The suitability of amaranth genotypes for grain and fodder use in Central Europe

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Die Nutzbarkeit verschiedener Amarant-Genotypen als Körnerfrüchte und Futterpflanzen in Mitteleuropa

Zusammenfassung

Ein Sortiment von 15 Amarant-Genotypen (*Amaranthus spp.*) aus unterschiedlichen botanischen Arten und geographischen Herkünften wurde in Feldversuchen hinsichtlich ihrer Nutzbarkeit als Körnerfrüchte und Futterpflanzen geprüft. Ihre Phänologie, Morphologie sowie die oberirdische Trockenmasse-Produktion zu Beginn der generativen Phase und zur Körnerreife wurden unter drei verschiedenen Umweltbedingungen (in Süddeutschland 1994 und 1995 sowie in Polen 1994) untersucht. Die Genotypen benötigten im Durchschnitt vier Monate von der Saat bis zur Körnerreife. Sie produzierten zwischen 1 und 270 g m^{-2} an Korn-Trockenmasse und zwischen 290 und 1440 g m^{-2} an oberirdischer Gesamt-Trockenmasse. Bei den angebauten Genotypen war mehr die geographische Herkunft als die botanische Art maßgebend für ihre Nutzbarkeit als Körnerfrüchte oder Futterpflanzen. Es bestanden starke Wechselwirkungen zwischen den Genotypen und den Umweltbedingungen. Dennoch können erste Empfehlungen zur Auswahl von Genotypen für den Anbau in Mitteleuropa abgeleitet werden.

Schlagworte: Amarant, Genotypen, Morphologie, Körnernutzung, Futternutzung.

Summary

A set of 15 amaranth (*Amaranthus spp.*) genotypes from different species and regions of the world was evaluated in field experiments with reference to their suitability as grain or fodder crops. The genotypes' phenology, morphology and dry matter production at beginning of flowering and at grain maturity were examined under three different environments, twice in South Germany (1994 and 1995) and once in Poland (1994). On average, they needed four months from sowing to grain maturity. Their yields ranged from 1 to 270 g m^{-2} of grain dry matter and from 290 to 1440 g m^{-2} of total above ground dry matter. Within the tested set of genotypes, the origin rather than the botanical species was decisive for their suitability for grain or fodder use in Central Europe. There were large interaction effects between genotypes and environments. However, preliminary genotype recommendations can cautiously be drawn from the results.

Key words: amaranth, genotypes, morphology, grain production, fodder production.

1. Introduction

The centre of origin of amaranth (*Amaranthus spp.*) cultivation is Central and South America. Several species can be utilized (NATIONAL RESEARCH COUNCIL, 1984). Because of their moderately high concentrations of high-grade protein in grains and vegetative plant biomass in combination with their high potential of biomass production as C_4 crops they are now cultivated all over the world, preferentially under dry and warm climatic conditions. In South America, Africa, Asia and Eastern Europe people use the grains or the leaves of young plants for human nutrition. The whole plants can also be used as fodder for ruminants, either fresh or ensiled (WEGERLE and ZELLER, 1995). The American Amaranth Institute is engaged in the development of cultivation practices and cultivars for grain amaranth production in the USA (WEBER et al., 1990). Attempts are made to introduce amaranth in Europe, too (e. g. DOBOS, 1992; LEE et al., 1994; NALBORCZYK, 1994).

Amaranth is a short day crop. But as most genotypes are frost susceptible and require high growth temperatures they can be sown in Central Europe not before May. Hence daylength insensitivity is an important trait for a successful production of grains. In Southern Germany cultivars from the USA were able to produce up to 1300 g m^{-2} of total above ground biomass, but the harvest index was low ($\leq$ 30) (AUFHAMMER et al., 1995). Additionally, losses of about 30 per cent of the hand harvested grains occured before and during combining (LEE et al., 1994). Breeding goals for grain amaranth are, besides high yield, a reduced plant size for better combining suitability, an increased seed size, a high grain protein content and a white seed colour (NATIONAL RESEARCH COUNCIL, 1984; SAUNDERS and BECKER, 1984).

A fodder utilization of whole amaranth plants could be realized either at an early stage of plant development, with a high digestibility of plant biomass, or later towards grain maturity with the maximum DM yield (GREGOROVA, 1994). For a vegetable utilization but also for a high feed intake, due to a good tastiness of the plants for animals, the yield of leaves is a crucial factor (NATIONAL RESEARCH COUNCIL, 1984).

