Optimal sowing dates of three species of grain-bearing amaranth in the semi-arid Argentine Pampa

R. M. de Troiani*, T. M. Sánchez, N. B. Reinaudi and L. A. de Ferramola
Facultad de Agronomía, Universidad Nacional de La Pampa. Ruta 35, km 335. Santa Rosa (La Pampa). Argentina

Abstract

Determining the optimal sowing date is important when evaluating the production potential of any new crop. Field trials were performed with *Amaranthus cruentus* L., *A. hypochondriacus* L. and *A. mantegazzianus* Pass. from 1999 to 2002 in the semi-arid Argentine Pampa in order to establish the best sowing dates for grain production. Crops were sown at 15 day intervals during November, December and January. The following variables were then measured: plant height, days to anthesis, production of biomass, grain production, harvest index, final number of plants and plant losses. Rainfall strongly influenced these variables, depending on sowing date. In all years, *A. mantegazzianus* produced the lowest grain yields. The latest sowing date is not recommended since the light and temperature conditions during the final part of the phenological cycle have a negative effect on grain yield. The best results were obtained when sowing was performed from the second half of November through to the end of December.

Key words: grain, production, yield, *Amaranthus sp.*

Introduction

The genus *Amaranthus*, family *Amaranthaceae*, has 65 member species, some 50 of which are native to the Americas. Some species are cultivated for their grain, other as vegetables or forage, and still others for their pigments. Some species are weeds (Granjero Colín et al., 1994; Kigel, 1994; Becerra, 2000). Their genetic variability has afforded them exceptional adaptability to a wide range of environmental conditions, although being C₄ plants they do require high temperatures (optimum 35°C; Kulakow and Hauptli, 1994) and strong light (Putnam, 1990; Covas, 1994a; Berti et al., 1996). Once a crop is established it is tolerant to drought. Growth occurs during the frost-free period, although a frost at harvest time is opportune since this helps dry the plants out and facilitates mechanical harvesting (Putnam et al., 2003). Soil temperature and humidity are probably crucial factors in the germination and emergence of plantlets (AGPG, 1990). Amaranth grain has received special attention in North America because of its high protein and lysine contents. Its starch and lipids have also been studied.
for potential use in the food and cosmetics industries (Henderson et al., 2000). Guillen Portal et al. (2003) report that 1800 ha of amaranth were sown in the USA in 1991; the west of Nebraska (on the Great Plains; mean annual rainfall 400 mm) is where most is now produced (Williams and Brenner, 1995).

In Argentina, amaranth cultivation could be an alternative for some 5 million ha north of Patagonia in the semi-arid region of the country (Covas, 1994a). However, this crop is not traditionally grown in the region (Frecenese, 1987) and its cultivation needs to undergo extensive experimentation. Knowing the best sowing date helps to maximise yield: different sowing dates imply that growing crops will face different soil temperatures and moisture levels, have different chances of being affected by a late frost, and that their growth cycles will last different lengths of time. The aim of the present work was to determine the optimal range of sowing dates for three species of amaranth cultivated for grain production in the semi-arid Argentine Pampa.

Materials and Methods

Trials were performed at the Campo Experimental de la Facultad de Agronomía UNLPam, Santa Rosa (36° 32.726’S and 64° 18.271’W , altitude 135 m) during the summers of 1999, 2000, 2001 and 2002. The experimental plants were three cultivars of amaranth obtained from the Estación Experimental Agropecuaria «Eng. Agr. Guillermo Covas» del INTA de Anguil, La Pampa, all of which have outstanding productive qualities and are well adapted to extensive agriculture: Amaranthus cruentus L. cv. Don Guien, Amaranthus hypochondriacus L. cv. Artaza 412 and Amaranthus mantegazzianus Passer. cv. Don Juan (Covas, 1994b).

Amaranthus mantegazzianus Passer. = A. edulis Spegaz. is used for both grain and forage production (Weber and Reider, 1989; Covas, 1992; Troiani et al., 1998).

