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Chemical Composition of the Above-ground Biomass of *Amaranthus cruentus* and *A. hypochondriacus*

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Abstract

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Forty samples of dry above-ground biomass of two species and four varieties of *Amaranthus cruentus* (varieties Olpir, Amar 2 RR-R 150, and A 200 D) and *A. hypochondriacus* (variety No. 1008) were analyzed to determine their nutritional value during the experimental period covering five growth stages since inflorescence emergence till full ripening of grain from day 80 to day 120 of cultivation. The content of crude protein in the investigated amaranth varieties significantly decreased (from 158.2 ± 1.20 – 185.4 ± 2.33 to 103.8 ± 1.20 – 113.1 ± 0.01 g/kg) as well as did the crude ash content (from 169.9 ± 0.14 – 192.2 ± 0.42 to 129.7 ± 0.14 – 138.4 ± 0.21 g/kg). In contrast, the ether extract content significantly increased (from 12.2 ± 0.14 – 15.9 ± 0.28 to 28.0 ± 0.28 – 36.4 ± 0.14 g/kg) as well as crude fibre (from 144.9 ± 2.12 – 170.0 ± 3.68 to 183.6 ± 7.00 – 276.0 ± 1.20 g/kg), and gross-energy (from 16.6 ± 0.03 – 17.2 ± 0.07 to 18.1 ± 0.14 – 18.4 ± 0.01 MJ/kg) between days 80 and 120 of cultivation. The relatively high content of crude protein in the above-ground biomass in the period between days 80 and 90 of cultivation suggests that the plants could be used as a nutrient substitute for conventional forages.

Amaranth varieties, growth stage, crude protein, ether extract, crude fibre, crude ash, nitrogen-free extractives, organic matter, gross-energy

Alternative sources of feeds offering high-quality nutrients, especially proteins, limiting amino acids but also energy, may be found in unconventional plants. The genus *Amaranthus* (L.) belongs to the *Amaranthaceae* family and includes more than 60 species (Kalač and Moudrý 2000), most of which are weeds. Under conditions of the Czech Republic, three grain species *Amaranthus cruentus*, *A. hypochondriacus,* and *A. caudatus* are of importance. The plants are characterized by a great diversity of species and forms, and green parts of some species are used as vegetable. In the Czech Republic the cultivation of amaranth was introduced in the early 1990s (Michalová 1999; Moudrý et al. 1999). Environmental requirements and technological conditions under which the plant can be grown are already well known.

Selected genotypes of *A. cruentus* (varieties Olpir, Amar 2 RR-R150, and A 200 D) and *A. hypochondriacus* (variety No. 1008) are characterized by early maturity, lower demands for temperature during germination, fast growth after germination, and early establishment of canopy. The plants are readily adaptable to soil and climatic conditions (Michalová 1998; Jarošová et al. 1997). Experience obtained up to now with its cultivation has shown that field yields range from 0.6 to 2.4 t/ha. However, preconditions for yield increase of amaranth grain exist (Jarošová et al. 1997). The possibilities of growing amaranth under Czech conditions have been studied by Michalová (1998), Moudrý et al. (1998), Jarošová and Moudrý (1999), Peterka et al. (1999).

The grain of the current amaranth species has a high nutritional value. The dry matter of the grain is 90 - 94% (Andrasofszky et al. 1998), crude protein ranges from 15 to 18%,

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ether extract (fat) from 6 to 8%, crude fibre from 3 to 5%, ash from 2 to 3%, and nitrogen-free extractives from 60 to 65% (Carlsson 1979; Bressani et al. 1987; Bressani and Liggoria 1994; Szelenyi-Galantai and Zsolnai-Harszi 1992).

The advantage of amaranth grains compared to conventional cereals is a relatively high content of proteins and a more balanced amino acid composition (Kalač and Moudrý 2000). The amaranth grain is rich in lysine, tryptophan and sulphur amino acids. A suitable content of lysine and tryptophan together with a low content of leucine makes it a high-quality supplement for e.g. maize, which is rich in leucine but poor in lysine and tryptophan (Vetter 1994). The relatively high lipid content in the amaranth grain is connected with a favorable composition of fatty acids. Grain lipids are rich in linoleic and palmitic acids (Lorenz and Hwang 1985); the presence of squalene is a specific factor that can be used in human medicine. Moreover, isolated squalene has been used in computers.