To make amaranth a profitable alternative for the European farmers a cropping system has to be developped and adapted genotypes have to be identified or new cultivars must be developped. A first step into this direction would be the phenotypic description of available genotypes under European growth conditions. Thus, the aims of the present study were:
– to describe the morphology, phenology and dry matter production of a collection of amaranth genotypes from different species and regions of the world and
– to evaluate their suitability for utilization as a grain crop or a fodder crop under Central European conditions.

2. Materials and methods

2.1 Experimental design and conditions

Three field experiments were conducted in 1994 and 1995 on experimental stations of the University of Hohenheim, South Germany, and the Agricultural University of Warsaw, Poland (Table 1). All experiments were of a randomized complete block design. For technical reasons, in the experiment in 1995 the number of replicates was reduced from four to three, but at the same time the size of the sub-plots and the sampling areas were expanded. Thus, the error variances were homogeneous between experiments. A set of 15 amaranth genotypes was tested (Table 2). They originated from the USA, Asia, Russia and South America and they

Table 1: Experimental conditions and records taken of three experiments in Central Europe in 1994 and 1995
Tabelle 1: Versuchsbedingungen und Untersuchungsparameter bei drei Feldversuchen in Mitteleuropa, 1994 und 1995

Experiment	D-1994	PL-1994	D-1995
Experimental sites:			
– Location	Ihinger Hof, Germany	Szepietowo, Poland	Ihinger Hof, Germany
– Latitude, Altitude	49° N, 470 m	53° N, 150 m	49° N, 480 m
– Mean year temperature	7.9° C	6.9° C	7.9° C
– Mean sum of rainfall	688 mm a^{-1}	632 mm a^{-1}	688 mm a^{-1}
– Soil type	Loam	Loamy sand	Loam
Crop husbandry:			
– Preceding crop	Oat	Winter wheat	Winter wheat
– Sowing date	13 May 1994	16 May 1994	05 May 1995
– Plant density at maturity	52 plants m^{-2}	29 plants m^{-2}	34 plants m^{-2}
– N rate	50 kg N ha^{-1}	92 kg N ha^{-1}	50 kg N ha^{-1}
Experimental design:			
– Replications (blocks)	4	4	3
– Sub-plot area, Sampling area per sub-plot for DM records	2x3 m^2, 0.5 m^2	2x3 m^2, 0.6 m^2, 2 m^2 for grain	2x6 m^2, 0.8 m^2

The morphological and phenological description of genotypes:
– Leaf, inflorescence and seed colour [descriptive terms]
– Plant hight at grain maturity [m] 1)
– Vegetation period (from sowing to grain maturity) [d]
– Vegetative period (from sowing to beginning of flowering) [d]

The suitability for fodder production:
– Total above ground DM at beginning of flowering [g m^{-2}]
– DM of leaves at beginning of flowering [g m^{-2}]
– Total above ground DM at grain maturity [g m^{-2}] 1)

The suitability for grain production:
– Grain yield by manual harvest at maturity [g DM m^{-2}]
– Grain yield by combine harvest of whole plots at maturity [dt DM ha^{-1}] 1)
– Harvest index ((grain yield by manual harvest x 100) x (total above ground DM at maturity)$^{-1}$) [%] 1)
– Grain weight [mg $grain^{-1}$]
– Grain protein concentration (grain N concentration x 6.25) [%]

1) not in experiment PL-1994

were of different utilization type and botanical species. Only the entries from the USA were registered cultivars.

The experiments in Germany were sown with a plot drill. In Poland the plots were thoroughly sown by hand. The intended population density was 40 plants m^{-2}, but the establishment of homogeneous amaranth crops is difficult to achieve (AUFHAMMER et al., 1994, 1995). We chose sowing densities between 150 and 200 seeds m^{-2}, depending on environmental conditions (temperature, soil structure), and the plant densities were corrected by hand thinning after emergence, resulting in plant populations between 29 and 52 plants m^{-2} at maturity (cf. Table 1). The plots were weeded by hand. Only in 1995 an insecticide was applied, in the middle of June, against flea beetles and aphids.

