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Field Evaluation of *Amaranthus* Species for Seed and Biomass Yields in Southern Italy

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Abstract

Amaranth is a crop with a potentially increasing cultivation area. Little information is available on amaranth cultivation in Mediterranean environments and in southern Italy. The aim of this study was to evaluate the agronomic traits and assess the grain and biomass yield responses of 11 genotypes belonging to 5 *Amaranthus* species, provided from the USDA-ARS, National Plant Germplasm System. There was wide diversity in agronomic traits among *Amaranthus* species and among genotypes within the same species. The accessions belonging to *A. cruentus* had the shortest growing cycle followed by *A. hybridus*, *A. hypochondriacus*, *A. caudatus* and, finally, *A. hybrid* that had the longest growing season. The *A. cruentus* accessions reached maturity more quickly than the other species. The total above-ground dry matter ranged from 15 to 23 t ha^{-1} with *A. cruentus*, *A. hypochondriacus,* and *A. hybridus* being the most productive. The stem plus branches dry matter was well correlated to the plant height ($r^2 = 0.75^{**}$). The tested amaranth genotypes showed appreciable biomass production that can thus be regarded as an interesting secondary product after seed harvesting. Grain yield and components varied among species and accessions. *A. hypochondriacus* showed the highest yield per plant (55.4 g) followed by five accessions belonging to *A. cruentus* and *A. hybridus* (26.4 g on average). Considering together their shorter growing season and their higher grain production, the five accessions belonging to *A. cruentus* species appear to be better adapted to Mediterranean environments and southern Italy as compared to the other species.

Key-words: Amaranth species, agronomic traits, growing cycle, Mediterranean environment.

1. Introduction

Amaranthus has been rediscovered as a promising crop for human nutrition and animal feed, mainly due to the high nutritional value of both seeds and leaves, all over the world (Becker et al., 1981; Kauffman, 1992; Ravindran et al., 1996; Zheleznov et al., 1997; Berger et al., 2003). Seeds are considered to have a unique composition of proteins, carbohydrates and lipids with regard to quantity and quality. They are generally high in protein content (14-18%) and in essential amino acids such as lysine, triptophan and sulphur-containing amino acids (Becker et al., 1981; Bressani, 1989; Zheleznov et al., 1997; Tosi et al., 2001; Pospišil et al., 2006). Noteworthy is the high content of arginine and histidine which makes amaranth interesting for child nutrition. Amaranth is also rich in vitamins (Zheleznov et al., 1997; Tosi et al., 2001), raw fiber and minerals (calcium, iron, sodium, magnesium, potassium and zinc) (Becker et al., 1981; Berghofer and Schoenlechner, 2002). The lipid fraction of the seed is characterised by a high content in unsaturated fatty acids (77%), with linoleic acid being predominant (Stallkencht and Schulz-Schaeffer, 1993). In addition to being gluten-free and having a favourable composition of the grains as well as low levels of antinutritional factors, the amaranth has remarkable nutritional benefits: it is advised for people suffering from celiac disease and helps prevent certain diseases and digestion disorders, which make its seeds a product of great interest for food formulation (Gallagher et al., 2004).

Various amaranth species show to have also considerable potential to be used as a forage or silage crop (Sleugh et al., 2001), as a new source of natural colorants such as betacyanin pigments (Cai et al., 1998), and for ornamental pur-

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poses. In addition, the residual biomass after seed harvesting may be a secondary product that is worth considering for energy uses though relevant information is not currently available. Owing to its outstanding nutritional and industrial applications, international demand for amaranth is increasing. *Amaranthus* is a genus that consists of more than 50 species (Stallkencht and Schulz-Schaeffer, 1993); *A. caudatus*, *A cruentus* and *A. hypochondriacus* are the major grain producing species. Referring to crop production, amaranth certainly is a specialty crop, since every aspect of production, from planting to harvest and storage, requires special attention (Stallkencht and Schulz-Schaeffer, 1993). Grain yields are extremely variable depending upon species and genotype, site, soil and weather conditions, growing season and agronomic practices. Grain yields from 1000 to 3000 kg ha^{-1} have been achieved in the United States (Myers, 1996) and in several countries of Northern Europe (Croatia, Slovak Republic, Austria and Germany) (Pospišil et al., 2006; Gimplinger et al., 2008); 1800-2300 kg ha^{-1} and exceptionally 4500 kg ha^{-1} in Argentina (Tosi and Ré, 2003); 5000 kg ha^{-1} or more under intensive cultivation in China (Wu et al., 2000); 1200-6700 kg ha^{-1} in southern Italy (Alba et al., 1997; Lovelli et al., 2005). The combination of its capacity to adapt to unfavourable growing conditions, such as low nutrient availability and a wide range of soil moisture, temperature and irradiation, as well as its tolerance to drought stress (Liu and Stützel, 2004), contribute to the plant's wide geographic adaptability to diverse environmental conditions, including marginal lands and semi-arid regions (Myers, 1996; Schahbazian et al., 2006). Little information is available on amaranth cultivation in semi-arid regions of southern Italy. The objective of this research was to study the suitability of growing amaranth in a semi-arid environment of southern Italy and to assess grain and biomass yield responses.

