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Investigation of amaranth cultivation and utilisation in Lithuania

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Abstract. Studies of amaranth (*Amaranthus* spp.) collections have been carried out at the Lithuanian Institute of Agriculture since 1978. During the period of 1998–2001, 13 varieties and populations of amaranth and some parameters of amaranth growing technology (sowing time, seed rate, row spacing, etc.) were investigated. The amaranth was grown in the six-course perennial grass breeding crop rotation after ploughed-in first year clover, sown after black fallow without additional fertilising and pesticides.

Preliminary amaranth growing technology was elaborated. The highest yield was produced when amaranth had been sown in the middle of May, at a seed rate of 2–4 kg ha^{-1}, with row spacings of 50 cm and thrashed dry after severe frosts (-3…-5°C). The technology needs further improvement, and it is especially necessary to investigate fertilisation of amaranth in ecological and conventional farming systems.

Three amaranth varieties – 'Raudonukai', 'Geltonukai' and 'Rausvukai' – were registered in Lithuania in 2001. It is necessary to continue selection of amaranth species and varieties best suited for local conditions and investigate possibilities for use of amaranth green material and seed for food, feed, and energy production.

Key words: amaranth, varieties, sowing time, seed rate, row spacing, chemical composition

INTRODUCTION

a. Historical review of amaranth cultivation

Expansion of worldwide co-operation results in the introduction of new plant species in Lithuania. One of the most promising species to be introduced in Lithuanian agriculture could be amaranth *(Amaranthus spp.).* This genus consists of about 60 species of plants, most of which are wild (Stallknecht & Schultz-Schaeffer, 1993). Amaranth is spread in all continents and is characterised by a good adaptability. 5 amaranth species are found in Lithuania (Vilkonis, 2001). Some of the species are found on a barren land, grown in flower-gardens as flowers, whereas *Amaranthus retroflexus* L. is a weed. Amaranth was cultivated by the Aztecs 5–7 thousand years ago. Its growing area extended from the south-west of the present USA, through Central America to Argentina. The largest area of amaranth was in Mexico around the year 1400. Later amaranth was forgotten (Putnam, 1990). In recent decades amaranth has been rediscovered, and its cultivation and breeding have been started in the continent of America and many European, Asian and African countries. In 1975 the American Institute of Amaranth was set up at Rodale Research Centre in Bricelyne (Minnesota state) where comprehensive research into amaranth is being carried out.

The Institute has accumulated over 1400 seed samples and is involved in intensive breeding of amaranth varieties (Arowhed mills, 1993).

4 groups of amaranth are currently being bred: lettuce (leaf), grain, garden and ornamental (Kauffman & Weber, 1990). In amaranth breeding the following factors are taken into account: high productivity, seed colour, stem height, earliness, stability of cenosis, seed shattering, satisfactory nutritive and utilisation properties (Weber, 1990). Due to the great variety of *Amaranthus* L. genus, taxonomic classification is rather complex.

b. Taxonomy and breeding of the amaranth

It is encumbered by the fact that various forms of amaranth readily cross, though hybrids of more distant species are often sterile. For this reason no universal botanical classification key for amaranth has been created so far, and botanists do not agree on the systematics of amaranth (Prokofyev et al., 1995). Various types of amaranth are still insufficiently investigated, and the developed varieties are imperfect (Meyers, 1996). Investigation of amaranth is also hindered by the fact that in various literature sources it is denominated differently, and its identity is most often defined between species (Breus, 1997).

In many countries the following three types of amaranth are most widely used for grain: *A. cruentus* L., *A. hypochondriacus* L. and *A. caudatus* L. (Saunders & Becker, 1984; Teutonico & Knorr, 1985). A collection including over 250 amaranth varieties and breeding lines has been accrued at the Russian Plant Production Institute (Gromov, 1995). Chemical composition of 30 amaranth species was tested at the Novosibirsk Institute of Genetics and Cytology. Their seeds contained on average 21% of crude protein and over 9% of crude fat. A very high protein heterogeneity was determined. Using the data of elecrophoretic and cytogenetic analyses, diversity of the investigated amaranths was determined, and they were divided into 7 groups. Phyllogenetic relationship was confirmed between *A. crucentus* L. and *A. hypochondriacus* L., and between *A. cruentus* L. and *A. edulis* L., a promising breeding material was developed by the methods of self-pollination and hybridisation (Zheleznov et al., 1995).

