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VARIABILITY, HERITABILITY AND CLASSIFICATION OF *AMARANTHUS* L. GENOTYPES BY CHIERARCHICAL ANALYSIS

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ABSTRACT

Ten amaranth genotypes were studied during a three year experiment. The object of this study was to evaluate variability and heritability of productive traits (such as total grain yield), as well as to classify the genotypes using chierarchical analysis UPMG. The aim of this study was to determine initial breeding material for future selection programmes of amaranth. The obtained data expressed significant variability in total leaf mass per plant ranging from 94.05 g (genotype 3 – *A. molleros*) to 246.81 g (genotype 1 – *A. mantegazzianus*), grain yield per plant ranging from 45.56 g (genotype 3 – *A. molleros*) to 67.55 g (genotype 1 – *A. mantegazzianus*), as well as total grain yield ranging from 2 220 kg ha^{-1} (genotype 3 – *A. molleros*) to 3 200 kg ha^{-1} (genotype 1 – *A. mantegazzianus*). Relatedness among the genotypes and their divergence were established by chierarchical cluster analysis which provided the foundation for further selection of individual amaranth genotypes and breeding programmes. These results will be helpfull for establishing new breeding programmes, especially intra-species hybridisation of genotypes 5 – *A. cruentus* and 10 – *A cruentus*; inter-species hybridisation should be between the genotypes 1 – *A. mantegazzianus* and 3 – *A. molleros*.

Key words: amaranth, variability, heritability, cluster analysis

INTRODUCTION

Amaranth species have become interesting to the researchers of non-traditional agricultural plants due to their unique properties. They are potentially important sourse of bioactive chemicals used in food and pharmaceutical industries. Archeologicas studies (Covas, 1994) of *Amarantus caudatus* seeds have confirmed that this plant came from America where it was one of the staple foods in the Inca and Aztec civilisations during the fifteenth century. The importance of amaranth in these societies is best represented by the fact that taxes were collected in amaranth seed instead of gold. Arrival of Spanish conquistadors meant that amaranth, together with the other local culivated plants, was subsequently replaced by European cereals and, as a result, almost completely vanished from agricultural practice (Gins et al., 1997). The revival of amaranth species began during the eithies in the last century when the first research was conducted. The research was initiated by the National Academy of Science in The USA, and, thus, the ancient species were rediscovered. Their nutritional value and productivity were reaffirmed; amaranth species have been the object of various studies in The USA (Wietmeyer, 1983), Mexico, Equador, Argentina (and other countries in South America), Russia, China and elsewhere around the world.

According to Saunders and Becker (1984) amaranth plants contain high quality proteins, starch, pectine, lipids and other active compounds which can be beneficial as nutrients or food supplements. Public health and general wellfare in any country depend on sufficient amount of good quality food based on proteins (Makobo et al., 2010; Nana et al., 2012). Adeyeye and Omolayo (2011) showed that protein content in *A. hibridus* leaves varied from 17.2 to 34.8 (g/100 g). Vracev (1997) emphasized that *A. caudatus*,

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A. cruentus and *A. mantegazzianus* Passer, according to the results of breeding programmes, proved to be of the highest nutritive value. Nowdays, amaranth is considered to be one of the ten novel cultivated species in the 21st century (Midler, 2003). Besides its nutritive value, it is also used as a natural source of red food coloring (Pasko et al., 2011). Bodroza-Solarov et al. (2003) suggested that amaranth should be a part of daily dietary regimes due to its high lysine content and others beneficial properties.