The climatic conditions in 1994 were favourable for amaranth growth at both experimental locations, D-1994 and PL-1994. The summer was warm and sunny and at combine harvest in Germany the weather was dry. However, on the light soil in Poland plants suffered from severe drought in early summer. On the contrary, the summer season of 1995 in Germany was cool and wet (Table 3).

2.2 Morphological and phenological description of genotypes

The colours of the upper, photosythetically active, leaves and of the inflorescences were scored at nine levels after flowering (Table 4). The seed colour (black or white) was determined after grain harvest. In all experiments the date of flowering was noticed when about 10 per cent of the flowers of the terminal inflorescences were blooming. Grain maturity was defined when the grains in the centre of the terminal inflorescences were hard. Both characters were assessed individually for each genotype.

2.3 Productivity of genotypes

Plant samples were collected from sampling areas of 0.5–0.8 m^2 at the individual dates of beginning of flowering and of

Table 3: Climatic conditions (mean temperatures and amounts of rainfall) of three experiments in Central Europe in 1994 and 1995
Tabelle 3: Klimatische Bedingungen (mittlere Temperaturen und Niederschlagssummen) bei drei Feldversuchen in Mitteleuropa, 1994 und 1995

Experiment	D-1994		PL-1994		D-1995	
Month	°C	mm	°C	mm	°C	mm
January	2.5	79	0.5	33	0.2	83
February	1.7	31	−0.1	18	4.5	28
March	7.5	44	1.9	52	2.7	71
April	6.8	91	9.4	74	8.3	50
May	12.4	113	12.5	59	11.8	94
June	15.8	82	15.1	15	13.5	77
July	20.0	115	21.7	9	19.2	96
August	17.4	57	18.2	74	16.6	78
September	13.1	80	14.3	61	10.9	75
October	7.8	18	5.7	70	11.5	37

Table 2: Botanical and morphological description of genotypes
Tabelle 2: Botanische und morphologische Beschreibung der Genotypen

Name	Species	Origin	Original utilization	Leaf colour	Inflorescence colour	Seed colour	Mean plant height [m]
K 266	*A. cruentus*	USA	grain	green	green-orange	white	0.97
K 432	*A. hypochondriacus* x *A. hybridus*	USA	grain	dark green+20% red	orange-red	white	0.94
MT 3	*A. cruentus*	USA	grain	light green	green-orange	white	1.21
Nu World	*A. cruentus*	USA	grain	light green	green-orange	white	1.29
A 10	*A. cruentus*	China	grain	dark green+40% red	dark red	white	1.31
C 4	*A. caudatus*	China	mixed	green	green	white	1.20
C 6	*A. caudatus*	China	mixed	dark green +80% red	dark red	white	1.27
Suvarna	*A. cruentus*	India	grain	light green	green	white	1.25
Pastewny 1	*A. hybridus*	Russia	fodder	dark green+40% red	dark red	black	1.25
Pastewny 2	*A. hybridus*	Russia	fodder	dark green+30% red	dark red	black	1.12
Turkiestan	*A. hybridus*	Russia	fodder	dark green+20% red	dark red	black	1.24
Ural	*A. hybridus*	Russia	fodder	dark green+20% red	dark red	black	1.39
Villarica	*A. cruentus*	South America	unknown	dark green+20% red	orange-red speckeled	white	1.51
Puerto M.	*A. cruentus*	South America	unknown	dark green+10% red	orange-red speckeled	white	1.48
Anden	*A. cruentus*	South America	unknown	dark green	orange-red speckeled	white	1.59

Table 4: Scoring system for colours of leaves and inflorescences
Tabelle 4: Boniturschemata für die Blatt- und Infloreszenzfarben

Scoring	Colour of leaves	Colour of inflorescence
1	light green	green
2	light green-green	green-orange
3	green-dark green	orange
4	dark green	orange-red
5	dark green + 20 per cent of leaf area red	orange-red speckeled
6	dark green + 40 per cent of leaf area red	light brown
7	dark green + 60 per cent of leaf area red	dark brown
8	dark green + 80 per cent of leaf area red	light red
9	red	dark red

grain maturity for each genotype. Plants were cut at the soil surface. At grain maturity the total above ground plant height was measured. Then plants were separated into stems, leaves and inflorescences. At grain maturity the grains were threshed out from the inflorescences with a stationary thresher. Additionally, in Germany (D-1994, D-1995) the residual plots were harvested by a plot combine (Hege model 180). In Poland (PL-1994) at grain maturity only inflorescences were sampled from 2.0 m^2 and threshed for grain yield. All plant samples were dried at 80° C for 24 h and weighed afterwards. Finally, the grain weight was taken from 1000 grains, and the nitrogen concentration in grains was determined by a Kjeldahl procedure.