The first amaranth seed samples were obtained by the Lithuanian Institute of Agriculture from the former All-Union Plant Production Institute in 1978. Over the period of many years, more than ten amaranth seed samples originated in various countries of the world have been investigated.

The accessions were tested for herbage and seed yield, and other agronomically valuable characters. Selection of plants best suited to the local climate conditions was performed. Most of the investigated numbers of amaranth grew satisfactorily, but failed to mature seed. The obtained samples were most often populations but not homogeneous varieties. Over many years, three earliest amaranth varieties, characterised by a different seed, leaf and stem colour and some other morphological traits, have been selected and developed. They are 'Raudonukai' (growing season – 100–120 days, red leaves, black seeds), 'Geltonukai' (growing season – 120–130 days, yellowish green leaves, yellow seeds) and 'Rausvukai' (growing season – 120–150 days, reddish leaves, white seeds). Since 2001 these varieties have been included in the National Variety List.

Amaranth is attributed to the plants with C_4 type CO_2 fixation. Plants of the C_4 type are characterised by a more effective photosynthesis, more intensive nitrogen metabolism, as well as physiological and biological peculiarities of metabolic processes (Breus, 1997). Selection of amaranth was focused on seed yield rather than on seed size. Individual plants grow more than two metres in height and mature up to 50 thousand seeds, and the length of their inflorescences is more than one metre. 0.5–3.0 kg of seeds is enough to sow one hectare. Amaranth can also grow on a poorer soil, it can well withstand drought and heat and is hardly attacked by any pests. It produces a seed yield from 1 to 6 t ha^{-1}, and that of green material up to 70 t ha^{-1} (Arowhed mills, 1993; Meyers, 1996). The leaves of young amaranth plants are used as lettuce in many regions. Of all green vegetables, they contain the highest content of calcium, phosphorus and iron. The leaves also contain much protein, carotene, vitamins, and other valuable substances. The most widely grown amaranth species are *A. cruentus* L., *A. caudatus* L., etc. Their seeds differ in colour depending on the variety. The seed has the taste of nuts. It is eaten boiled, roasted, crushed, or ground. It is used for porridge production, as well as in confectionery, pasta and candy production. Amaranth is especially suited for mixing with other plants' flour (Stallknecht & Schultz-Schaeffer, 1993; Nalborczyk et al., 1994; Meyers, 1996).

The most valuable property of amaranth seeds and dry leaves is that they contain 16–18% of high quality protein. The content of lysine, the chief amino acid, in amaranth is 3–3.5 times higher than in maize, 2–2.5 times higher than in wheat. Amaranth is especially suitable for people allergic to the proteins (glutenine) of other plant species. Its seed contains about 7% of fat, which is used as raw material for the production of steroid preparations. Amaranth oil contains as much as 8% of squalen, which takes oxygen from the environment, and saturates our tissues and organs. Squalen is used for cancer treatment. Furthermore, it easily penetrates the skin and acts as immunostimulator. Amaranth oil is used for the treatment of oncological diseases, sclerosis, malfunctions of the brain and periferic blood circulation system, immunodeficient states, gynaecological, skin, stomach and liver diseases, wounds, bruises, bedsores, ulcers, vitamin deficiency, and for disease preventive purposes (Bogolyubov, 1999).

This "sacred plant" was included in the ration of NASA (USA) astronauts a long time ago. Specialists attribute amaranth to the most important plant species of the 20th century, and the USA National Science Academy mentioned it among the 36 most promising plant species in the world already in 1975 (Stallknecht & Schultz-Schaeffer , 1993).

During the panicle formation stage, amaranth green material contains about 4% of digestible protein, a sufficient amount of amino acids to livestock, and its leaf and seed protein equals to that of eggs in quality (Breus, 1997). Amaranth cultivation should be a special interest of pig producers, since when it is cut green at the beginning of panicle emergence stage, it is willingly eaten by pigs, silage can be made from pure amaranth, or mixed with other plants. Amaranth panicles are very ornamental, which makes it suitable for flower-gardens and various bouquets.

