GRAIN AMARANTH - SEED DEVELOPMENT, YIELD AND QUALITY

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ABSTRACT

Seed development, yield components and seed quality were monitored in a spring sown crop of *Amaranthus cruentus L.* Seed was precision sown on 15 November 1986, and peak flowering was recorded on 24 March 1987. Physiological maturity was reached around 38 days after peak flowering (DAPF) when seed moisture content was 45 %. Maximum seed viability (98 %) was reached 30 DAPF, and maximum germination at 38 DAPF. However, the actual germination at this time was only 25 %, the remainder of the seed being dormant. Dormancy was maintained until 65 DAPF, but could be broken in the laboratory by pretreatment with chilling plus KNO_3.

At a population of 46 plants/m^2, panicles per plant ranged from 11 to 36, with a mean of 19. The terminal panicle at 99 mm was over twice as long as any lower order panicles, and contained four times more seeds (506 or 11 % of the total). Individual lower order panicles contributed less than 3 % of the total seed numbers. Seed germination and thousand seed weight did not differ significantly with panicle position. However, seed from the top two panicles contained greater levels of field fungi (*Alternaria alternata* and a *Phoma* sp.) than seed from lower order panicles. Storage fungi (*Aspergillus* and *Penicillium* spp.) did not differ with panicle position.

At 10 DAPF, potential seed yield was 2,082 kg/ha. Seed abortion, particularly from shaded lower order panicles reduced yield to 1,150 kg/ha at 24 DAPF and seed shedding and particularly bird damage further reduced yield to 552 kg/ha at 51 DAPF. In caged areas a harvested seed yield of 1,097 kg/ha was obtained. Further work is required to determine the optimum plant population for seed production.

Additional key words: *physiological maturity, germination, dormancy, seed yield components, seed loss.*

INTRODUCTION

Grain amaranth (*Amaranthus cruentus L.*), the once and future crop (Tucker, 1986), is a native of Mexico and the Andean countries where it was cultivated by the thousands of tonnes until the early sixteenth century. Its production was banned by the Spanish Conquistadors because of its role in Aztec religious ceremonies, and the crops faded almost into obscurity. Only in the past decade has there been a resurgence of interest in the crop, and small scale commercial production is underway in India, Nepal and the United States of America.

Amaranth is a C_4 plant which grows well under low fertility and high temperatures (Wyn-Williams & Logan 1985), and is one of the few non-grasses to produce significant amounts of grain. The leaves are edible, young plants can be used as pot herbs, and the seeds which have a mild nutty flavour, can be used directly in breakfast cereals and granolas, ground into whole-grain meal or white flour for baking (Tucker, 1986), cooked for gruel, or popped. The grain contains 16 to 18 % protein and high levels of the amino acid lysine, although it is low in leucine (Tucker, 1986).

Wyn-Williams & Logan (1985) noted that New Zealand cropping farmers need a wider range of crops to spread financial and climatic risks and provide break crops in rotations. They suggested that grain amaranth may have a place as a crop in the warmer areas of New Zealand, particularly as a grain which could increase the range of bread products available to the consumer. McLeod (1985) considered that the crop had a potential yield of 1 to 2 t/ha under South Canterbury conditions, after he recorded yields ranging from 0.3 to 1.6 t/ha. However, Wyn-Williams & Logan (1985) reported that yield was the most likely single factor to limit the development of amaranth as a commercial crop.

As yet there is little information about the crop in New Zealand. The objectives of this experiment were to monitor seed development, investigate seed yield and its components, and assess the quality of the seed produced.

MATERIALS AND METHODS

Amaranthus cruentus seed was sown at 0.4 kg/ha by precision garden seeder (Earthway Products, Bristol) at a depth of 1.0 cm into a finely worked Tokomaru river silt loam at Massey University on November 15, 1986. The site had been in garden peas the previous summer, fallowed during winter, had a pH of 5.7 and MAF Soil Quick Test values (Cornforth & Sinclair 1982) of 17 for phosphorous and 8 for potassium. An area of 24 m^2 was sown at 75 cm row spacings. No fertilizer or chemicals were applied either at sowing or subsequently. Weeds were controlled by a single interrow cultivation before the canopy closed and a later hand removal of *A. retroflexus*. Four 3 x 5 x 2 m bird proof cages, each of which enclosed 5 m of three adjacent rows were placed at random in the field before canopy closure.