The results of He and Corke (2003) showed that, in 104 genotypes from thirty species, mean total oil (fat) content was 5% ranging from 1.9% to 8.7%. Many species from genus *Amaranthus* L. expressed beneficial nutritive and medicinal properties. It was recorded that amaranth biomass was rich not only in high-lysine, easily digested proteins, but also in other active ingredients and minerals which further enhance its nutritive value (Saunders-Becker, 1984). Kolesnikov and Gins (1997) studied *A. cruentus* and *A. tricolor* genotypes. They concluded that regarding their medicinal properties amaranth plants were similar to mint. Tender amaranth leaves had low ashes and cellulose content, but were relatively rich in proteins, pectin and flavonoids, similar to well established medicinal herbs. Moreover, *Amaranthus L.* plants produce high grain yield associated with low cost processing. Therefore, they can be easily introduced to regions without previous history of amaranth cultivation. Cultivated *Amaranthus* L. are conditionally categorised as: grains/cereals *(A. cruentus, A. caudatus, A. hypochondriacus, A. mantegazzianus, A. paniculatus)*, vegetables *(A. tricolor, A. cruentus, A. spinosus, A. graecizans)*, forage crops, medicinal herbs and decorative plants *(A. caudatus, A. hybridus A. hypochondriacus, A. molieros* i *A. paniculatus).* Regarding the exact number of *Amaranthus* L.species in Europe, there are different findings. *Prodromus Florae Peninsulae Balcanicae* reported 9 species (Hayek, 1927**),** *Flora Europaea* 12, while, according to Med-Checklist, there are 21 species including the Mediterranean countries which are not in Europe (Greuter et al., 1984). *Amaranthus* L. species belong to the subfamily of *Amaranthoidae,* family of *Amaranthaceae* (order *Caryophyllales),* which contains approximately 60 to 90 widely spread herbaceous plants, rarely low shrubs, while trees are found only in the tropical regions.

The object of this study was to determine variability and heritability of: leaf mass per plant, grain weight per plant and total grain yield. Another objective was to classify amaranth genotypes using chierarchical cluster analysis. Results obtained in this research were used to define initial breeding material for further selection programmes. Divergent genotypes could be used as parents in subsequent hybridisations.

MATERIAL AND METHODS

The study included 10 amaranth genotypes of which the genotype 1 belongs to *A. mantegazzianus*, the genotypes 2 and 4 belong to *A. caudatus*, the genotype 3 belongs to *A. molleros,* and the genotypes 5 to 10 belong to *A. cruentus.* Material (local populations) used in these studies was introduced from Russia, St. Petersburg, All-Russian Scientific Research Institute (VIR) Russian Academy of Agricultural Sciences. The field trial was set according to random block design in 4 replications in the experimental field Beli Potok, Republic Serbia. Basic plot area was 10.5 m^2 (2.1 m x 5 m). The one treatment (70 cm x 30 cm) as well as plant density were planned according to the standards of the national cultivar recognition authority. The parameters of variability in the traits studied were: mean value ($\bar{x}$), standard deviation (S) and coefficient of variation (Cv %).

Mean sample value $\bar{x} = \frac{\Sigma\, xi}{N}$

Standard deviation $S = \sqrt{\frac{\Sigma\, (x - \bar{x})^2}{N - 1}}$

Coefficient of variation $Cv = \frac{S \text{ x } 100}{\bar{x}}$

The two-factorial analysis of variance of multiple-year trials was completed for all the traits studied (Hadzivukovic, 1991). The two-

factorial analysis of variance was used to estimate components of genetic and phenotypic variance.

$\delta^2 g = (MS_4 - MS_2) / bG$

$\delta^2 gG = (MS_2 - MS_1) / b$

$\delta^2 f = \delta^2 g + \delta^2 g\, G/G + \delta^2 p/bG$

$\delta^2 g$ – genetic variance;

$\delta^2 f$ – phenotypic variance;

$\delta^2 gG$ – interraction genotype x year variance;

$\delta^2 p$ – error variance;

MS_4 – genotype mean square;

MS_2 – genotype x year mean square;

MS_1 – error mean square;

b – replications;

G – year.

Coefficient of heritability can be used to estimate the probability of obtaining similar or identical progeny :

$$h^2 = \frac{\delta^2 g}{\delta^2 f} \cdot 100$$

In order to construct a dendrogram, the method of average connection *UPGMA* (*Unweighted pair-group method, arithmetic average*) was used. This method (Ward, 1963) starts from similarity index matrix (*D*1) among all studied genotypes (*n*), therefore form *n* to *n*. Determination of the cluster and the graphical representation of dendrogram in this study were performed by using Windows SPSS, the option Agglomeration schedule using the Between-groups linkage and interval measures of Euclidiean Squared distance.