The disadvantage of amaranth is its very fine seed, which makes its sowing and thrashing difficult. There is little experimental evidence on weed control and fertilisation in amaranth crops. Some literature sources suggest that abundant nitrogen fertilisation can lead to heavy nitrate accumulation (1,100–1,400 mg kg^{-1}) in green material (Breus, 1997). Although the seed of cultivated amaranth does not have a long dormancy period, part of the shattered seeds emerge the following year and contaminate crop stands. Amaranth is very sensitive to herbicides. Furthermore, it can be grown as a monoculture.

MATERIALS AND METHODS

The experiments of 1998–2001 with the amaranth sowing and investigation of breeding nurseries were carried out at the Lithuanian Institute of Agriculture (Dotnuva) in the fields of perennial grasses' crop rotation after ploughed-up first-year clover sown into a black fallow. The soil of the experimental site is calcareous, gleyic (RDg 4-k2), medium heavy, drained with a thickness of the ploughlayer of 25–30 cm, pH_{KCl} value 6.7–7.5, humus 1.7–3.3%, total nitrogen 0.15–0.26%, mobile phosphorus and potassium 201–270 and 101–175 mg kg^{-1} soil, respectively. In spring the soil was harrowed, and before sowing it was cultivated with a Germinator and rolled. In the experiment, amaranth was sown into furrows made with a marker, with 50 x 50 cm row spacings by hand, or the hand-operated sowing machine "Senjor". Each plot consisted of a 2-row band. There was a one-meter distance between the bands. The experimental plots were sown at a seed rate of 3 kg ha^{-1}. Following the sowing, the soil was rolled. After rows of amaranth had become visible, the row spacings were loosened by a four-row rototiller, and in rows – manually. After amaranth had reached 15–20 cm, the row spacings were loosened again. In the multiplication plots, amaranth was sown with the sowing machine "Feonia". In the autumn, after severer frosts, amaranth was thrashed by the combine harvester ""Sampo 130", (for multiplication – "Sampo 500"), the seed was dried in stationary dryers, pre-cleaned by a winnower, column OPS-1 and the cleaning machine "Petkus Selectra". Pesticides were not used. The experimental data were processed by statistical methods, using the software package "Selekcija" (Tarakanovas, 1999).

In 1998 the mean air temperature of the growing season differed insignificantly from many-year average. Compared with the summers of the recent years, in 1998 it was cool and rainy. Such conditions delayed amaranth flowering and ripening. The first severe frosts (-3…-5°C) started early in October and affected amaranth leaves and seeds that had failed to ripen on the tops. The plants looked as if they had been sprayed with Reglon. This facilitated thrashing of amaranth.

In 1999 the weather conditions were very different from those in 1998. An early and warm spring was followed by late frosts and a drought in May. The summer was hot and dry, and the autumn was normal. This had an effect on amaranth growth and development. Because of the cool and dry weather, the amaranth was sown on 12 May and emerged almost in a month's time. Later, the amaranth plants developed rather fast and were less damaged by the drought compared with spring cereals. Nevertheless, late frosts in the second half of October frosted incompletely mature plants, and a lower seed yield was obtained, compared with 1998.

In 2000 the spring was very early, sunny, warm and droughty. April was unusually warm, while May was the driest month. After the drought that had lasted for more than a month there was a heavy rain (37.4 mm) on 19–20 May. In the spring of 2000 there were very great variations in the daily temperature: the air temperature used to rise to 17–22°C, and at night it used to drop to -1…-4°C. Relative air humidity was as low as 26–32%. The crust that formed after the heavy rain impeded emergence and establishment of amaranth plants, however, it was surprising that the emerged amaranth plants had not been affected by the frosts, only their growth and development had been slowed down. The summer was cool and rainy, and the autumn was changeable. The frosts that started in the middle of September lasted almost until the end of the month. The warm, sunny and dry weather that had settled in October was conducive to amaranth seed harvesting.