From 10 days after peak flowering (DAPF) (2 April 1987) until 56 DAPF, five plants were collected at random twice weekly. In the laboratory seeds were separated from individual panicles by hand rubbing; they were then sieve screened, passed through an air blower (Leggatt, 1950) and finally hand winnowed to remove any remaining non-seed material. Seed moisture was determined using the air oven method (130 °C for 1 h, ISTA, 1985) using duplicate samples of 200 seeds. Seed viability was determined by tetrazolium staining (ISTA, 1985) and germination tests by the top of paper method (ISTA, 1985) at both 20 °C constant and 20/30 °C alternating temperatures, using 4 replicates of 100 seeds. Dormancy breaking treatments used were either prechilling at 5 °C for 4 days, adding 0.2 % KNO_3 solution to the germination pad, or a combination of both prechilling and KNO_3 (ISTA, 1985). Seedling evaluations were made after 7 and 14 days, seedlings being classified as normal, abnormal, fresh ungerminated or dead seeds according to ISTA rules (ISTA, 1985). The presence of field and storage fungi was determined using the agar plate method (ISTA, 1985); potato dextrose agar fro field fungi and high salt potato dextrose agar for storage fungi. At each sampling, 100 seeds were surface sterilized for 5 minutes in 2 % sodium hypochlorite solution, rinsed in tap water for 10 minutes, blotted dry and placed on agar (10 seeds/plate) under sterile conditions. Plates were incubated for 7 days at 25 °C and fungal colonies identified by spore characteristics. Thousand seed dry weight was determined using 5 replicates of 200 seeds. At 24 and 52 DAPF seeds from individual panicles were not bulked; at the first date germination and thousand seed weight for each panicle position were determined, while at the later date, germination and the incidence of field and storage fungi were assessed.

Yield components were recorded at 24 DAPF on 25 plants removed at random from the field. Panicle number and length were measured and the number of seeds per panicle was calculated after obtaining the weight of the panicle and a thousand seed weight. Potential seed yield was assessed at 10 DAPF (after assuming a final TSW of 0.7 g), and actual seed yields recorded at 24, 38 and 52 DAPF by removing all plants from 5 m x 1 m of row and threshing in a stationary thresher. Seed was then air dried to 14 % seed moisture content.

RESULTS

Seed development: Seed development occurred in a typical three stage pattern (Figure 1). The initial growth stage lasted for around 17 days after peak flowering (DAPF) and was characterised by high seed moisture content (> 70 % SMC) and low seed viability. The food accumulation stage, during which there was an increase in seed dry weight and seed viability, occurred between 17 and 38 DAPF. Physiological maturity (the attainment of maximum seed dry weight) occurred around 38 DAPF when SMC was 45 %, although maximum viability (98 %) was reached eight days earlier at 30 DAPF. The ripening stage then took 20 days for SMC to fall from 45 to 14 %.

Germination/dormancy: At the time of maximum seed viability, germination was only 10 % (Figure 1) and did not exceed 25 % until 65 DAPF (Figure 1; Table 1), because of seed dormancy. At germination temperatures of 20 °C and 20/30 °C, prechilling alone failed to break dormancy, and KNO_3 only broke dormancy of seed harvested at 40 DAPF and then only at the 20/30 °C germination temperature. However, the combination of prechilling plus KNO_3 broke dormancy at both germination temperatures (Table 1).