The nutritional value of the above-ground biomass depends on the growth stages of plants. The contents of crude protein were 29.5, 22.7, and 16.3%, those of crude fibre were 11.1, 14.3, and 17.0%, and the yield was 19.7, 154.3, and 510.7 kg/ha at the harvest 25, 45 and 60 days after planting, respectively, as reported by Alfaro et al. (1987). Crude fat content ranged from 2.0 to 3.0%, crude fibre from 11.1 to 24.4%, and ash from 13.1 to 17.8% in dry matter of the above-ground biomass of amaranth according to the data in literature (Alfaro et al. 1987; Škultéty et al. 1991; Zeman et al. 1995).

The aim of our study was to determine the dependence of chemical composition and gross-energy in the above-ground biomass of four different genotypes in two amaranth species (*A. cruentus* and *A. hypochondriacus*) on the growth stage between days 80 and 120.

Materials and Methods

Samples of the dry above-ground biomass of two species and four varieties of amaranth: *A. cruentus* (varieties Olpir, Amar 2 RR-R 150, and A 200D) and *A. hypochondriacus* (variety No. 1008) were analyzed to determine their nutritional value (40 samples have been taken from 4 cultivars, 10 samples per cultivar, 5 harvest times, 2 samples per harvest time per cultivar). The plants were grown in experimental fields in 1999, and the seeds were sown on May 13. Plant density was 36 plants per m^2. When the plants were 15 cm high, nitrogen fertilizer (27.5% calcium ammonium nitrate, $CaNH_4NO_3$) was added at the dose of 50 kg N/ha. The plants were harvested on September 20 when they were ripe for cutting. Samples collected during the growing season were analyzed for the dynamics of changes in selected variables of nutritional value.

Growth stages (DC) in selected varieties in 1999

Days of cultivation	57	68	78	89	99	109	120
Olpir	24-30	30	30-39	40	61-68	70-80	90
Amar 2 RR-150	24-30	30	30-39	40	61-68-70	80-90	90
A 200 D	24-30	30	30-39	40	61-68	70-80	90
No. 1008	24-30	30	30-39	40	61-68	70-80	90

Samples of the above-ground biomass were collected on days 80, 90, 100, 110, and 120 of cultivation. According to a macrophenological assessment of growth stages, the following stages can be observed: from day 80 – a rapid elongation and stem branching, and the inflorescence emergence; from day 90 – an apex formation in the main panicle, the onset of flowering; from day 100 – the anthesis, pollination, and the onset of seed formation; from day 110 – the milk and dough development of seeds; and from day 120 the full ripening of seeds (Jarošová et al. 1997). Samples were taken at representative quantities (Anonymous 2001). After harvesting, the plants were spread and dried at room temperature.

Treatment of samples for chemical analyses was carried out in accordance with the Czech Standards (Anonymous 1996). Dry matter, crude protein, ether extract, crude fibre, and crude ash were established in two parallel samples using the standard methods for laboratory testing of feeds published in the AOAC (2001). Calorimetry was used to determine gross-energy (Kacerovský et al. 1990). The values of nitrogen-free extractives and organic matter were calculated. The final results are presented in dry matter so that comparisons could be made. Statistical characteristics were obtained using the program Stat Plus (Matoušková et al. 1992). The dependence of chemical composition on the plant growth stage was established using linear regression and regression coefficients (r).

Results and Discussion

The composition of all plants throughout the growing season changes, and therefore the feeding value and digestibility change, too. There is a high content of crude protein in young plants but this gradually decreases. By comparison, the content of nitrogen-free substances, especially that of fibre, increases (Nehring 1955). Chemical composition, gross-energy, and regression coefficients of the above-ground biomass in the variety Olpir, Amar 2 RR-R 150, A 200 D and No. 1008 are presented in Tables 1, 2, 3, and 4. During the investigated period from day 80 to day 120 of cultivation, the content of crude protein linearly decreased: in Olpir from 170.2 to 103.8 g/kg ($p < 0.05$) (Table 1), in Amar 2 RR-R 150 from 158.2 to 110.2 g/kg ($p < 0.05$) (Table 2), in A 200 D from 185.4 to 108.9 g/kg (Table 3) and in No. 1008 from 183.6 to 113.1 g/kg (Table 4).