In 2001 the spring started at usual time. It was drier and warmer than many-year average, but changeable. In May there were a few nights when frosts up to -1°C were recorded on the soil surface. The summer was warm (1.3°C higher than the mean of many years), but the distribution of rainfall was uneven. The autumn was warm and rainy, only at the end of October there was a sharp decline in air temperatures. Amaranth plants were frost-killed, and thrashed on 7 October. The different weather conditions during the study period had an effect on amaranth growth, development, and yield.

RESULTS AND DISCUSSION

The present paper describes the results of the experiments conducted in Dotnuva. The differences between our results and those obtained in Kaunas University of Agriculture are inappreciable (Spruogis, 2000). The amaranth cv. 'Raudonukai' was mostly used in our experiments since the seed of the other varieties was of a low germination power.

Our experimental results were influenced by the dry and cool weather. The amaranth sown at all the three terms emerged almost at the same time – beginning of June. The amaranth sown early was somewhat thinner (Table 1). As amaranth growing season is longish, it should be sown as soon as possible. The last frosts occurred on 12–13 May, before amaranth emergence, therefore the effect of frost on amaranth was not investigated. However, severe frosts in 2001 had practically no damaging effect on the emerged amaranth plants.

Amaranth seeds are very small. The weight of 1,000 seeds varies from 0.7 to 1.0 g. In our trials it was 0.95 g ('Raudonukai') and 0.9 g ('Geltonukai'). So its ***sowing rate*** is very much dependent on the soil, sowing methods, locality, varietal peculiarities, and destination – green forage or seed. The data found in research literature are rather controversial. Various authors recommend sowing from 0.4 to 8 kg ha^{-1}, or from 20 thousand to 1 million ha^{-1} plants (Putnam, 1990; Chernov, 1992; Breus, 1997; Jamrishka, 1998). The latest experimental evidence suggests that the optimum seed rate for *A. cruentus* grown for grain with 76-cm row spacings is 173 thousand plants ha (Henderson et al., 1993).

In 1998 amaranth was sown on 17 May, and in 1999 on 12 May. In 1998 and 1999 the greatest amaranth herbage, dry matter and seed yield was obtained in the treatments sown at a seed rate of 4 kg ha^{-1} (Table 2). Plants sown at a lower seed rate were larger. In normal years, a seed rate of 2–4 kg ha^{-1} should be sufficient. It is very important that the seed is placed at the optimum (0.5–1.0 cm) depth, and the soil is rolled after the sowing.

Amaranth sowing methods. Young amaranth plants are sensitive to weeds. If the soil is contaminated with the seed of *A. retroflexus*, it is better not to sow amaranth in such a soil at all. As herbicide application in amaranth crops is not advisable, it is recommended to sow amaranth with wide row spacings, which facilitates mechanical weed control or weeding. It is essential to control weeds by pre-sowing soil tillage (Stallknecht et al., 1993).

In 1998 the experiment was set up on 17 May, and in 1999 on 12 May. The experiment included three treatments: bands of 0.5 x 0.5 x 0.5 x 0.5 m (4 row strips), 0.5 x 0.5 m (2 row strips) and 1 x 1 x 1 x 1 m, with 1-m distances between the bands, 3 replications. In both experiments, the highest herbage dry matter and seed yield was obtained in the treatments sown with narrower row spacings (Table 3).

Investigation of amaranth collections bas been continued with breaks since 1978. The collections were studied according to the methodology developed by the former All-Union Crop production Institute (Varadinov, 1985). In 2000 we received (through P. Jamrishka) 2 amaranth accessions K-17 (*A. cruentus*) and K-343 'Plainsman' (*A. hypochondriacus*) from Slovakia and were able to compare them with the varieties available in our collection. According to the morphological characteristics, most of our amaranth accessions (including 'Geltonukai' and 'Raudonukai') were attributed to the *A. cruentus* species, while part of amaranth accessions (including 'Rausvukai') corresponded more to the *A. hypochondriacus* species. The electrophoretic method used to identify amaranth species (V. Paplauskienė) did not reveal any significant differences. The data on amaranth collections' studies from 2000 reflect a great diversity of the accessions (Table 4). The highest seed yield was produced by 'Raudonukai', and that of green material by 'Bordo' (individual selection from many varieties). This confirms the opinion that in many cases the seed yield is inversely proportional to green material yield. This fact is corroborated by the many-year yield data of the three Lithuania - registered amaranth varieties (Table 5). Averaged 4-year data suggest that the highest seed yield was produced by 'Raudonukai', and the highest green material yield by 'Rausvukai'. Regardless of this, the most promising is 'Geltonukai' whose yellowish seeds are the most attractive for food production. 'Raudonukai' should be grown as grain for feeding or for technical purposes, and 'Rausvukai' for silage or as an energy crop. It is likely that extra fertilisation, especially nitrogen, would have increased amaranth yield more, as this plant is a demanding one in terms of nutrients.