2.4 Evaluation

All data about dry matter production were statistically analysed by the GLM procedure of the Statistical Analysis System (SAS Institute Inc., 1987). We used a model for analysis of variance estimating the main effect of experiments, i. e. different environmental conditions, the main effect of genotypes and the interaction effect experiment * genotype. For all traits this interaction term was significant. Thus results are given individually for each experiment and genotype.

In order to describe the morphology, phenology and dry matter production of amaranth genotypes comprehensively a star plot was designed to summarize the important characters for grain or fodder utilization. The mean values and the ranges for these characters are given in Figure 1. The axis are scaled between the minimum and the maximum value for each trait. Idealized optimum patterns for both utilizations, grain and fodder, are shown for an easier interpretation of the results.

3. Results

The colour scorings differed hardly between the three experiments, indicating the genetic homogeneity of the seed material. Together with mean values of the plant height, they are given in Table 2 for the morphological description of the genotypes. The different regions of origin could easily be recognized. The cultivars from USA were characterized by green leaves and orange inflorescences. The K-selections were very small. Genotypes from Russia had green leaves with large percentages of red, dark red inflorescences and black seeds. The South American entries were the tallest with dark green leaves and orange-red speckeled inflorescences. Only the Asian genotypes were quite variable.

Figure 1 gives absolute mean values and ranges for the most important characters which determine grain or fodder use of amaranth. Idealized optimum patterns for grain or fodder utilization are shown by line drawings. They indicate that an optimum grain amaranth genotype should be early in development for harvesting under dry summer conditions. It should give a maximum grain yield and quality, i. e. grain weight and protein concentration. On the other hand, an optimum fodder amaranth should produce much DM, especially leaves, either in an early or in a late stage of development. The reproductive development can be later than that of the grain type, but in view of seed production grain maturity should be achieved.

Figure 2 shows star plots describing each genotype under three different environmental conditions. The axis are scaled between the minimum and the maximum value observed for each trait. The optimum patterns for grain or fodder use are repeated. Generally, the grain yield was higher and the vegetation period was shorter in Germany than in Poland. The earliest ripening in combination with the highest grain yields was noted in Germany 1994. This may reflect the weather conditions, which were less favourable for grain production in Poland 1994 and in Germany 1995, due to severe drought conditions (PL-1994) or to cool and rainy weather (D-1995). But grain weight and grain protein concentration showed the opposite reaction. They were best in Poland 1994. For the vegetative yield parameters the interactions beween genotype and environment were stronger.

