heavy shattering of grains is noticed which leads to heavy grain loss. The terminal inflorescences or heads are cut when the plant is still somewhat green and start weathering and kept for sundrying for 6–7 days in the threshing yard. Threshing is done by beating. The produce is threshed and winnowed like other cereals. Unusually the harvesting is done early in the morning when the plants are somewhat wet due to night dew to avoid grain shattering in cut heads. When the grains mature, the inflorescence heads are cut dried under shade.

10.4.6 Pests and Diseases

In general, soil fungus, damping-off, leaf blight, white rust and mycoplasma and virus-related diseases have been identified as the serious diseases of grain amaranth in India. Amaranths are generally affected with some fungal diseases, specially damping-off disease of seedlings caused by *Pythium*, *Rhizoctonia* and *Aphanomyces* spp. and cankers caused by either *Phoma* or *Rhizoctonia*. Various root and stem rots can occur later in the season when the soils are wet, which contribute to lodging problem. *Alternaria* leaf spot is the most serious foliar disease in amaranth. Amaranth is generally considered tolerant to nematodes and often has been recommended as a rotation crop to reduce nematode populations for subsequent crops. The presence of root-knot nematodes in amaranth roots has been reported. It is important to know whether or not amaranth can be used to control nematodes and/or whether it can be cultivated where nematodes are a problem. A lot of insects are known to feed on amaranth leaves that may account for severe and sustaining yield loss. A few insects may cause substantial damage. Amaranth may succumb to caterpillars, webworms, blister beetles, lygus bugs and stem borers. The lygus bug, coffee bug or tarnished plant bug (*Lygus* spp.) is a sucking insect that attacks flowers and seeds and causes severe damage both by preventing flowers from producing seeds and also by reducing seed weight. Solutions of pyrethrum or synthetic pyrethrins are helpful to control lygus. Other insects that can injure the developing amaranth include fall armyworm (*Spodoptera frugiperda*), corn earworm (*Heliothis zea*) and the cowpea aphid (*Aphis craccivora*). The amaranth weevil (*Conotrachelus seniculus*) can damage roots, resulting in lodging or other root diseases. The potato flea beetle (*Epitrix cucumeris*) can damage seedlings, and the beet leafhopper (*Circulifer tenellus*) can transmit curly top virus, but this has been seen only in areas nearing large areas of sugar beet production.

Hymenia recurvalis and other caterpillars are serious pests of amaranth like *Cletus* sp., *Asparia* sp. and *Lygus lineolarus* bug (cabbage looper), *Trichoplusiani* (European cornborer), *Ostrinia nubilalis* (corn earworm), *Heliothis zea* (cowpea aphid), *Aphis craccivora* (striped blister beetle), *Epicauta vittata*, *a* weevil, spinach flea beetle, *Disonycha xanthomelas*, etc. Lygus bugs, more specifically the tarnished plant bug, are recently considered to be the most important insect pest of grain amaranth. These insect feedings result in localised wilting and tissue necrosis followed by abscission of fruits, morphologically deformed fruit and seed and altered vegetative growth. Serious damage of amaranths has been caused by spider mites and stem weevil. Stem borer (*Lixus truncatucus*) is another problem in Africa and Asia in early-sown plants which causes high degree of lodging in plants. A considerable damage is done by the leaf rotters during rainy seasons. Seedbeds should be protected against ants and termites. The other pests damaging the crops are *Hypolixus nubilaus* (Egypt), *Rhachi creagra* (Costa Rica), *Chrotogonus* (Pakistan), *Hyphurus* (India), *Geocoris* (California), *Thysanoptera* (Hawaii), *Diabnotica barberi* and *Spodoptera exigua*. The fungal population was higher in the pre-flowering stage of the host. Pandy and Gupta (1985), while studying the leaf surface mycoflora of *Amaranthus paniculatus* grown in Almora hills, observed 24 fungal species on leaves of this crop. McLean and Roy (1988) reported *Colletotrichum domatium* damaging *Amaranthus hybridus* plant in Mississippi, USA. The other species damaging the crop are C. *truncatum* and *C. capsici*. *Choanephora cucurbitarum*, causing wet rot, is the most troublesome disease of amaranth in Africa. *Albugo bliti*, causing white rust, is a serious disease in Southeast Asia. Reddy et al. (1980) reported *Xanthomonas amaranthicoia* as a causal organism of bacterial leaf spot disease of amaranths in India. Sharma et al. (1981) and Naseema et al. (1983) reported that *Aspergillus flavus*, *A. niger* and *Rhizopus stolonifer* were externally as well as internally seed borne in most of the seeds of *Amaranthus gangeticus* and *A. caudatus* and are the major storage fungi of amaranth crop in India. Sammons and Barnett (1987) reported about tobacco ringspot virus damaging *Amaranthus hybridus* in California, USA. A severe mosaic disease caused by cucumber mosaic virus in *Amaranthus caudatus* was reported in Himachal Pradesh by Sharma and Chawla (1987) damaging the crop. The other viruses affecting the crop are ivy vein clearing virus, alfalfa mosaic virus and beet western yellow virus.