Yield components: At a population of 46 plants/m^2, panicle number per plant ranged from 11 to 36 with a mean of 19 $\pm$ 2.3. The terminal panicle at 99 mm was over twice as long as any lower order panicles (Table 2)

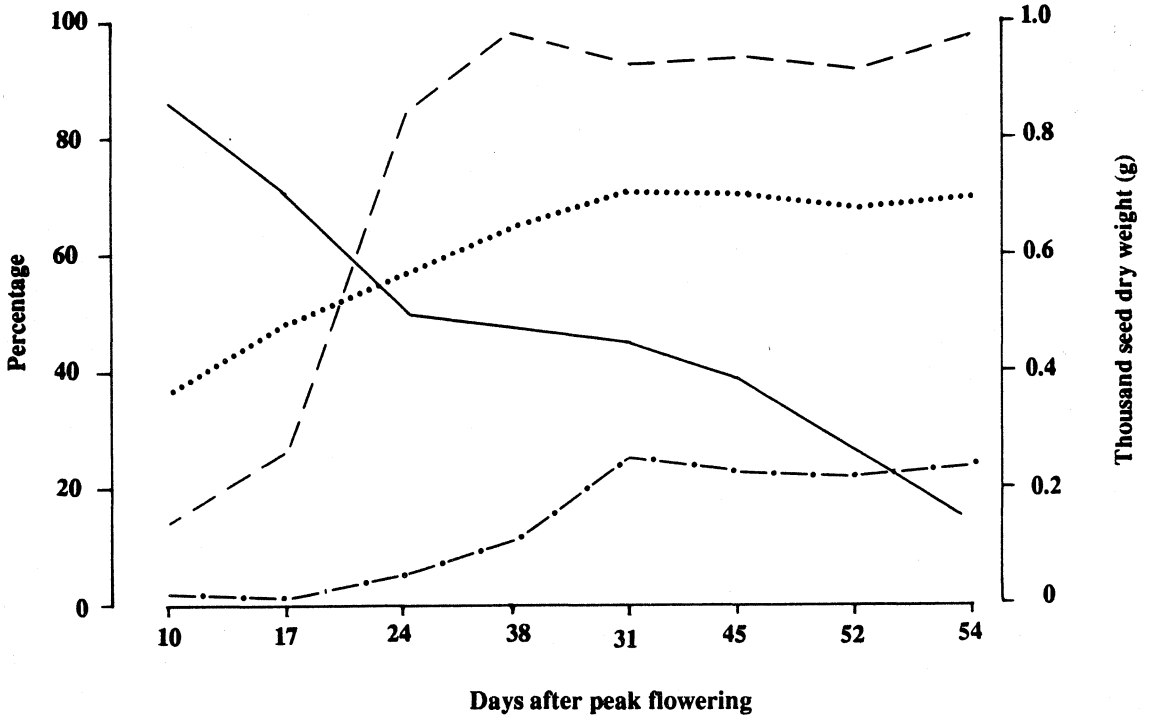

Figure 1. **Changes in seed moisture content, seed dry weight, seed viability and germination during development of *A. cruentus* (_____ seed moisture content, ... seed dry weight, _ _ _ _ _ seed viability, __ . __ . __ seed germination).**

Table 1: **Effect of temperature and dormancy breaking treatments on the germination of *A cruentus* seed harvested at four development stages.**

DAPF	Percentage germination			
	20 °C		20/30 °C	
	No pretreatment	Chilling/KNO_3	No pretreatment	Chilling/KNO_3
30	10 ± 4	32 ± 3	14 ± 5	64 ± 4
45	23 ± 3	79 ± 3	19 ± 7	86 ± 3
59	24 ± 3	84 ± 4	23 ± 6	92 ± 3
65	87 ± 4	90 ± 5	95 ± 4	96 ± 2

Table 2: **Effect of panicle position on panicle length and seed number per panicle, 24DAPF**

Panicle position	Panicle length (mm)	Seed number /panicle	% total seed number
Terminal	99 ± 7	506 ± 32	11.5
1*	40 ± 3	75 ± 18	1.6
5	43 ± 4	96 ± 17	2.1 (10.2)+
10	45 ± 5	115 ± 21	2.6 (11.8)
15	50 ± 10	118 ± 23	2.6 (13.3)
20	50 ± 17	130 ± 28	2.9 (13.4)
25	44 ± 20	175 ± 27	3.9 (21.6)
30	46 ± 31	130 ± 24	2.9 (18.4)

* 1 = panicle immediately below the terminal panicle, 30 = bottom panicle. + mean for panicles 1-5, 6-10, etc.

and at 24 DAPF contained over four times more seeds (a mean of 506 or 11 % of the total). Individual lower order panicles contributed less than 3 % of the total seed numbers, although branching of basal panicles increased the seed numbers slightly (Table 2).