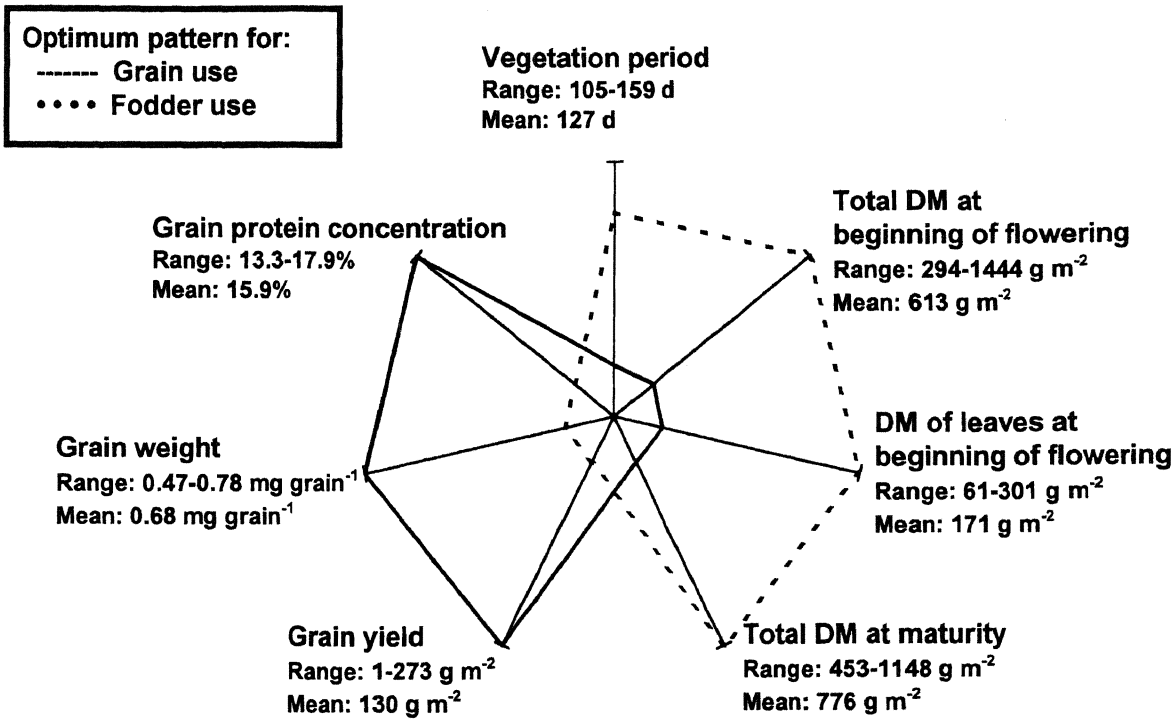

Figure 1: Explanation of star plot used for the comprehensive description of genotypes' suitability for grain or fodder use and idealized optimum patterns for both utilizations

Abbildung 1: Erläuterung der Sterndiagramme zur zusammenfassenden Darstellung der Nutzbarkeit der Genotypen als Körnerfrüchte oder Futterpflanzen sowie idealisierte optimale Ausprägungsmuster für beide Nutzungsrichtungen

The large differences between experiments, i. e. environmental conditions, obstruct a simple characterization of the different genotypes. Despite large interactions with environmental conditions, some generalizations for the genotypes can be made. The grain amaranth cultivars from the USA produced always low amounts of total above ground DM, showed an early ripening of grains and medium to high grain yields. K 432 and MT 3 had a better grain quality, i. e. higher grain weight and protein concentration. Nu World performed much better in both experiments in Germany than in Poland. The genotype A 10 was similar to those from USA. It was earlier in development than the other Asian genotypes, especially C 4. The black-seeded Russian fodder genotypes had a short vegetation period and produced medium total above ground DM and grain yields, characterized by heavy grains. Both, Villarica and Puerto showed patterns similar to the Russian types. All three genotypes from South America gave medium grain yields, but heavy grains. The genotype Anden produced very much dry matter in Poland (PL-1994) but gave no grain yield at all in this experiment, while in Germany it performed similar to the other genotypes from South America.

The grain yield harvested by combine in Germany was less variable than that by hand harvest (Figure 3). In 1994 there were genotypes from all origins which yielded more than 20 dt ha^{-1}. Due to wet combining conditions in 1995, the yields were generally below 20 dt ha^{-1}. Across both years, the genotype C4 gave the lowest (10 dt ha^{-1}), and the grain type K 432 from USA gave the highest (24 dt ha^{-1}) yield by combine. The cool and wet growth conditions in Germany 1995 did generally reduce the proportional grain production, i. e. the harvest index (Figure 4). The inverse reaction of all Russian genotypes indicates their adaptation to northern latitudes.

4. Discussion

4.1 Environmental effects

The different growth conditions of our three experiments (warm and sunny in D-1994, too dry in PL-1994, cool and wet in D-1995) represent quite a good range of environmental conditions for amaranth production in Central Europe. Thus, genotypic effects that can be generalized across these environmental conditions are relevant. In spite