In 1998 chemical composition of green material of the varieties 'Raudonukai' and 'Gelsvukai' was estimated at the analytical laboratory (V. Paplauskienė), and that of seed in 2001 (A. Mašauskienė). Chemical composition of both varieties differed insignificantly and confirmed the high nutritional and feeding value of amaranth (Table 6). The high nutritional value of amaranth in comparison with main food and fodder crops demonstrates and USDA data has been presented in Table 7.

Table 1. Effect of amaranth sowing time on the yield in Dotnuva, 1998–1999.

Sowing time	Plant height m	Herbage yield		DM yield		Seed yield	
		t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
	08 06	1998					
04 29	1.26	22.6	100.0	8.6	100.0	1.41	100.0
05 04	1.35	25.5	112.8	9.4	109.9	1.71	121.3
05 11	1.50	23.2	102.7	8.1	94.8	1.41	100.0
05 18	1.45	24.0	106.2	8.4	97.8	0.93	66.9
05 27	1.40	21.6	95.6	8.1	77.3	1.17	83.0
LSD$_{05}$		1.4		0.7	8.1	0.21	18.0
	08 28	1999					
04 28	1.16	15.0	100.0	4.8	100.0	1.02	100.0
05 12	1.04	13.2	88.0	4.3	89.6	0.78	76.5
05 25	1.20	16.4	109.3	5.2	108.2	0.98	96.1
LSD$_{05}$		1.3		0.7	8.0	0.20	17.0

Table 2. Effect of amaranth seed rate on the yield in Dotnuva, 1998–1999.

Seed rate kgha^{-1}	Plant height m	Herbage yield		DM yield		Seed yield	
		t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
	08 06	1998					
2	1.30	22.1	100.0	7.7	100.0	1.41	100.0
4	1.38	26.0	117.6	9.3	120.4	1.50	106.3
8	1.20	21.4	96.8	8.0	104.0	1.33	94.5
LSD$_{05}$		0.78		0.61	7.9	0.30	
	08 26	1999					
2	1.04	12.2	100.0	4.3	100.0	1.20	100.0
4	1.02	14.0	114.8	5.0	116.3	1.42	118.3
8	8.0	10.2	83.6	3.8	7.6	0.96	80.0
LSD$_{05}$		1.2		0.50	6.0	0.18	

Table 3. Comparison of amaranth sowing methods. Dotnuva, 1998–1999.

Bands m	Plant height m	Herbage yield		DM yield		Seed yield	
		t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
		1998					
0.5 x 0.5 x 0.5 x 0.5*	1.40	25.7	100.0	9.5	100.0	1.56	100.0
0.5 x 0.5**	1.35	21.1	82.1	7.4	78.3	1.18	75.6
1.0 x 1.0 x 1.0 x 1.0 ***	1.23	20.1	78.2	6.2	65.6	0.79	50.6
LSD_{05}		2.2		1.3	13.5	0.3	23.8
		1999					
0.5 x 0.5 x 0.5 x 0.5*	1.26	14.6	100.0	4.6	100.0	1.32	100.0
0.5 x 0.5**	1.20	13.0	89.1	4.0	87.0	1.26	95.4
1.0 x 1.0 x 1.0 x 1.0 ***	1.43	12.4	84.9	3.9	84.8	1.20	90.9
LSD_{05}		2.0		1.2	13.0	0.24	

seed rate kgha^{-1}: * - 4, ** - 3, *** - 2.

Table 4. Yield data of the amaranth varieties grown in the collection nursery in Dotnuva, 2000.