ENVIRONMENTAL CONDITIONS FOR THE RESEARCH PERIOD

Meteorological data were obtained from the National meteorological institute for the region representative for the experimental field of Beli Potok, south-east Serbia (the country of arable land), where the conducted tests of the ten amaranth genotypes were performed. We presented the meteorological data for the period from May-September for all three years of study (Table 1). This period includes the annual development cycle of amaranth.

Table 1. Meteorological data

Month	Absolute air temperature (^{0}C)			Extremes temperatures (^{0}C)				Hyumidity (%)		Insolation (h)	Precipitation (mm)
	max	min	medium	max	day	min	day	max	min		
Meteorological data for the first year											
V	24.0	11.7	17.7	32.6	19	6.3	24	67	24	226.2	94.0
VI	28.2	13.0	21.0	33.4	22	5.7	15	58	19	336.8	8.4
VII	29.7	13.4	22.1	38.4	8	7.2	12	50	15	331.6	20.8
VIII	29.3	15.7	21.9	34.7	3	11	22	64	22	255.8	25.4
IX	19.5	10.5	14.0	28.4	1	4	18	79	23	110.3	186.0
Meteorological data for the second year											
V	24.0	8.9	16.4	31.6	21	4.1	10	59	17	233.8	75.2
VI	27.8	13.4	20.9	35.4	23	7.6	2	61	20	271.1	22.5
VII	27.6	14.4	20.8	37.6	5	11.2	3	64	16	255.6	62.5
VIII	26.3	13.2	19.2	32.4	29	7.5	22	72	24	214.4	64.4
IX	23.0	8.1	14.8	30.3	13	1.8	29	72	21	236.1	28.7
Meteorological data for the third year											
V	21.6	10.3	15.6	27.3	31	3.6	24	74	30	139.5	74.8
VI	28.3	13.9	21.1	34.0	30	8.8	20	69	30	302.3	55.7
VII	29.9	14.6	22.2	38.2	2	7.4	10	68	27	319.0	70.3
VIII	30.3	15.0	22.3	37.4	3	9.0	27	65	25	293.5	96.2
IX	22.1	11.0	15.9	30.9	12	6.0	16	80	34	139.0	114.1

RESULTS AND DISCUSSION

The mean leaf mass varied from 94.0 g (genotype 3 – *A. molleros*) to 246.81g (genotye 1 – *A. mantegazzianus*). High temperatures and arid growth conditions (Year 1) cause amaranth plants to increase their biomass (Grubben, 1979), (Table 4). The highest mean value of leaf mass in all years of trial respectivelly was recorded in Genotype 1 – *A. mantegazzianus* (340.50 g in Year 1; 237.6 g in Year 2; 162.34 g in Year 3). The lowest mean value of the same trait was recorded in Genotype 3 – *A. molleros* (115.61 g in Year 1; 95.63 g in Year 2; 70.92 g in Year 3). Interval of variation ranged from 91.42 g (Year 1) to 204.83 g (Year 3). Maximal standard deviation (60.40%) was recorded in Year 1, while considerably lower value of the same parameter (24.01%) was observed in Year 3. Variability of all the genotypes respectively in all years of trial showed that Genotype 3 varied the least (18.27%); the highest value of the same parameter was observed in Genotype 1 (72.07%) – the least variation was noticed in *A. molleros*, while the largest variation was recorded in *A. mantegazzianus*. Coefficient of variation for all studied genotypes in Year 1 was 31.18%, 28.26% in Year 2 and 24.71% in Year 3 (Table 2). Average leaf mass per plant, according to Kononkov (1997), in Podmoskovlje region varied from 92 g to 366 g in *A. caudatus*; from 222 g to 654 g in *A. tricolor*; approximately 220 g in *A. cruentus*. Formation of larger biomass is caused by a specific mechanism of photosynthetic assimilation of CO_2 (Tchernov, 1996). According to Tchernov (1992), high biomass productivity is based on specific metabolic pathways of both Carbon and Nitrogen, thus causing morphological, physiological and biochemical peculiarity of amaranth.