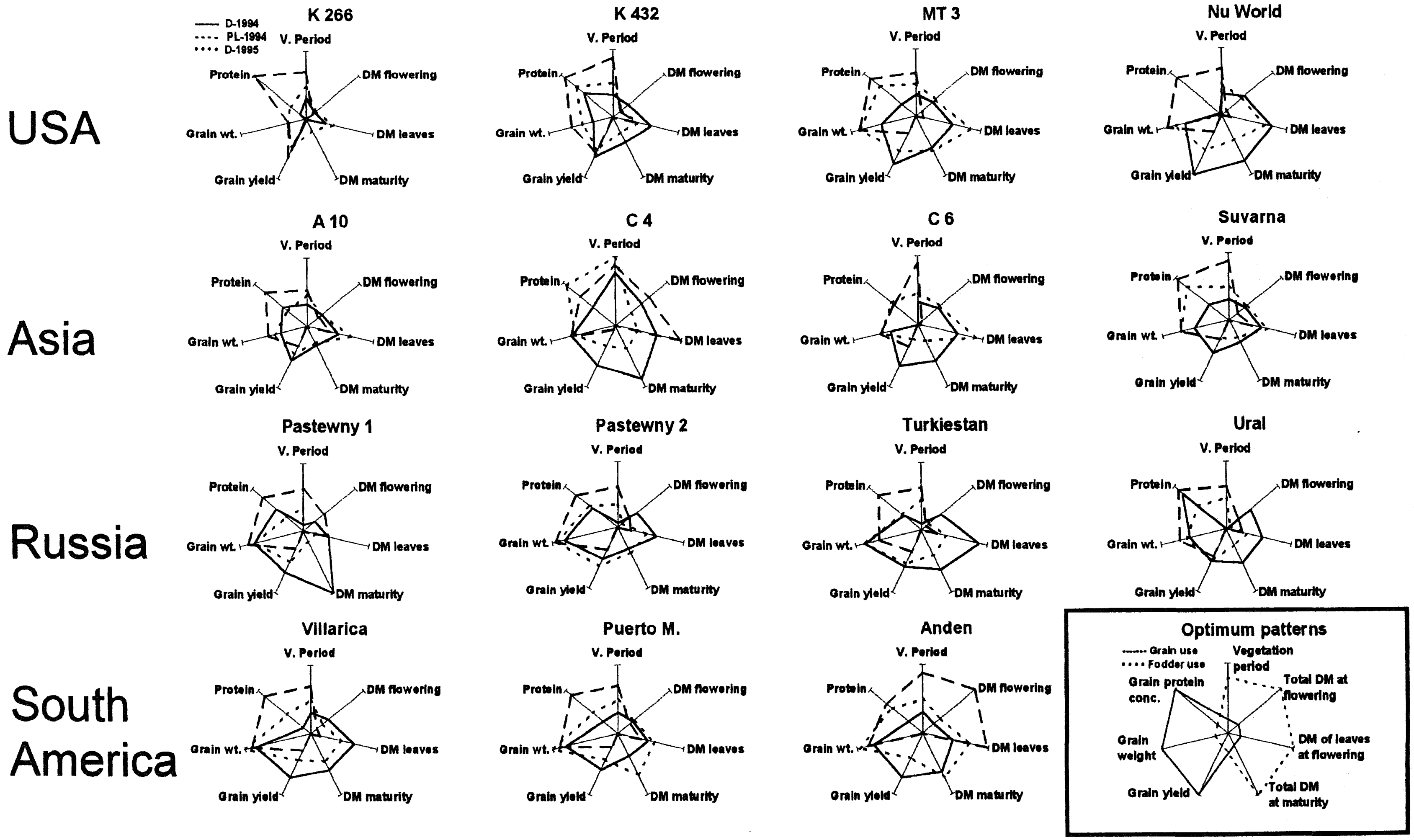

Figure 2: Star plots indicating the genotypes' suitability for grain or fodder use under different environmental conditions and a star plot with idealized optimum patterns for both utilizations

Abbildung 2: Sterndiagramme für die zusammenfassende Darstellung der Nutzbarkeit der Genotypen als Körnerfrüchte oder Futterpflanzen in Abhängigkeit von den Umweltbedingungen sowie ein Diagramm mit idealisierten optimalen Ausprägungsmustern für beide Nutzungsrichtungen

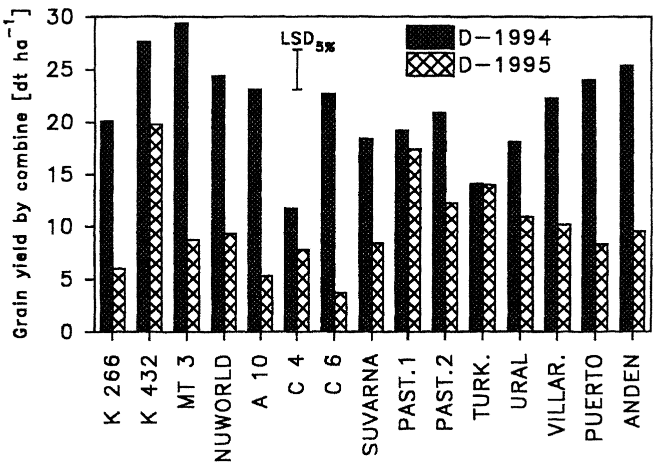

Figure 3: Grain yield results after combine harvest of different amaranth genotypes from both experiments in Germany, D-1994 and D-1995