Seed quality: Germination and thousand seed weight did not differ significantly with panicle position (Table 3). However, seed from the top two panicle positions contained greater levels of field fungi (*Alternaria alternata* (Fr.) Kiessl. and a *Phoma* sp) then seed from lower order panicles. (Table 3). The incidence of storage fungi (*Aspergillus* and *Penicillium* spp) was low and did not differ with panicle position. *Penicillium spp.* were present on seed from 10 DAPF (Table 4), but field fungi, particularly *A. alternata*, were not detected until 24 DAPF and did not become widespread until 66 DAPF.

Seed yield: At 10 DAPF, potential seed yield was calculated to be 2,082 kg/ha (assuming a 0.7g TSW), and the mean seed number per panicle recorded was 340 (Table 5). By 24 DAPF the potential seed yield was almost halved as seed aborted, particularly from lower order panicles (e.g. 130 seeds/panicle at 24 DAPF for panicle 20 c.f. 250 seeds/panicle at 10 DAPF). The final actual harvested seed yield (552 kg/ha was only around one-quarter of the potential seed yield, because bird grazing resulted in further seed loss. In plots protected from birds, the harvested seed yield was 1,097 kg/ha (Table 5).

DISCUSSION

Under the environmental conditions at the site, *A. cruentus* seed took 38 days to reach physiological maturity. The growth stage lasted for 17 days, the food reserve accumulation stage lasted for 21 days and the ripening stage lasted for a further 20 days. At the same site in the 1984 season, days to physiological maturity were 33, 36, 37 and 41 for sunflower, barley, oil seed rape and wheat respectively, (Anon., 1984). The duration of the growth stage and food reserve accumulation stage was also very similar to that reported for herbage legumes (Hare & Lucas, 1984). The length of the ripening stage is particularly environment dependant, and conditions during May produced a three week ripening period. Although harvest time (late May) was similar to that reported in South Canterbury by McLeod (1985), further work should investigate sowing earlier in the spring so that the crop can be maturing when temperatures are more favourable for seed ripening. In Latin and North America, crops usually mature in 4-5 months (NRC, 1984).

Although ISTA (1985) recommended germination at either 20°C at 20/30°C for *Amaranthus* sp, Grubben (1976) suggested that 20°C was approaching a germination temperature boundary, in that germination was poor at temperatures lower than 20°C, particularly in the presence of white light. *Amaranthus* germination is photoinhibited; in the dark, independent of temperature, but in the light, germination at constant temperature increases with increasing temperature. With *A. cruentus* germination was usually greater at 20/30°C than at 20°C. the optimum germination temperature for *A. albus*. This requires further investigation. Seed dormancy in *Amaranthus* spp is a form of relative secondary dormancy, a photodormancy (Kendrick & Frankland 1969) induced by prolonged exposure 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*.

McLeod (1985) did not report any pest or disease problems in the *Amaranthus* crops grown in South Canterbury, and similarly none were detected in the field in 1987. There are several important pests and diseases of *Amaranthus* spp. (Tucker 1986), and *Alternaria* spp. are commonly found in seed (Weaver & McWilliams 1980). However, whether the presence of

Table 3: Effect of panicle position on seed quality.