The soil at the experimental site was an entic haplustol with a calcareous layer at a depth of 1.2 m. The characteristics of the top 0.5 m of the soil were: clay 13.2%, silt 17.8%, sand 65.0%; organic matter 1.3%, pH 6.9 (saturated soil paste), and electrical conductivity 0.64 dsm⁻¹. Table 1 shows the total monthly rainfall and mean monthly air temperatures for the experimental period: maximum and minimum temperatures and rainfall were recorded daily, as was soil moisture level and soil temperature at a depth of 5 cm (using a fixed geothermometer, Cátedra de Climatología y Fenología Agrícola de la Facultad de Agronomía UNLPam). The annual mean rainfall for the experimental area is 550-600 mm, and there are approximately 120 frost-free days between November and March.

Sowing was performed four times each year at 15 day intervals: S₁ (24-11-1999, 22-11-2000, 26-11-2001), S₂ (14-12-99, 6-12-00, 17-12-01), S₃ (29-12-99, 20-12-00, 28-12-01), and S₄ (11-01-00, 3-01-01, 14-01-02). The sowing dates were not exactly the same each year since a pre-sowing rainfall was awaited. However, they were within the same fortnight.

The soil preparation techniques used were those typical for summer crops: one pass with a disc plough in September to allow water and nitrates to accumulate, and one pass with a chisel harrower two days before sowing to eliminate weeds and to level the soil surface. Sowing

<table>
<thead>
<tr>
<th>Years</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>D</td>
<td>Total</td>
<td>D</td>
<td>Total</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999/00</td>
<td>155.8</td>
<td>55.2</td>
<td>118.2</td>
<td>–4.3</td>
<td>66.7</td>
</tr>
<tr>
<td>2000/01</td>
<td>32.6</td>
<td>–68.0</td>
<td>23.2</td>
<td>–99.3</td>
<td>68.7</td>
</tr>
<tr>
<td>2001/02</td>
<td>62.4</td>
<td>–38.2</td>
<td>49.5</td>
<td>–73.0</td>
<td>176.4</td>
</tr>
</tbody>
</table>

| Air temperature (°C) |
| 1999/00 | 17.8 | –1.5 | 20.1 | –2.1 | 23.2 | 0.0 | 21.1 | –1.1 | 18.4 | –1.4 |
| 2000/01 | 17.2 | –2.1 | 21.7 | –0.5 | 23.8 | 0.6 | 24.1 | 1.1 | 19.1 | –0.7 |
| 2001/02 | 16.8 | –2.5 | 21.5 | –0.7 | 21.7 | –1.5 | 20.7 | –1.5 | 19.0 | –0.8 |

* Means are for 20 years. D: difference compared to mean. Data collected by the Cátedra de Climatología y Fenología Agrícola, Facultad de Agronomía UNLPam.
was performed by hand at a dose of approximately 4.5 kg seed ha⁻¹. These species autoregulate their density through vigorous competition (Covas, 1987). The maximum sowing depth was 1.5 cm. The plots used were 5.50 m long and 2 m wide, with 6 rows 0.40 m apart. The two central rows were destined for manual harvest at maturation. The contiguous rows were used to measure seed production and aerial dry matter content. The two outside rows and the first and last 0.25 m of every row were not used.

The dry matter content was obtained by drying plants in an oven at 60°C with circulating air until they reached a constant weight.

The harvest index was calculated thus: HI (%) = (economic yield/biological yield) × 100, where the economic yield is the production of seed, and the biological yield is the dry matter content of the same plants. Plant height was also measured, as was the number of days till anthesis (from sowing until 50% of flowers reached anthesis) and the initial and final plant populations (to calculate the percentage loss). The initial population was determined for the plants in the two central rows when it was sure that all had emerged. The final population was determined at harvest by counting the plants in optimal condition for gathering with a mechanical harvester. The percentage of plants lost per plot was determined by taking into account the number of plants that did not reach harvest through stalk breakage or strong initial competition.