2. Materials and methods

Field experiment was carried out in 2006 at Policoro (MT – southern Italy, 40° 02' N; 16° 55' E) on alluvial, silty-clay soil, with sub-alkaline reaction. Eleven genotypes from five different species, *A. caudatus, A. cruentus, A. hybrid, A. hybridus, A. hypochondriacus* were compared (see Table 1 for taxonomic information and origin of the compared accessions). The germplasm was provided from the USDA-ARS, North Central Regional Plant Introduction Station (NCRPIS), Iowa State University, Ames, IA. Sowing was done in alveolate containers on April the 29th and seedlings were transplanted 35 days after in open field, previously ploughed and fertilized with 60 and 120 kg ha^{-1} of N and P_2O_5 respectively. The experimental design was a randomized complete block with three replicates; the plots were 2 m long with a row spacing of 0.5 m, and a crop density of 18 plants m^{-2}. Rainfall during the growing season was about 110 mm; in addition, 250 mm of water was applied by a drip irrigation system from June through September. During the growing cycle the main phenological stages (inflorescence head emission, flowering, seed formation, ripening) were recorded. Plant height was measu-

Table 1. Species, accession and origin of the *Amaranthus* germoplasm.

*Genotype code number	Species	Accession	Origin
1	*A. caudatus*	Ames 15150	Peru, Ancash
2	*A. cruentus*	PI 477913	Mexico
3	*A. cruentus*	PI 482051	Zimbabwe
4	*A. cruentus*	PI 527570	Rwanda
5	*A. cruentus*	PI 604666	USA, Pennsylvani
6	*A. hybrid*	PI 604567	Mexico, Puebla
7	*A. hybridus*	PI 500249	Zambia
8	*A. hybridus*	PI 605351	Greece
9	*A. hypochondriacus*	PI 604577	Mexico, Puebla
10	*A. hypochondriacus*	PI 615696	India, Himachal Pradesh
11	*A. cruentus*		Unknown

* Genotype code number from 1 to 10 were provided from the USDA – ARS, NCRPIS, National Plant Germoplasm System, Iowa State University, Ames, IA.

red from the ground surface to the top of the inflorescence head at the harvest. After seed formation, inflorescences were protected with paper bag to prevent grain losses, before and at the harvest, to assess potential yield. Hand-harvest was carried out at maturity by cutting plants at soil level. Five plants from each plot were separated into components (stems, leaves and inflorescences), subsequently dried in ventilated oven at 75°C to measure the dry weight (DW). Number of seeds plant^{-1}, grain yield plant^{-1} and 1000 seed weight were measured from 5 plants air-dried and trashed by hand.

3. Results and discussion

The duration of the growing season differed among species and accessions (Fig. 1). In particular, the accessions belonging to *A. cruentus* had the shortest growing cycle (on average 115 days), followed by *A. hybridus* (135 days), *A. hypochondriacus* and *A. caudatus* (150 days) and finally, *A. hybrid* that had the longest growing season (163 days). The latter species was characterized by a long vegetative period (120 days from transplanting to inflorescence emission) with a delayed inflorescences emission in late November, which is an unfavourable period for full grain development and ripening. Conversely, the other genotypes completed their biological cycle and produced seeds. *A. hypochondriacus,* genotype 10, despite being a late genotype, showed the shortest vegetative growth period (28 days) and a long period from inflorescence emission to seed ripening (Fig. 1). The results indicated that many of the species were probably sensitive to daylength. Testing a large *Amaranthus* germoplasm collection, Wu et al. (2002), observed differences in growth period responses between species and genotypes; such differences were partially attributed to sensitivity to daylength and similarity of climate between the site of origin of the genotypes and the target area for production. On the basis of our observations, *A. cruentus* genotypes reached maturity more quickly than the other species. The total above-ground dry matter ranged from 15 to 23 t ha^{-1} (Fig. 2). In particular, *A. cruentus* genotypes, *A. hypochondriacus* genotype 10, *A. hybridus* genotype 7 and *A. caudatus* were the most productive. *A. hypochondriacus,* genotype 10, showed a dry matter partitioning equally subdivided between stems plus leaves and inflorescences (Fig. 2). For similar total DW production, earlier genotypes had higher inflorescences and lower stem plus branches DW production, while later genotypes showed an inverse DW partitioning.

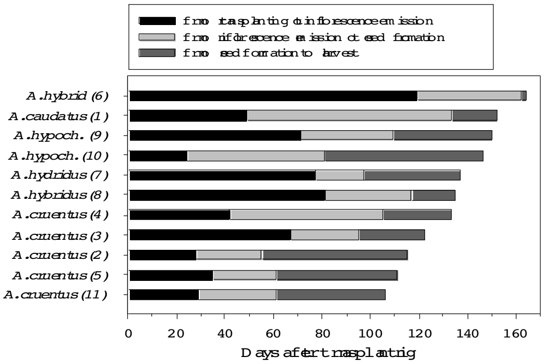

Figure 1. Duration of growing season and of biological stages for the tested amaranth genotypes.