Panicle position	24 DAPF		52DAPF			
	Thousand seed weight (g)	Germination (%)	% seeds carrying			
			Field fungi		Storage fungi	
			Alternaria	*Phoma*	*Aspergillus*	*Penicillium*
Terminal*	0.63	44 (97)+	20 ± 3	5 ± 1	2 ± 1	2 ± 1
1	0.59	28 (97)	25 ± 5	28 ± 4	1 ± 1	3 ± 1
5	0.60	24 (98)	-	-	-	-
10	0.58	31 (97)	3 ± 1	0	0	2 ± 1
15	0.54	25 (97)	-	-	-	-
20	0.52	30 (98)	1 ± 1	0	3 ± 1	1 ± 1
25	0.59	26 (97)	-	-	-	-
30	0.56	30 (98)	0	0	2 ± 1	2 ± 1
LSD (P < 0.05)	0.13	21.4				

* 1 = panicle immediately below the terminal panicle; 30 = bottom panicle. + % viable seed.

Table 4: Incidence of field and storage fungi in seed bulk at five harvest dates.

DAPF	Percentage of seeds carrying:			
	Alternaria alternata	*Phoma* sp	*Penicillium* sp.	*Aspergillus* spp.
10	0	0	5 ± 1	0
24	5 ± 1	0	8 ± 2	0
38	4 ± 1	1 ± 1	22 ± 4	2 ± 1
52	5 ± 1	7 ± 2	4 ± 1	1 ± 1
66	24 ± 2	9 ± 1	4 ± 1	0

A. alternata in the seed is of any consequence requires investigation; the fact that the fungus was only detected at the very end of the seed ripening period suggests it may not be a problem. In seed dried to 10 % SMC after harvest, storage fungi remained at very low levels, but increased rapidly in seed kept at 18 % SMC, with *Aspergillus flavus, A. glaucus* and *A. candidus* predominating, These increases in storage fungi content were associated with a subsequent loss of germination (Bartolini, 1988).

A hand harvested seed yield of around 1 t/ha was obtained when bird losses were prevented. This was similar to that recorded by McLeod (1985) and within the range of yields reported from USA and India (Joshi 1985; Tucker 1986). However, selection and breeding has now resulted in named cultivars which are capable of yielding up to 4 t/ha (Joshi, 1985). The sowing rate used was similar to that of McLeod (1985) and approximately 80 % of seeds sown established as plants, McLeod (1985) suggested that this sowing rate would produce a high plant density, but the population of 46 plants/m^2 allowed each plant to produce seed from up to 30 different panicles. In the USA, populations of 100-125 plants/m^2 have been used (NRC 1984), and Edwards (1981) recommended using up to 250 plants/m^2 to produce a crop where virtually only the terminal particle could set and sustain seed.

Problems with seed production of this species include uneven ripening, lodging and seed shatter, and mechanical harvesting often recovers only 50 % of the actual yield (Tucker 1986). For this reason the crop is often cut and stooked prior to threshing, or in many countries, hand harvested as seed ripens in individual panicles. Plant breeding efforts have focused on these problems (Tucker 1986). For this reason the crop is often cut and and stooked prior to threshing, or in many countries, hand harvested as seed ripens in individual panicles.

Table 5: Seed number and seed yield of *A. cruentus* at four harvest dates.

DAPF	Mean seed number		Seed yield kg/ha	% Seed loss
	per panicle	per plant		
10	340 ± 24	6,460 ±456	2,082 ±125	
24	188 ± 23	3,572 ±436	1,150 ± 98	44.7
38	142 ± 12	2,698 ±221	868 ± 95	58.3
52	90 ± 5	1,710 ± 94	552 ± 52	73.4
52 (caged)*	179 ± 16	3,401 ±311	1,097 ± 81	47.3

* protected from bird damage

Plant breeding efforts have focused on these problems (Tucker 1986); for example, one goal is the release of a cultivar with a single large panicle which matures uniformly and can be direct combined.

CONCLUSIONS

1. The potential seed yield in New Zealand may be greater than 1-2 t/ha but this will require further work to determine optimum sowing time and plant population.
2. The potential for grain amaranth to produce well in low rainfall and/or low fertility sites should be investigated.
3. Grain amaranth could become an alternative New Zealand arable crop if:
   (i) cultivars bred for uniformity of ripening and resistance to lodging and seed shatter become available
   (ii) a market demand becomes established, and returns are economically realistic.

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