Table 2. Mean value (x) (g), standard deviation (S) and coefficients of variation (Cv %) in leaf mass per plant for the ten genotypes of amaranth during three years

Genotype	Year 1	Year 2	Year 3	$\bar{X}$ (g)	Cv (%)
	$\bar{x}$ (g)	$\bar{x}$ (g)	$\bar{x}$ (g)		
A.mantegazzianus (Genotype 1)	340.50	237.60	162.34	246.81	72.02
A. caudatus (Genotype 2)	249.37	166.47	107.45	174.43	58.21
A. caudatus (Genotype 4)	219.44	170.52	104.62	164.86	47.04
A. molleros (Genotype 3)	115.61	95.63	70.92	94.05	18.27
A. cruentus (Genotype 5)	180.43	160.31	82.94	141.22	42.02
A. cruentus (Genotype 6)	183.94	131.94	94.74	136.87	36.58
A. cruentus (Genotype 7)	184.78	123.46	91.70	133.31	38.63
A. cruentus (Genotype 8)	159.88	119.54	90.36	123.26	28.07
A. cruentus (Genotype 9)	156,36	121,54	85,72	121,20	28,83
A. cruentus (Genotype10)	146.87	99.15	81.14	109.05	27.73
I.V.	224.89	141.97	91.42	-	-
S	60.40	40.29	24.01	-	-
Cv (%)	3118	28.26	24.71	-	-
LSD	0.05	22.375			
	0.01	29.672			

The data in Table 3, as well as mean squares in the analysis of variance indicated that the variability of the number of leaves per plant was significantly influenced by genotype, year and the interaction genotype x year. It is worth mentioning that leaves of cultivated species *A. cruentus, A. dibius, A. tricolor* and *A. blitum* are part of human diet (Daloz, 1979). In their research of *A. cruentus* and *A. tricolor*, Kolesnikov and Gins (1997) came to a conclusion that amaranth was similar to mint. Tender amaranth leaves had low ashes and cellulose content, but were relatively rich in proteins, pectin and flavonoids, similar to most of well established medicinal herbs. Akubugwo et al. (2008) concluded that leaves of *A. hybridus* contained significant amounts of nutrients, vitamins, minerals, amino acids and phytochemicals.

Table 3. Mean Squares (MS) from ANOVA of the number of leaves, grain weight and grain yield in ten amaranth genotypes

Source of variation	Degrees of freedom (df)	MS No. leaves/plant	MS Grain weight/plant	MS Yield/plant
Replications	3	0.42	141.33	0.34
Year (A)	2	653.74**	8609.43**	20.67**
Genotype (B)	9	172.80**	419.29**	1.01**
Inter. (A x B)	18	6.84**	52.43	0.12
Error	87	0.85	78.58	0.19

The average grain weight per plant in three years of study varied from 45.56 g to 67.55 g (Table 4). The genotypes with the lowest mean values of this trait were Genotype 3 (56.95 g, Year 1; 41.40 g, Year 2) and Genotype 4 (38.04 g, Year 1) which means *A. molleros* and *A. caudatus*. The highest mean value in all three years showed Genotype 1, of *A. mantegazzianus* (82.02 g Year 1; 69.10 g, Year 2; 51.53 g, Year 3). The interval of variation for this trait ranged from 13.49 g (Year 3) to 25.07 g (Year 1). Analyzing variability in all three years of trials within the studied genotypes, one can conclude that Genotype 8 varied the most (15.39%), while Genotype 3 varied the leas (8.14%) (Table 4). Variability among the genotypes in Year 1 was 13.75%; 9.95% in Year 2 and 8.64% in Year 3. Higher degree of variability was noted in *A. cruentus,* lower degree of variability in *A. mantegazzianus.* Research in morpho-biochemical properties in *A. cruentus, A. caudatus* and *A. lividus* indicated that grain weight per plant varied from 16.3 g to 32.8 g (Jeleznikov, 1996). Grain weight per plant is highly dependent on plant density per unit of area – direct influence on total grain yield.

Mean squares of the ANOVA components confirmed highly significant variability among the genotypes and years. In contrast, there was no significant difference in case of Genotype x Year interaction (Table 3).