Variety or population	Plant height m	Beginning of flowering	Herbage yield		Seed yield	
			t ha^{-1}	%	t ha^{-1}	%
	08 17	2000				
'Raudonukai', standard	1.60	07 20	25.6	100.0	1.41	100.0
K-23, USA	1.68	07 18	21.8	85.2	1.01	71.7
K-27123, Russia	1.60	07 21	24.4	95.6	1.21	85.8
K-17, Gvatemala	1.58	08 21	27.1	106.1	1.15	81.1
K-128, Peru	1.76	07 26	24.7	96.5	1.19	84.0
K-25/2, Kazakhia	1.70	07 26	26.4	103.5	1.20	84.9
K-1, Kaukaz	1.80	07 30	25.6	100.0	0.75	52.8
'Bordo,' individual selection	2.00	08 05	36.8	128.7	0.53	37.7
K-8, India	1.70	07 28	25.8	100.9	1.08	76.4
K-151, Peru	1.64	07 26	27.6	107.8	0.53	37.7
K-343, Plainsman, USA	1.40	07 24	29.3	114.8	1.11	78.3
LSD_{05}			4.19	15.4	0.14	14.3

Table 5. Seed yield data of the amaranth varieties registered in Lithuania.

Variety	Plant height	Herbage yield		Seed yield	
	m	t ha^{-1}	%	t ha^{-1}	%
1	2	3	4	5	6
		1998			
'Raudonukai', stand.	1.15	18.2	100.0	1.43	100.0
'Geltonukai'	1.20	20.5	112.6	0.98	68.5
'Rausvukai'	1.10	16.9	92.9	1.01	70.6
LSD_{05}		2.0		0.19	
		1999			
'Raudonukai', stand.	1.02	16.2	100.0	1.23	100.0
'Geltonukai'	0.9	14.6	90.0	0.92	74.8
'Rausvukai'	1.13	18.4	113.6	0.80	65.0
LSD_{05}		1.9		0.13	
		2000			
'Raudonukai', stand.	1.60	25.6	100.0	1.41	100.0
'Geltonukai'	1.60	26.0	101.7	1.23	86.8
'Rausvukai'	1.78	32.9	128.7	0.61	43.4
LSD_{05}		4.2		0.14	
		2001			
'Raudonukai',stand.	1.50	29.9	100.0	1.34	100.0
'Geltonukai'	1.68	32.9	110.0	0.82	61.2
'Rausvukai'	1.84	38.4	128.6	0.40	29.8
LSD_{05}		0.88		0.09	
		Averaged data from 1998-2001			
'Raudonukai',stand.	1.32	22.5	100.0	1.35	100.0
'Geltonukai'	1.35	23.2	103.1	0.99	73.3
'Rausvukai'	1.46	26.7	118.7	0.70	51.1
LSD_{05}		2.6		0.14	

Table 6. Chemical composition of dry matter of 2 amaranth varieties, Dotnuva, 1998–2001.

Variety or part of plant	DM %	Crude protein %	Crude fibre %	Crude fat %	Digestibi-lity in vitro %
'Raudonukai'					
Total	19.5	11.7	31.5	-	60.0
Stems	15.5	7.1	37.0	-	57.6
Inflorescences	19.1	19.6	26.9	-	58.5
Leaves	18.4	20.3	14.1	-	71.0
Seeds	11.0	15.1	12.7	5.28	-

Table 6 continuation

1	2	3	4	5	6
'Geltonukai'					
Total	17.5	11.3	25.9	-	63.5
Stems	16.7	5.9	31.7	-	62.2
Inflorescences	19.1	19.3	28.3	-	60.9
Leaves	19.5	19.9	18.6	-	70.4
Seeds	11.0	15.4	5.8	6.48	-

Table 7. Nutritional data of amaranth, millet, barley and wheat. (Amount in 100 grams of edible portion).