The experiments had a randomised block design with four replicates. ANOVA was used to examine the effects of sowing date and years on plant height, biomass production, grain production days to anthesis, final population size, harvest index, and the percentage of plants lost (sowing dates as fixed effects, years as random effects). Data for the final plant populations were transformed into logarithms.

Results and Discussion

Emergence and establishment of plants

The mean monthly soil temperatures for the four sowing dates and the three different years varied between 19.7 and 26.9°C, much higher than the 15.6°C reported by Weber (1990) and the 16-18°C recorded by Henderson et al. (2000), at which these authors saw good establishment of A. cruentus, A. hypochondriacus and A. hibridus.

In November and December of 1999/2000 and 2000/2001, the mean monthly air temperature was 17.2-21.7°C (Table 1). Good plant establishment was achieved.

The germination and establishment of plants was uniform and very good in the first two years of the experiment. In the third year, however, the November rainfall came during the first days of the month (quite distant from the S₁ sowing time), and in December it came at the end of the month. Therefore, despite total rainfall for this period being greater than that of the previous year (though below the mean; Table 1), water was not provided in an adequate way. This led to the S₁, S₂ and S₃ seeds germinating at the same time. Soil moisture was therefore a limiting factor for germination at the first sowing dates of this year.

The effect of sowing date

The sowing date significantly affected plant height, days to anthesis, the production of biomass and grain, and the percentage of plants lost (Table 2). Plants sown at the last date (S₄) tended to be shorter (Table 3). The shortening of the days over the summer period had an important effect on plant development (Kigel, 1994). This also affected the production of biomass which was significantly lower for plants sown at S₄ compared to those of S₁ and S₂ in the first year, and with those sown at S₂ in the last year.

Grain production was significantly lower among the S₄ plants of 1999/00 and 2001/02. However, no significant differences were seen between sowing dates in 2000/01 with respect to this variable.

Species effect

All three species showed similar grain production values, final population sizes and percentage plant losses over the experimental period. Significant differences were seen, however, in plant height, days to anthesis, and harvest index. Very significant differences were seen with respect to the production of biomass (Table 2). Amaranthus mantegazzianus plants were...
taller than those of the other two species; those of *A. hypochondriacus* were the shortest (Table 4). *Amaranthus mantegazzianus* also branched more and produced significantly more biomass than the other species, the order being *A. mantegazzianus*, *A. cruentus* and *A. hypochondriacus* (Table 4). The interaction sowing date x species was not significant with respect to these characteristics (Table 2).

The harvest index of *A. mantegazzianus* was significantly lower than those of the other two species in all three years (Table 4). The interaction sowing date x species was not significant with respect to these characteristics (Table 2).

The harvest index of *A. mantegazzianus* was significantly lower than those of the other two species in all three years (Table 4). The interaction sowing date x species had a significant effect on this variable; the interactions year x species and year x species x sowing date had very significant effects (Table 2).

Significantly fewer days were required to reach anthesis by both *A. cruentus* and *A. hypochondriacus* compared to *A. mantegazzianus* (Table 4).

### The interaction of sowing date and year

Depending on the year, sowing date led to different growth conditions for the plants. The responses of the different agronomic variables varied from year to year.
The growth of amaranth plants is influenced by the distribution of rainfall not just during initial development but also before emergence (Henderson et al., 1998). In 2000/01 there was a large reduction in the number of plants that reached harvest; losses were 66.8, 67.5 and 66.8% for S2, S3 and S4 respectively (Table 3), possibly caused by strong competition for soil moisture. There was a notable water deficit during the initial development of the plants during this season (Table 1), which was more important with respect to sowing date than species.

Grain production was affected differently by sowing date each year. The greatest production was achieved by S1 and S3 plants in 1999/00, by S1 plants in 2000/01, and by S2 and S3 plants in 2001/02 (Table 2). Grain production in 2000/01 was relatively low, as was production by S1 and S2 plants in 1999/00 and S1 plants in 2002. Grain production for the last sowing date (S4) fell in 1999/00 and 2001/02 due to the reduced time available for the plants to finish their phenological cycle, and because of the low levels of light and low temperatures during grain filling and seed maturation. The fall in production by the S2 plants of 1999/00 may have been caused by the water deficit that occurred during anthesis. The low grain production of the 2000/01 season for all sowing dates may have been caused by water stress during November and December 2000 and January 2001; with respect to the mean monthly rainfall, values were down by 68, 99.3 and 27.3 mm respectively (Table 1). In addition, December and January had high temperatures (Table 1).