Grain yield is a cultivar property, but considerably dependent on growing conditions, cultivation system and agricultural practice. Mean values of total grain yield in three years of trials ranged from 2,220 kg ha^{-1} to 3,300 kg ha^{-1}. The lowest mean yield in year 1 was noted in Genotype 3 (2,790 kg ha^{-1}) of *A. molleros*.

During Year 2, the lowes mean yield was recorded in the same genotype of *A. molleros* (2,020 kg ha^{-1}). Genotype 4 of *A. caudatus* had the lowest grain yield during Year 3 (1,860 kg ha^{-1}). In the three years of trials, the highest mean yield per hectare was observed in Genotype 1 of *A. mantegazzianus* 3,300 kg ha^{-1} (Table 5). Variability within studied genotypes in three years of trials showed that Genotype 8 (*A. cruentus*) varied the least (0.75%), while Genotype 3 of *A. molleros* and Genotype 10 of *A. cruentus* varied the most (0.48%). Variability among the genotypes in Year 1 was 9.87%, 13.68% in Year 2 and 8.59% in Year 3 (Table 5).

Table 4. Mean value ($\bar{x}$) (g), standard deviation (S) and coefficient of variation (Cv) (%) of grain weight per plant in the ten genotypes during three years of trials

Genotype	Year 1 $\bar{x}$ (g)	Year 2 $\bar{x}$ (g)	Year 3 $\bar{x}$ (g)	$\bar{X}$ (g)	Cv (%)
A. mantegazzianus (Genotype 1)	82.02	69.10	51.53	67.55	12.49
A. caudatus (Genotype 2)	66.92	47.60	41.03	51.85	10.58
A. caudatus (Genotype 4)	66.06	46.81	38.04	50.30	11.70
A. molleros (Genotype 3)	56.95	41.40	38.35	45.56	8.14
A. cruentus (Genotype 5)	78.77	58.51	43.90	60.39	14.29
A. cruentus (Genotype 6)	70.42	57.92	41.13	56.49	12.00
A. cruentus (Genotype 7)	75.00	55.74	39.90	56.88	14.35
A. cruentus (Genotype 8)	78.77	49.41	43.58	57.25	15.39
A. cruentus (Genotype 9)	72.25	53.14	43.42	56.27	11.97
A. cruentus (Genotype 10)	67.77	53.71	43.63	55.03	9.89
I.V.	25.07	27.70	13.49	-	-
S	7.11	7.31	3.66	-	-
Cv (%)	9.95	13.72	8.64	-	-
LSD	0.05	7.20			
LSD	0.01	9.50			

Table 5. Mean value (x) (kg ha^{-1}), standard deviation (S) and coefficients of variation (Cv) (%) for total grain yield in the ten amaranth genotypes during three years of trials

Genotype	Year 1 $\bar{x}$ (kg ha^{-1})	Year 2 $\bar{x}$ (kg ha^{-1})	Year 3 $\bar{x}$ (kg ha^{-1})	$\bar{X}$ (kg ha^{-1})	Cv (%)
A. mantegazzianus (Genotype 1)	4,020	3,380	2,520	3,300	0.61
A. caudatus (Genotype 2)	3,300	2,330	2,010	2,540	0.54
A. caudatus (Genotype 4)	3,230	2,290	1,860	2,460	0.57
A. molleros (Genotype 3)	2,790	2,020	1,870	2,220	0.48
A. cruentus (Genotype 5)	3,850	2,860	2,110	2,940	0.71
A. cruentus (Genotype 6)	3,450	2,830	2,010	2,760	0.57
A. cruentus (Genotype 7)	3,670	2,760	1,950	2,790	0.70
A. cruentus (Genotype 8)	3,860	2,420	2,130	2,800	0.75
A. cruentus (Genotype 9)	3,540	2,600	2,120	2,750	0.58
A. cruentus (Genotype 10)	3,320	2,630	2,130	2,690	0.48
I.V.	1.23	1.36	0.66	-	-
S	0.34	0.35	0.17	-	-
Cv (%)	9.87	13.68	8.59	-	-
LSD	0.05	0.505			
LSD	0.01	0.670			

Tchernov (1996) found in his research that high values of total grain and leaf production occur due to certain mechanisms of photosynthetic assimilation of CO_2. Average grain yield is different in different countries: in California it varies from 90 kg ha^{-1} to 1,670 kg ha^{-1}, in Portorico from 470 kg ha^{-1} to 1,930 kg ha^{-1}, in Sweden from 111 kg ha^{-1} to 1,920 kg ha^{-1}. In recent years, the average grain yield has exceeded 2,000 kg ha^{-1} due to improved cultivation and advanced technology it has further increased to 3,000-6,000 kg ha^{-1} (Kononkov et al., 1997).