Nutrients	Units	Ama-ranth	Millet	Bar-ley	Hard wheat	Soft wheat
1	2	3	4	5	6	7
Proximates:						
Water	g	9.84	8.67	9.44	10.94	6.57
Energy	kcal	374	378	354	3.39	342
Energy	kj	1,565	1,582	1,481	1,418	1,431
Protein	g	14.45	11.02	12.48	13.68	11.31
Total lipid (fat)	g	6.51	4.22	2.30	2.47	1.71
Ash	g	3.04	3.25	2.29	1.78	1.52
Carbohydrate	g	66.17	72.85	73.48	71.13	75.90
Fiber, total dietary	g	15.2	8.5	17.3	12.0	12.2
Minerals						
Calcium	mg	153	8	33	34	32
Iron	mg	7.59	3.01	3.60	3.52	4.56
Magnesium	mg	266	114	133	144	93
Phosphorus	mg	455	285	264	508	355
Potassium	mg	366	195	452	431	432
Sodium	mg	21	5	12	2	2
Zinc	mg	3.18	1.68	2.77	4.16	3.33
Copper	mg	0.777	0.750	1.943	0.553	0.363
Manganese	mg	2.260	1.632	0.498	3.012	3.82
Vitamins						
Ascorbic acid	mg	4.2	0.0	0.0	0.0	0.0
Thiamin	mg	0.080	0.421	0.646	0.419	0.387
Riboflavin	mg	0.208	0.290	0.285	0.121	0.108
Niacin	mg	1.286	4.720	4.604	6.738	4.381
Pantothenic acid	mg	1.047	0.848	0.282	0.935	0.954
Vitamin B-6	mg	0.223	0.384	0.318	0.419	0.368
Folate	mg	49	85	19	43	38
Vitamin E	mg	1.030	0.180	0.600	-	-

Table 7 continuation

1	2	3	4	5	6	7
Lipids						
Saturated, total	g	1.662	0.723	0.482	0.454	0.277
Monounsaturated, total	g	1.433	0.773	0.295	0.344	0.203
Polyunsaturated, total	g	2.891	2.134	1.108	0.978	0.750
Amino acids						
Tryptophan	g	0.181	0.119	0.208	-	-
Threonine	g	0.558	0.353	0.424	0.366	0.342
Isoleucine	g	0.582	0.465	0.456	0.533	0.396
Leucine	g	0.879	1.400	0.848	0.934	0.763
Lysine	g	0.747	0.212	0.465	0.303	0.315
Methionine	g	0.226	0.221	0.240	0.221	0.174
Cystine	g	0.191	0.212	0.276	0.286	0.300
Phenylalanine	g	0.542	0.580	0.700	0.508	0.681
Tyrosine	g	0.329	0.340	0.358	0.357	0.327
Valine	g	0.679	0.578	0.612	0.594	0.498
Arginine	g	1.060	0.382	0.625	0.483	0.522
Histidine	g	0.389	0.236	0.281	0.322	0.256
Alanine	g	0.799	0.986	0.486	0.427	0.412
Aspartic acid	g	1.261	0.726	0.779	0.617	0.557
Glutamic acid	g	2.259	2.356	3.261	4.743	3.663
Glycine	g	1.636	0.287	0.452	0.495	0.455
Proline	g	0.698	0.877	1.484	1.453	1.166
Serine	g	1.148	0.644	0.527	0.667	0.540
NDB N_0		20001	20032	20004	20076	20072

USDA Nutrient Database for Standard Reference, Release 13 (1999).

CONCLUSIONS

1. In 1998 the highest dry matter (9.4 t ha^{-1}) and seed (1.71 t ha^{-1}) yield of amaranth was obtained in the treatment sown on 4 May, in 1999 (DM yield 5.2 t ha^{-1}) in the treatment sown on 25 May. The highest seed yield (1.02 t ha^{-1}) was obtained in the treatment sown on 28 April.

2. The highest dry matter yield (9.3 and 5.0 t ha^{-1}, respectively) and seed yield (1.50 and 1.42 t ha^{-1}, respectively) was obtained in the treatment sown at a seed rate of 4 kg ha^{-1} in 1998 and 1999.

3. The highest dry matter yield (9.5 t ha^{-1} and 1.32 t ha^{-1}, respectively) was obtained in the treatment sown in bands with row spacings of 0.5 x 0.5 x 0.5 x 0.5 m (4 strips) in 1998 and 1999 .

4. The optimum seed harvesting method is a direct combine harvesting after severe frosts (-3…-5°C).

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