Abbildung 3: Druschertrag verschiedener Amarant-Genotypen bei zwei Feldversuchen in Süddeutschland, D-1994 und D-1995

of the correspondence in morphological traits between all three experiments, large deviations in productivity of some genotypes in individual experiments occured, see e. g. the total DM and grain yield results of Nu World and Anden in PL-1994. They underline the fact that amaranth crops react phenotypically to different environmental conditions (AGONG and AYIECHO, 1992). On the other hand, the genotypes A 10 and C 4 from Asia and Pastewny 2 from Russia

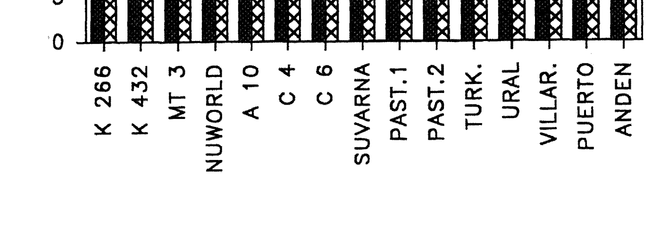

Figure 4: Harvest index of different amaranth genotypes from both experiments in Germany, D-1994 and D-1995

Abbildung 4: Ernteindex verschiedener Amarant-Genotypen bei zwei Feldversuchen in Süddeutschland, D-1994 und D-1995

reacted quite stable to different environments. Although comparatively drought tolerant (PIHA, 1995), all tested amaranth genotypes showed significantly reduced growth under the dry conditions in Poland 1994.

4.2 Suitability of genotypes

None of the tested amaranth genotypes showed an ideal pattern for grain or fodder utilization. An advantage of *A. cruentus* genotypes for grain production because of their daylength insensitivity, as reported by the NATIONAL RESEARCH COUNCIL (1984) from the USA or by DOBOS (1992) from Austria, was not evident in our experiments. The origin of amaranth genotypes was decisive for their suitability for grain and fodder use in Central Europe. The cultivars from USA generally produced high grain yields and gave, on average, the highest yields by combine. Genotypes from Asia and the large-seeded but quite tall South American genotypes would be suitable for grain, fodder and vegetable utilization. The Russian genotypes were early in development but due to the black grains suitable only for fodder use, despite their medium grain yields. They performed best under cool and wet conditions.

Amaranth requires temperatures above 15° C for high field emergence percentages, which allow sowing in Central Europe not earlier than May (LEE, 1995). The maximum vegetation period which we observed was more than five month (159 d). This is too long for a successful production of grain amaranth in Central Europe, but from the average period of about four month follows a harvest in the beginning of September. This would mean a harvest date similar to that of late sommer cereal crops or sunflower. All the Russian genotypes from *A. hybridus* reached grain maturity quite early.

The maximum total above ground DM and DM of leaves noticed was 1444 g m^{-2} and 301 g m^{-2}, respectively. The maximum grain yield produced was 273 g m^{-2} of grain DM and the harvest index was between 10 and 30 per cent. Amaranth reached up to 17.9 per cent protein in grains. These figures are in agreement with other reports (BRESSANI et al., 1987; LEE et al., 1994; AUFHAMMER et al., 1995). The maximum grain weight of 0.78 mg $grain^{-1}$ was low in comparison to results from WEBER et al. (1990) who found a range of 0.7–0.9 mg $grain^{-1}$. For the selection of genotypes for grain amaranth production on a farm scale, it has to be considered that the correlation between the grain yield produced and that combined were only small. The coefficients of correlation were r = 0.24 in 1994 and r = 0.30 in 1995. In 1994 the differences between the grain yield produced and that combined, i. e. grain losses before and during combining, were negligible due to optimum combining conditions, while in 1995 28 g m^{-2} of grain were lost on average. LEE et al. (1994) found from two years experiments with two genotypes much higher losses of about 100 g m^{-2}.