The ANOVA results confirmed variability in total grain production; mean square values showed that there was highly significant difference among the genotypes and years, respectively. However, Genotype x Year interaction did not cause any significant effects (Table 3). Genetic divergence of amaranth genotypes are essential for further breeding programmes. Variability of quantitative traits is conditioned by both genetic and environmental factors. However, the share of these components in total variability was different in different traits. Phenotypic variance for the traits studied showed that in the majority of those traits (leaf mass per plant, grain weight per plant) genetic control prevailed, while influence of the environment was not very strong (Table 6). This fact was emphasised by the share of the genetic variance in the total phenotypic variance (leaf mass 1768.49 from 1911.91; grain weight per plant 30.57 from 35.49; total grain yield 0.07 from 0.08) (Table 6). In case of all morphological traits, estimated values of genetic variance were considerably higher than environmental variance (Table 6). Broad sense heritability varied from 86% (grain weight per plant) to 92% (leaf mass per plant); this parameter indicated strong influence of the genotype on variability. In all studied traits there was a small difference between genetic and phenotypic coefficient of variation which further confirmed that the expression of those traits was under stronger infuence of genetic factor (Table 6). The lowest genetic coefficient of variation was 9.69 % (total grain production), while the highest one was 29.48% (leaf mass per plant); phenotypic coefficient of variation ranged from 10.36 % (total grain production) to 31% (leaf mass per plant).

Table 6. Genetic (δ^2 g), environmental (δ^2 e) and phenotypic (δ^2 f) variance; coefficients of genetic (GCV) and phenotypic (PCV) and heritability (h^2) of amaranth traits

Traits	δ^2 g	δ^2 e	δ^2 f	h^2 (%)	GCV (%)	PCV (%)
Leaf mass per plant	1768.49	143.42	1911.91	92	29.48	31
Grain weight per plant	30.57	4.92	35.49	86	9.91	10.68
Total grain yield	0.07	0.01	0.08	87.50	9.69	10.36

Dendrogram of phenotypic differences of the ten amaranth genotypes and their productive traits was divided in four clusters (Figure 1). Genotypes within certain groups were joined in different ways which indicated presence of hierarchical levels. The first cluster contained only Genotype 1 of *A. mantegazzianus.* And it had the top level of hierarchy, consequently, the biggest grain production (3.3 t ha^{-1}). The second cluster contained Genotype 2 and Genotype 4, both of the *A. caudatus.* Both genotypes were at the same level of hierarchy which means that they are not very different (grain weight per plant in Genotype 2 was 51.85 g and 50.30 g in Genotype 4; leaf mass per plant in Genotype 2 was 174.13 g and 164.86 g in Genotype 4). The majority of the genotypes (six of them) were in the third cluster. The third cluster was further divided in two subsets. Genotypes 5, 6, 7, 8 and 9 were in the first subset of the third cluster, while Genotype 10 was separate in the second subset. Within the first subset the most similar

and, in the same time, the most closely related were Genotype 8 and Genotype 9 (total grain yield of Genotype 8 was 2,800 kg ha^{-1} and 2,750 kg ha^{-1} in Genotype 9). Remaining genotypes (except Genotype 10) formed the rest of the subset at the same level of hierarchy. Genotype 10 belonged to the second subset with the lowest total grain yield (2,690 kg ha^{-1}) compared to the rest of the third cluster genotypes. All third cluster genotypes were of the *A. cruentus*. The fourth cluster contained only Genotype 3 of *A. molleros* and had the lowest total grain yield (2,220 kg ha^{-1}). The results of Lahmann et al. (1991) indicate that interhybridisation is a promissing way to increase the biomass: interspecies crossing between *A. cruentus* and *A. hypochondriacus.* provides significant heterosis in respect of biomass and it is possible, indirectly, to increase production of grain.