Table 1. Chemical composition (g/kg), gross-energy (MJ/kg) in dry matter of *Amaranthus cruentus*, variety Olpir in dependence on growth stage

Days of cultivation	80	90	100	110	120	r	
Crude protein[1]	170.2 ± 4.60	161.9 ± 3.54	122.4 ± 2.40	122.2 ± 2.26	103.8 ± 1.20	-0.9565	*
Ether extract	13.9 ± 0.21	19.3 ± 0.42	29.0 ± 0.78	32.1 ± 0.21	33.4 ± 0.21	0.9599	*
Crude fibre	138.0 ± 2.97	168.6 ± 3.32	184.2 ± 3.89	200.8 ± 2.19	206.3 ± 7.21	0.9689	*
Crude ash	192.2 ± 0.42	158.7 ± 0.14	139.7 ± 1.56	138.4 ± 0.07	137.5 ± 0.85	-0.8746	NS
Nitrogen-free extractives	485.7 ± 2.05	491.5 ± 1.85	524.7 ± 2.16	506.5 ± 1.20	519.0 ± 2.40	0.7643	NS
Organic matter	807.8 ± 0.50	841.3 ± 0.20	860.3 ± 1.80	861.6 ± 0.15	862.5 ± 1.60	0.8746	NS
Gross energy	16.8 ± 0.05	17.8 ± 0.04	18.1 ± 0.02	18.2 ± 0.42	18.3 ± 0.11	0.8802	NS

[1](N × 6.25), r = regression coefficient, significance of linear regression* $p < 0.05$, ** $p < 0.01$
NS = non-significant

Table 2. Chemical composition (g/kg), gross-energy (MJ/kg) in dry matter of *Amaranthus cruentus*, variety Amar 2 RR-R 150 in dependence on growth stage

Days of cultivation	80	90	100	110	120	r	
Crude protein[1]	158.2 ± 1.20	144.4 ± 2.97	118.8 ± 1.77	112.3 ± 1.84	110.2 ± 2.47	-0.9480	*
Ether extract	12.2 ± 0.14	16.1 ± 0.28	18.6 ± 0.07	24.1 ± 0.21	28.0 ± 0.28	0.9943	**
Crude fibre	144.9 ± 2.12	189.0 ± 5.69	219.6 ± 5.51	243.6 ± 2.12	276.0 ± 1.20	0.9944	**
Crude ash	169.9 ± 0.14	161.6 ± 0.50	149.2 ± 0.57	146.9 ± 0.14	134.0 ± 0.42	-0.9858	**
Nitrogen-free extractives	514.8 ± 1.41	488.9 ± 2.36	493.8 ± 1.98	473.1 ± 1.13	451.8 ± 1.08	-0.9510	*
Organic matter	830.1 ± 0.20	838.4 ± 0.55	850.8 ± 0.63	853.1 ± 0.31	866.0 ± 0.40	0.9858	**
Gross-energy	16.6 ± 0.03	17.4 ± 0.01	17.8 ± 0.23	18.0 ± 0.04	18.1 ± 0.14	0.9333	*

[1](N × 6.25), r = regression coefficient, significance of linear regression * $p < 0.05$, ** $p < 0.01$
NS = non-significant

The content of crude ash linearly decreased: in Olpir from 192.2 to 137.5 g/kg (Table 1), in Amar 2 RR-R 150 from 169.9 to 134.0 g/kg ($p < 0.01$) (Table 2), in A 200 D from 182.7 to 129.7 g/kg ($p < 0.01$) (Table 3), and in No. 1008 from 192.2 to 138.4 g/kg (Table 4). In contrast, the contents of crude fibre linearly increased: in Olpir from 138.0 to 206.3 g/kg

Table 3. Chemical composition (g/kg), gross-energy (MJ/kg) in dry matter of *Amaranthus cruentus*, variety A 200 D in dependence on growth stage

Days of cultivation	80	90	100	110	120	r	
Crude protein[1]	185.4 ± 2.33	149.9 ± 3.68	114.9 ± 2.05	110.0 ± 2.83	108.9 ± 0.63	-0.9129	NS
Ether extract	15.9 ± 0.28	18.6 ± 0.21	26.5 ± 0.21	33.4 ± 0.42	36.4 ± 0.14	0.9867	**
Crude fibre	170.0 ± 3.68	173.3 ± 3.68	177.9 ± 3.75	181.5 ± 3.96	183.6 ± 7.00	0.9935	**
Crude ash	182.7 ± 0.14	159.7 ± 0.14	150.8 ± 0.35	142.4 ± 0.07	129.7 ± 0.14	-0.9787	**
Nitrogen-free extractives	446.0 ± 1.61	498.5 ± 1.93	530.8 ± 1.59	532.7 ± 1.80	541.4 ± 1.90	0.9064	NS
Organic matter	817.3 ± 0.21	840.3 ± 0.20	849.2 ± 0.40	857.6 ± 0.19	870.3 ± 0.20	0.9787	**
Gross-energy	17.0 ± 0.07	17.6 ± 0.17	17.9 ± 0.01	17.9 ± 0.01	18.4 ± 0.01	0.9558	*

