The biology and non-chemical control of Common Amaranth (*Amaranthus retroflexus* L.)

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Common amaranth

(redroot pigweed, rough pigweed)
***Amaranthus retroflexus* L.**

Occurrence

Common amaranth is an introduced annual found as a casual weed on cultivated land and in waste places (Clapham *et al.,* 1987; Stace 1997). It is considered to be native to North America but is now distributed worldwide (Frankton & Mulligan, 1970). It has come into the UK from many sources including in birdseed. It is frequent on rubbish tips and in vegetable crops. Due to the sowing of contaminated seed it has appeared in several crops including lucerne and alsike clover (Salisbury, 1961). Common amaranth predominates on loose, friable soils rich in nitrogen (Hanf, 1970). It is very responsive to the level of P and K in soil but growth is reduced below pH 5.2 (Weaver & McWilliams, 1980).

In seedbank studies in arable fields in France, common amaranth was well represented in the seedbank but was less frequent in the emerged vegetation (Barralis & Chadoeuf, 1987). In a series of 4 national weed surveys made in Hungary between 1950 and 1997, common amaranth moved from 17th to 3rd place in the rankings (Tóth *et al.,* 1999; 1997).

Morphological variants have been distinguished in Canada (Weaver & McWilliams, 1980). Common amaranth will hybridise with *A. powellii* and *A. hybridus* but the hybrids are usually sterile.

Mature plants have been used as animal feed but if eaten in large quantities younger plants of common amaranth can be poisonous to livestock (Costea *et al.,* 2004). The green leaves and stems contain oxalates and high levels of nitrate. Nitrate levels increase in the period up to flowering. Sheep, swine and cattle, particularly young calves, are reported to have been affected. The problem can be worse in periods of drought (Mitich, 1997). Nevertheless, it is palatable to sheep, has a nutritional composition equivalent to alfalfa and it is used as a green vegetable in some parts of the world (Weaver & McWilliams, 1980). The seeds of common amaranth are ground into flour.

Common amaranth may be used for bioremediation of contaminated soil, having been shown to accumulate high levels of caesium 137 and strontium 90. The growing plant and its residues are reported to have an allelopathic effect on the germination and growth of other plants. It can be an alternate host for broomrape, *Orobanche ramosa*, for the aphid *Myzus persicae* and for cucumber mosaic virus (Weaver & McWilliams, 1980). Common amaranth can become infected with *Rhizoctonia solani* and *Fusarum oxysporum*.

Biology

Common amaranth flowers from July to September (Clapham *et al.*, 1987). The date of flowering depends on latitude, and the time to flowering is hastened in short days. The flowers are unisexual and predominantly wind pollinated but some insect pollination can occur (Mitich, 1997). Common amaranth is self-compatible and the flowers are self-pollinated (Weaver & McWilliams, 1980). Seed matures from August to October (Frankton & Mulligan, 1970). The minimum time for seed development following fertilization is 30 days (Costea *et al.*, 2004). The average seed number per plant is given as 117,400 (Stevens, 1932) and 9,254 (Pawlowski *et al.*, 1970) but a large plant may have 229,175 seeds (Stevens, 1957). Closely spaced plants produced an average of 34,600 seeds per plant (Weaver & McWilliams, 1980). The 1,000 seed weight ranges from 0.340 to 0.439 g. The seeds on plants that matured earlier in the season were found to be significantly heavier than seeds on plants that matured later (Cavers & Steele, 1984). Seeds can be retained in the inflorescence overwinter (Mohler & Callaway, 1995).

Common amaranth seed is dormant when harvested but the extent of the dormancy is influenced by the growing conditions experienced by the mother plant (Costea *et al.*, 2004). It has been observed that fresh seeds from different populations of common amaranth may differ in their germination characteristics but these differences are lost during dry storage (Frost & Cavers, 1975). Dormancy is lost after 2-3 months of dry storage possibly due to changes in the structure of the seed coat (Crocker, 1916). Seeds lose dormancy faster when stored at 24^{o}C than at 5^{o}C (Chancellor, 1982). Water uptake is not prevented by the tough seedcoat, but germination is hindered because the seed contents cannot rupture the coat easily (Crocker, 1916). Anything that weakens the seedcoat will aid germination. Nitrogen is thought to stimulate germination (Costea *et al.*, 2004).

Cyclical changes in the dormancy of seeds in the soil are regulated primarily by seasonal variations in temperature. Under favourable conditions a temperature of 40^{o}C will produce some germination of ripe seeds soon after harvest. The optimum germination temperature declines as after-ripening progresses. In laboratory studies the minimum germination temperature was 10^{o}C (Wiese & Binning, 1987; Ghorbani *et al.*, 1999). Maximum germination occurred at 35 to 40^{o}C. Seed of common amaranth gave 50% less germination at 15^{o}C than at 25^{o}C (Chakrabarti, 1977). In laboratory tests with dry stored seeds sown on moist paper or soil in the light, there was around 70% germination at a constant 18-20^{o}C (Cross, 1930-33). At alternating temperatures of 20/30^{o}C or 8/20/30^{o}C there was around 90% germination. In other tests, there was little difference between germination under diffuse light or light filtered through a leaf canopy to reduce the red light ratio compared with the far-red (Taylorson & Borthwick, 1969). There is some disagreement on the effect of light on germination. Some authors suggest it inhibits others that it promotes germination.