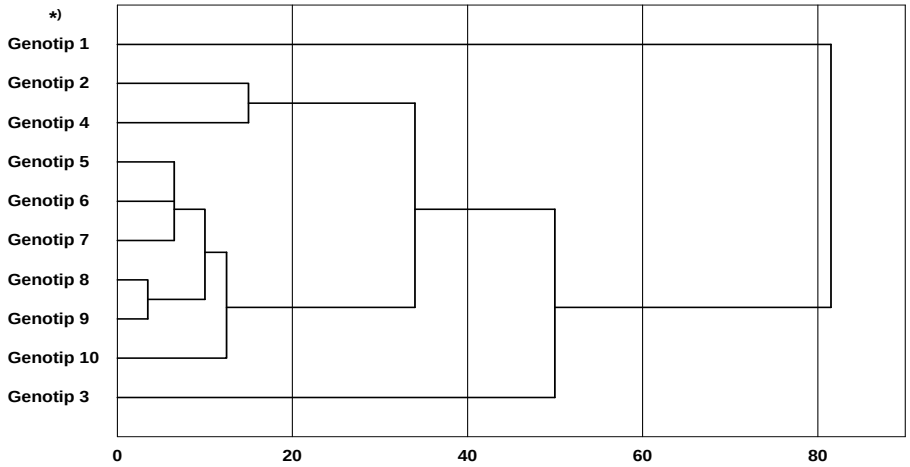

Figure 1. Dendrogram constructed according to UPGMA cluster analysis of genetic distances of ten amarantus genotypes

*) Species *A. mantegazzianus* contains Genotype 1;
Species *A. caudatus* contains Genotypes 2 and 4;
Species *A. molleros* contains Genotype 3;
Species *A. cruentus* contains Genotypes 5, 6, 7, 8, 9 and 10.

CONCLUSIONS

Results of this study may be helpful to amaranth breeding programs. Amaranth plants contain high quality proteins, starch, pectine, lipids and other active compounds which can be beneficial as nutrients or food supplements.

There was significant divergence in productive traits: leaf mass per plant, varying from 94.05 g (Genotype 3 – *A. molleros*) to 246.81 g (Genotype 1 – *A. mantegazzianus*); grain weight per plant, varying from 45.56 g (Genotype 3 – *A. molleros*) to 67.55 g (Genotype 1 – *A. mantegazzianus*); total grain yield, varying from 2,220 kg ha^{-1} (Genotype 3 – *A. molleros*) to 3,200 kg ha^{-1} (Genotype 1 – *A. mantegazzianus*). High degree of heritability was estimated in leaf mass per plant, grain weight per plant and total grain yield which led to a conclusion that successful breeding for those traits was achievable. This was further confirmed by the fact that variability of those traits was to a great extent controlled by the genetic factor: the influence of the genetic variance was decisive in determination of phenotypes. The dendrogram obtained in this study confirmed significant genetic divergence. The diversity of these genotypes could indicate presence of considerable heterogeneity in examined collection of amaranth genotypes. Genotypes from different groups represent a solid base for further breeding programs of amaranth. Parental choices will, of course, depend on a projected model, but general recommendation is to choose distant genotypes as prospective parents. In intra-species hybridizations one should use Genotype 5 – *A. cruentus* and Genotype 10 – *A. cruentus*; inter-species hybridizations should be best performed using Genotype 1 – *A. mantegazzianus* and Genotype 3 – *A. molleros*.

The results of this research confirmed that amaranth was a highly productive plant, both in respect of leaf mass and grain yield. These ten amaranth genotypes represent a solid foundation for further selection projects/programs

REFERENCES

Akubugwo, I.E., Obasi, N.A., Chinyere, G.C., Ugbogu, A.E., 2008. *Mineral and phytochemical contents in leaves of Amaranthus hybridus L and Solanum nigrum L. subjected to different processing methods.* African Journal of Biochemistry Research, 2 (2): 40-44.