5. Conclusions

The observed reaction patterns of the amaranth genotypes, as well as the morphological characters, were more depending from the origin than from the botanical species. From our results, the cultivar K 432 from USA could be recommended for grain production due to a high and stable grain yield, produced as well as combined. In previous experiments, this cultivar had also shown a very efficient nitrogen translocation into the grains, i. e. a high N harvest index (AUFHAMMER et al., 1995). The Russian genotypes, especially Pastewny 1, were also quite productive but black-seeded. They should be used for cross-breeding programmes. For a fodder or vegetable utilization at early developmental stages the Asian genotype C 4 and the South American genotype Anden seem to be favourable due to a high total above ground DM yield with much leaves. The Russian genotypes Turkiestan and Ural could be used for whole-crop silage at grain maturity with medium DM yield but high nutrient concentration due to high grain percentages in the fodder.

References

AGONG, S. G. and P. O. AYIECHO (1992): Regression and correlation analysis in grain amaranth (*A. hypochondriacus* and *A. cruentus*). Indian J. agric. Sci., 62, 822–826.

AUFHAMMER, W., H.-P. KAUL, P. HERZ, E. NALBORCZYK, A. DALBIAK and M. GONTARCZYK (1995): Grain yield formation and nitrogen uptake of amaranth. Eur. J. Agron., 4 (3), 379–386.

AUFHAMMER, W., H.-P. KAUL, M. KRUSE, J. H. LEE and D. SCHWESIG (1994): Effects of sowing depth and soil conditions on seedling emergence of amaranth and quinoa. Eur. J. Agron., 3 (3), 205–210.

BRESSANI, R., J. M. GONZALES, J. ZUNIGA, M. BREUNER and L. G. ELIAS (1987):Yield, selected chemical composition and nutritive value of 14 selections of amaranth grain representing four species. J. Sci. Food Agric., 38, 343–356.

DOBOS, G. (1992): Körneramaranth als neue Kulturpflanze in Österreich – Introduktion und züchterische Aspekte. Diss. Universität für Bodenkultur, Wien.

GREGOROVA, H. (1994): Nutritive value of Amaranthus during ontogenesis. Proc. 2nd Int. Conf. Amaranth, Olmouc, 12.

LEE, J. H. (1995): Ertrag und Kornqualität der Pseudogetreidearten Buchweizen *(Fagopyrum esculentum* Moench), Reismelde *(Chenopodium quinoa* Willd.) und Amarant *(Amaranthus hypochondriacus* L. x *A. hybridus* L.) im Vergleich zur Getreideart Hafer *(Avena sativa* L.) in Abhängigkeit vom Anbauverfahren. Diss., Universität Hohenheim.

LEE, J. H., W. AUFHAMMER and E. KÜBLER (1994): Yield Potential and grain quality of alternative grain crops (oats, buckwheat, quinoa, amaranth). Proc. 3rd ESA Congress, Padua, 716–717.

NALBORCZYK, E. (1994): Amaranth in Poland. Proc. 2nd Int. Conf. Amaranth, Olmouc, 8.

NATIONAL RESEARCH COUNCIL (1984): Amaranth: Modern prospects for an ancient crop. National Academy Press, Washington, D. C.

PIHA, M. I. (1995): Yield potential, fertility requirements, and drought tolerance of grain amaranth compared with maize under Zimbabwean conditions. Trop. Agric. (Trinidad), 72 (1), 7–12.

SAS INSTITUTE INC. (1987): SAS/STAT Guide for Personal Computers, Version 6 Edition. SAS Institute Inc., Cary, USA.

SAUNDERS, R. M. and R. BECKER (1984): *Amaranthus*: A potential food and feed resource. Adv. Cereal Sci. Technol., 6, 357–396.

WEBER, L. E., W. W. APPLEGATE, D. D. BALTENSPERGER, M. D. IRWIN, J. W. LEHMANN and D. H. PUTNAM (1990): Amaranth grain production guide. Rodale Res. Center and American Amaranth Inst., Bricelyn.

WEGERLE, N. and F. J. ZELLER (1995): Körner-Amarant, (*Amaranthus* spp.): Anbau, Züchtung und Werteigenschaften einer alten Indio-Pflanze. J. Agron. Crop Sci., 174, 63–72.

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