Seeds do not germinate until the late-spring or summer (Hanf, 1970). In the USA, germination occurs from May to August (Chepil, 1946a). However, emergence can occur from mid-April with most seedlings appearing in April/May (Ogg & Dawson, 1984). The time of seedling emergence and the prevailing climate at seed ripening can influence the germinability of common amaranth seeds under natural conditions (Chadoeuf-Hannel & Barralis, 1982). Seeds from the main inflorescence of plants that developed relatively late under natural conditions were less dormant at harvest

than seeds from plants that emerged in April under controlled conditions (Chadoeuf-Hannel & Barralis, 1983). Plants grown at 20°C in long days (16hr) produced seed more dormant than that from plants grown at 20°C in short days (8hr) or 25°C in long days. The differences in dormancy were reduced but not completely lost after dry storage at 20°C for 6 months or soil burial during the winter. Soil burial had a more favourable effect on breaking seed dormancy than dry storage.

The optimum depth of seedling emergence ranges from 0.6 to 1.3 cm depending on temperature (Mohler, 1993). In the laboratory, seed germinated best between 5 and 30 mm deep in soil (Ghorbani *et al.*, 1999). Germination was better in a clay than a sandy soil. Below 40 mm and on the soil surface seed germination was much less. However, when seed in trays of field soil was subjected to different cultural treatments, the highest germination was from seeds left on the soil surface (Chepil, 1946b). Seedling emergence decreased with increasing burial depth but fatal germination did not occur and a greater number of seeds simply remained ungerminated. Cultivation increases seedling emergence by bringing seeds into the upper soil layers. Seedling emergence was less in untilled than in tilled soil even when seeds were maintained at the same depth (Mohler & Galford, 1997). Few of the seeds sown in a 7.5 cm layer of soil in open cylinders in the field and stirred periodically 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 is a C_4 plant in terms of carbon fixation during photosynthesis (Baskin & Baskin, 1978). It grows best at higher temperatures, light intensity and nitrogen level. The seedlings are frost sensitive. It forms a shallow taproot.

Persistence and Spread

In moist soil, common amaranth seeds can remain viable but dormant for over 30 years (Crocker, 1916). Crocker (1938) refers to Beal's burial experiment where some seeds were able to germinate after 40 years. However, in other studies seed viability was just 1% after 5.5 years in soil (Egley & Chandler, 1983). In Duvel's burial experiment, seed buried at 20, 56 and 107 cm gave 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 30 months dry storage at low temperatures seeds retained full viability but after burial in field soil for the same period viability was less than 13% (Egley & Chandler, 1978). Common amaranth seed sown in the field and followed over a 5-year period in winter wheat and spring barley showed an annual decline of around 40% (Barralis *et al.*, 1988). Emerged seedlings represented 8% of the seedbank. The viability of seeds recovered from 10 cm deep in soil declined from 98% to 90% over a 12-month period while the viability of seeds recovered from the soil surface declined from 93% to 62% (Omami *et al.*, 1999).

After 2 weeks of windrow composting at temperatures of 50 to 65°C, 3.5% of common amaranth seeds were still viable but after 4 weeks all had been killed (Tompkins *et al.*, 1998). Seeds are said to survive digestion by cows, sheep and horses. Apparently-viable seeds have been found in samples of cow manure (Pleasant & Schlather, 1994). The seeds survived 1 month of anaerobic fermentation at 400 mm depth in manure but not at 1800 mm (Simpson & Jefferson, 1996). Seeds gave

4% germination after 2 weeks ensilage but none germinated after 4 weeks (Zimdahl, 1993). Most seeds were killed by ensiling for 8 weeks or a combination of ensilage and 24 hrs of rumen digestion (Blackshaw & Rode, 1991). Rumen digestion alone left 27% of seeds still able to germinate. In other studies, common amaranth seeds gave 36% germination after 47 hours digestion by cattle and 11.5% germination if then stored for 3 months in the manure (Zimdahl, 1993).

Pig slurry may be dried to aid transport and the effect of drying temperature and the duration of heating on the viability of common amaranth seeds was tested in the laboratory (Bloemhard *et al*., 1992). Seeds were imbibed in pig manure and heated in an oven at different temperatures. Seed survived up to 15 minutes at 50^{o}C but did not survive 3 minutes at 75 or 100^{o}C. A heat treatment of 90^{o}C will kill most weed seeds but over 100^{o}C is needed to guarantee this. In other studies, seed was killed when heated at 85^{o}C for 15 minutes in dry heat (Hopkins, 1936). In dry soil, heating seeds to 60 or 70^{o}C for up to 7 days had little effect on seed viability (Egley, 1990). In moist soil, viability was gradually lost over 7 days to around 5%. At 50^{o}C the viability was reduced to 44% but at 40^{o}C there was little effect. Heating seeds in a loamy soil for 30 minutes at 60-70^{o}C significantly reduced seedling emergence (Rubin & Benjamin, 1984).