Adeyeye, E.I., Omolayo, F.O., 2011. *Chemical composition and functional properties of leaf protein concentrates of Amaranthus hybridus and Telfairia occidentalis*. Agric. Biol. J. N. Am., 2: 499-511.

Bodroza-Solarov, M., Mastilovic, J., Kevresan, Z., Filipcev, B., Torbica, A., 2003. *Seed of Amarantus cruentus as breakfast cereal and snack product.* In: Proceedings of the 7th International Symposium Interdisciplinary Regional Research, Hunedora, Romania: 157-160.

Covas, G., 1994. *Perspectivas del cultivo de los amarantos en la Republica Argentina*. Estacion Experimwntal Agropecuaria, Angeuil, Instituto Nacional de Technologia Agropecuaria, 13: 1-10.

Kolesnikov, M.P., Gins, V.K., 1997. *Biochemical and chemical composition of amaranth and some herbs. Second international symposium. New and innovative plants and prospects of their practical use*. Pushcino. Russian: 20-21.

Kononkov, P.F., Gins, V.K., Gins, N.S., 1997. *Amarant - promising plant XXI century*. Publisher home Evgenia Fedorova, Moscow, Russian: 160-176.

Daloz, C., 1979. *Amaranth as a leaf Vegetable Horticultural Observation in a temperature climate.* Proceedings of the Second Amaranth Conference, Rodale Press: 68-74.

Greuter, W., Burdet, H.M., Long, G., 1984. Med-Checklist 1. Berlin Dehlem, Geneve.

Gins, V.K., Kononkov, P.F., Chernjadev, I.I., Gins, M.S., Strukova, M.V., 1997. *Photosynthesis and growth of green and ornamental species of amaranth in the initial stages of ontogenesis.* Applied biochemistry and microbiology. Moscow, Russian, 2: 230-236.

Hayek, A., 1927. *Amaranthus L.* Prodromus Florae Peninsulae Balcnicae 1, Berlin-Dehlem: 160-162.

He, H.P., Corke, H., 2003. *Oil and squalene in amaranthus grain and leaf.* J. Agric. Food Chem., 51: 7913-7920.

Hadzivukovic, S., 1991. *Statistical methods the application in agricultural and biological research*. Institute of Agricultural Economics and Rural Sociology, Novi Sad, Serbia.

Zheleznov, A.V., Zheleznova, N.B., Burmakina, N.V., Kidlo, L.A., 1997. *Materials for understanding mating system Amaranta.* Second international symposium. New and innovative plants and prospects of their practical use: 89-92.

Midler, E., 2003. *Food as medicine*, Familet, Beograd: 326-328.

Makobo, N.D, Shoko, M.D., Mtaita, T.A., 2010. *Nutrient content of amaranth Amaranthus cruentus L. under different processing and preservation methods*. World J. Agric. Sci., 6: 639-643.

Nana, F.W., Hilou, A., Millogo, J.F., Nacoulma, O.G., 2012. *Phytochemical composition, antioxidant and xanthine oxidase inhibitory activities of Amaranthus cruentus L. and Amaranthus hybridus L. extracts*. Pharmaceuticals, 5: 613-628.

Pasko, P. H., Barton, P., Zagrodzki, P. and Gorinstein, S., 2011. *Effect of amaranth seeds Amaranthus cruentus in the diet on some biochemical parameters and essential trace elements in blood of high fructose-fed rats.* Nat. Prod. Res., 25: 844-849.

Saunders, R., Becker, R., 1984. *Amaranthus: a potential food and feed resourse*. Advences in cereal science and technology, 6: 357-396.

Tchernov, I.A., Plemenkova, S.F., Kulakov, A.A., 1996. *Amarantus as the source of slightly extractive and high quality protein.* Conference on Plant Proteins from European Crops. Food and Non-Food Applications: Abst., Nantes: 89.

Ward, J. H., 1963. *Hierarchical grouping to optimize an objective function*, Journal of Amer. Statist. Assoc., *58* (301): 236-244.

Wietmeyer, N.D., 1983. *Amaranth: Return of the Aztec Mystery Crop*. Yearbook for Science and the Future. Enciclopedia Britanika, Chicago.