For all sowing dates and all years, the final population sizes achieved were greater than those mentioned by Henderson et al. (1998 and 2000); using mechanical sowing these authors obtained 173,000 and 272,000 plants ha⁻¹ with *A. cruentus* and *A. hypochondriacus x A. hybridus* respectively. In the present work, S1 and S3 of 2001/02 and S3 of 2000/01 produced the smallest final population sizes (Table 3).

Manual sowing with a large number of seeds initially leads to too high a plant density for areas where there is competition for water during the vegetative period of growth (Weber, 1990). In general, high sowing densities promote the development of plants with reduced stem diameters, the formation of secondary inflorescences and a lack of uniformity in...
height. But in amaranth this facilitates stalk breakage and the loss of plants through competition (Fitter et al., 1996; Henderson et al., 2000), leading to what Covas (1987) describes as autoregulation of sowing density.

Table 3 shows that in the 2001/02 season, the number of plants obtained per hectare was similar for all sowing times. The $S_1$ and $S_3$ sowings led to the lowest density figures, although grain production was still over 1000 kg ha$^{-1}$. This might be due to the ‘elasticity’ of amaranth, which compensates for a drop in density by an increase in the amount of grain produced by each plant (Hauptli, 1977). A reduction to below 171,000 plants ha$^{-1}$ is not beneficial, however, since the plants can then develop thick stems which might hinder mechanical harvesting (Henderson et al., 1998).

In the third and fourth seasons, the number of days to anthesis fell as sowing time was delayed. A notable effect was seen in 2001/02, in which the difference in time to anthesis between $S_1$ and $S_3$ was 39 days; in 1999/00 it was only 8 days. In agreement with Peiretti and Gesumaria (1998), *A. mantegazzianus* showed the greatest reduction in the number of days necessary to reach anthesis as sowing time was delayed. The same effect was reported by Henderson et al. (1998) for *A. cruentus* and *A. hypochondriacus x A. hybridus* in every year of their trial. This is common in plants that depend on high light intensities and temperatures for their development (Gardner et al., 1985; cited by Henderson et al., 1998).

In the 2000/01 season, however, the number of days needed to reach anthesis changed, possibly due to the distribution and scarcity of rainfall being more important than the effect of temperature (temperatures were similar in each month in all three seasons).

The $S_4$ plants were the shortest every season (Table 3). This was due to the marked effect of shortening day length towards the end of summer since, after January (the last month of sowing), rainfall was both above or below the mean depending on the year.

### The interaction of year and species

The interaction *year x species* had a significant effect on all the variables analysed, except for the production of biomass (Table 2). If the means for the three years together are compared, significant differences are seen between the three species, with *A. mantegazzianus* producing the most biomass (Table 4). This species, however, showed a lower grain production and harvest index than the other two; this occurred every year and was a consequence of its height (Table 4) and the number of shoots sprouting from axillary buds. Grain production by the three species did not differ significantly in the first year of the study (Table 4) when rainfall was greater and close to the mean during the first days of development (Table 1). *Amaranthus hypochondriacus* produced significantly more grain than the other species in 2000/01 and 2001/02, when rainfall deficiency was at its worst compared to the mean for the initial months of growth (Table 1); this species recovered better than the others with the rain that fell during the latter stages of development. This may have been helped by its height (shorter than *A. cruentus* and significantly shorter than *A. mantegazzianus*; Table 4).

It would therefore seem recommendable to sow amaranth after the 20th of November and during December to ensure maximum plant development and the maturation of all the grain produced. This range will allow growers to wait for adequate pre-sowing rainfall.

### Acknowledgements

The authors thank Juan Vaquero and Enrique Sianca for their help in data gathering.

### References