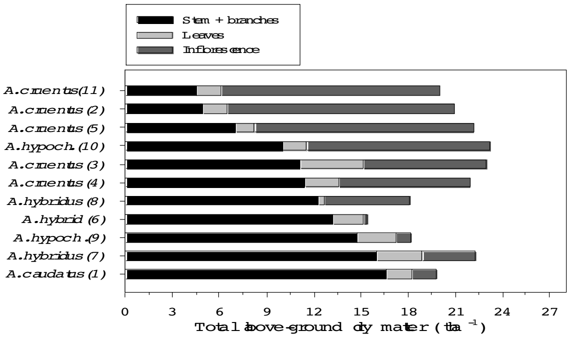

Figure 2. Partitioning of the total above-ground dry matter for the compared amaranth genotypes. LSD ($P \leq 0.01$): 5.4 for stem plus branches; 1.1 for leaves; 5.1 for inflorescence. LSD ($P \leq 0.05$) = 4.2 for total DW.

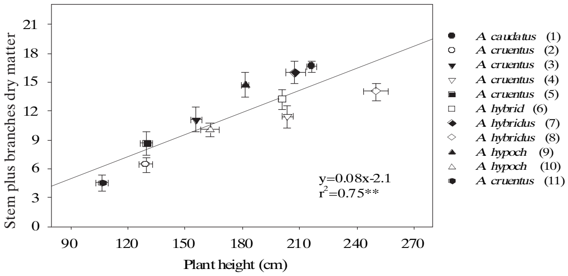

Figure 3. Relationship between stem plus branches dry matter and plant height of eleven genotypes of amaranth at the harvest. Bars indicate the standard error of the mean (n = 5).

The stem plus branches dry matter was well correlated to the plant height ($r^2 = 0.75^{**}$) (Fig. 3). Among genotypes, although *A. hybridus,* ge-

Table 2. Grain yield and components for the tested amaranth genotypes.

Accessions	Seeds per plant (n)	1000 seed weight (g)	Grain yield per plant (g)
A. caudatus (1)	12,615 F	0.49 CD	6.1 EF
A. cruentus (2)	26,097 E	0.75 A	19.5 BD
A. cruentus (3)	88,565 B	0.33 FG	28.8 B
A. cruentus (4)	47,486 C	0.31 G	14.6 CE
A. cruentus (5)	48,670 C	0.63 B	30.7 B
A. hydrid (6)	4,846 G	0.42 DE	2.0 F
A. hybridus (7)	33,484 DE	0.27 G	8.7 DF
A. hybridus (8)	50,488 C	0.51 C	25.9 BC
A. hypochondriacus (9)	27,911 E	0.40 EF	11.2 DF
A. hypochondriacus (10)	113,301 A	0.49 CD	55.4 A
A. cruentus (11)	35,876 D	0.76 A	27.1 B

Numbers with different letters are significantly different (Duncan, $P \leq 0.01$).

notype 8, was the tallest (250 cm), it produced relatively less stem plus branches DW due to its thinner stems.

The tested amaranth genotypes showed, on average, appreciable production of biomass, which can thus be regarded as an interesting secondary product after seed harvesting. Expectably, that biomass was in close relationship with the height of plants, as reported by many authors for various crops. Moreover, the diversity of tissues that make up the residual biomass (leaves, stems, different components of the inflorescences) makes it reasonable to assume that it might be used as raw material to generate heat. Grain yield and components varied among species and accessions (Tab. 2). *A. hypochondriacus,* genotype 10, showed the highest yield per plant (55.4 g) followed by *A. cruentus* genotypes and *A. hybridus,* genotype 8 (26.4 g on average). Due to compensation between seed number (higher with *A. hypochondriacus,* genotype 10, and *A. cruentus,* genotype 3) and individual seed weight (higher with *A. cruentus*, genotypes 2, 5 and 11), the above-mentioned genotypes showed similar grain yields. Comparable results about grain yield of *A. cruentus,* genotype 11, are reported by Lovelli et al. (2005). *A. hybridus,* genotype 7, *A. caudatus* and *A. hybrid* were the lowest yielding species due to their lower number and weight of seeds (Tab. 2). Potential grain yield per hectare ranged from 0.4 to 9.9 tons (data not showed); *A. hypochondriacus,* genotype 10, *A. cruentus* genotypes 2, 3, 5, 11, and *A. hybridus* genotype 8, showed the highest values. However, it has to be noticed that crop harvest management is still critical, as amaranth is prone to grain shattering and losses due to wind. Preliminary studies indicate that losses caused by seed shattering can decrease yield of some cultivars over 1.0 t ha^{-1} (Shroyer et al., 1990). Other authors report that mechanical harvesting recovered about 80% (Gimplinger et al., 2008) and, in same cases, only 50% of the potential yield (Tucker 1986). Considering together the shorter growing season and the higher grain production, the five accessions belonging to *A. cruentus* species seem to be more adapted to Mediterranean environments of southern Italy compared to the other genotypes. Equally interesting were the two accessions of *A. hybridus*, intermediate in terms of growing cycle duration, seed and biomass yields.

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