Common amaranth seed is dispersed by wind, water, on farm machinery, by the spreading of manure, sewage sludge and compost, and by birds and animals (Costea *et al.*, 2004). Seeds have been found as a contaminant of crop seeds including clover (Mitich, 1997). In a survey of weed seed contamination in 1960-61, common amaranth seed was found in 14% of lettuce seed samples tested (Gooch, 1963). Seed has been recovered from irrigation water in the USA (Kelley & Bruns, 1975; Wilson 1980). Seeds stored in freshwater for 33 months gave 9% germination (Zimdahl, 1993).

Management

Control is by repeated surface cultivations and the prevention of seeding. Small seedlings are easily controlled by hoeing, rotary cultivations and flaming. Seedlings cut below the cotyledonary node are unable to regenerate from the decapitated hypocotyl (Langston *et al.*, 1984). Seedlings are most susceptible to cultivation in the first 4 weeks (Weaver & McWilliams, 1980). Adult plants can recover from mechanical injury.

Seedling emergence of common amaranth may be greater from untilled than tilled soil (Buhler *et al.*, 1996). While increased emergence results in greater seed production there is greater seed predation in the absence of tillage. (Mohler & Callaway, 1995). A mulch of rye (*Secale cereale*) had little effect on seed production. The effect of maize residues on seedling emergence depends on tillage and rainfall.

Based on studies in maize and soybeans in the Corn Belt of the USA, it has been suggested that seedbank densities of 100 seeds per m^2 would result in weed populations too low to affect crop yield (Forcella *et al.*, 1993). A seedbank density of 100 to 1,000 seeds per m^2 is likely to produce up to 400 weeds per m^2, a population that can be controlled adequately by mechanical means. Seedbank numbers above 1,000 per m^2 are unlikely to be controlled by mechanical means alone. Sowing date

and the prevailing temperature and soil moisture level will affect the timing and extent of weed emergence.

Field applications of ammonium nitrate did not increase seedling emergence (Fawcett & Slife, 1978).

Common amaranth seed is susceptible to soil solarization. The germination of seeds in pots of moist soil heated with warm air for 6 hours was reduced by 30% at 47^{o}C, 60% at 52^{o}C and 80% at 54^{o}C (Laude, 1957). A novel way to use sunlight for direct weed control involves using a curved freshnel lens to concentrate sunlight into a narrow band at the soil surface. The wheeled device is pulled slowly along between crop rows to wither and burn off the inter-row weeds or kill exposed weed seeds. Under the full mid-day sun the mean soil surface temperatures was 309^{o}C with a 20 second exposure (Johnson *et al.,* 1990). The germination of common amaranth seed left on or near the soil surface was reduced to almost zero by this treatment but a few seeds remained viable. In greenhouse tests of seedling susceptibility to ultraviolet-B radiation, common amaranth was a relatively tolerant species (Furness & Upadhyaya, 2002). However, shoot height was reduced and root biomass was also affected.

In field studies, mulching the soil with residues of hairy vetch (*Vicia villosa*) and of rye (*Secale cereale*) reduced the emergence of common amaranth (Mohler & Teasdale, 1993). Weed emergence declined with increasing rates of residue, however, the natural amount of residue that remains after a cover crop is killed off was insufficient for good weed control.

In greenhouse tests, corn gluten meal (CGM) applied as a surface and incorporated treatment to soil sown with common amaranth seed has been shown to reduce plant development (Bingaman & Christians, 1995). Application rates of 324, 649 and 973g per m^2 reduced common amaranth survival by 87, 96 and 99% respectively. Root and shoot length was reduced by up to 100%. Corn gluten hydrolysate (CGH), a water soluble material derived from CGM, was found to be more active than CGM when applied to the surface of pots of soil sown with common amaranth seed (Liu & Christians, 1997). Wheat gluten meal (WGM) at 1 or 3 g.dm^{-2} dusted over seeds put to germinate on moist paper reduced germination by 52 and 100% respectively (Gough & Carlstrom, 1999).

In Canada, pre-dispersal seed predation, principally by larvae of the micro-moth *Coleophora lineapuvella*, was variable but reduced seed production of common amaranth by 4 to 40% (Swanton *et al.,* 1999). Predation was greater at lower plant densities. The mean rate of pre-dispersal seed predation in common amaranth growing in soyabeans was 26% (Nurse *et al.,* 2003). Predation was greater in the absence of the crop. Common amaranth seeds are eaten by many species of birds, rodents and insects (Costea *et al.,* 2004). In North America, the fungus *Phomopsis amaranthicola* is specific to *Amaranthus* species and has shown promise as a biocontrol agent. Other fungi have been evaluated in Europe as control agents.

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