[1](N × 6.25), r = regression coefficient, significance of linear regression * $p < 0.05$, ** $p < 0.01$
NS = non-significant

Table 4. Chemical composition (g/kg), gross-energy (MJ/kg) in dry matter of *Amaranthus hypochondriacus*, variety No. 1008 in dependence on growth stage

Days of cultivation	80	90	100	110	120	r	
Crude protein[1]	183.6 ± 1.41	150.0 ± 0.64	117.6 ± 1.27	117.2 ± 1.63	113.1 ± 0.01	-0.9063	NS
Ether extract	14.8 ± 0.49	17.6 ± 0.35	28.7 ± 0.78	29.6 ± 0.28	33.2 ± 0.01	0.9559	*
Crude fibre	163.5 ± 3.39	173.5 ± 3.60	196.6 ± 7.71	196.7 ± 7.70	233.7 ± 5.23	0.9552	*
Crude ash	192.2 ± 0.50	158.1 ± 0.28	141.7 ± 1.34	141.4 ± 0.85	138.4 ± 0.21	-0.8727	NS
Nitrogen-free extractives	445.9 ± 1.45	500.8 ± 1.22	515.4 ± 2.75	515.1 ± 1.40	481.6 ± 1.08	0.4653	NS
Organic matter	807.8 ± 0.60	841.9 ± 0.34	858.3 ± 0.40	858.6 ± 0.98	861.6 ± 0.36	0.8727	NS
Gross-energy	17.2 ± 0.07	17.6 ± 0.17	18.0 ± 0.07	18.1 ± 0.01	18.4 ± 0.01	0.9821	**

[1](N × 6.25), r = regression coefficient, significance of linear regression * $p < 0.05$, ** $p < 0.01$
NS = non-significant

($p < 0.05$) (Table 1), in Amar 2 RR-R 150 from 144.9 to 276.0 g/kg ($p < 0.01$) (Table 2), in A 200 D from 170.0 to 183.6 g/kg ($p < 0.01$) (Table 3), and in No. 1008 from 163.5 to 233.7 g/kg ($p < 0.05$) (Table 4).

The content of ether extract linearly increased: in Olpir from 13.9 to 33.4 g/kg ($p < 0.05$) (Table 1), in Amar 2 RR-R 150 from 12.2 to 28.0 g/kg ($p < 0.01$) (Table 2), in A 200 D from 15.9 to 36.4 g/kg ($p < 0.01$) (Table 3), and in No. 1008 from 14.8 to 33.2 g/kg ($p < 0.05$) (Table 4); and there was a corresponding increase of gross-energy: in Olpir from 16.8 to 18.3 MJ/kg (Table 1), in Amar 2 RR-R 150 from 16.6 to 18.1 MJ/kg ($p < 0.05$) (Table 2), in A 200 D from 17.0 to 18.4 MJ/kg ($p < 0.05$) (Table 3), and in No. 1008 from 17.2 to 18.4 MJ/kg ($p < 0.01$) (Table 4).

The values of nitrogen-free extractives ranged in Olpir from 485.7 to 524.7 g/kg (Table 1), in Amar 2 RR-R 150 the values linearly decreased from 514.8 to 451.8 g/kg ($p < 0.01$) (Table 2), in A 200 D nitrogen-free extractives ranged from 446.0 to 541.4 g/kg (Table 3), and in No. 1008 from 445.9 to 515.4 g/kg (Table 4). The content of organic matter linearly increased, Olpir from 807.8 to 862.5 g/kg (Table 1), Amar 2 RR-R 150 from 830.1 to 866.0 g/kg ($p < 0.01$) (Table 2), A 200 D from 817.3 to 870.3 g/kg ($p < 0.01$) (Table 3) and No. 1008 from 807.8 to 861.6 g/kg (Table 4).

The above mentioned data correspond with those obtained by Alfaro et al. (1987) who reported that in *A. hypochondriacus* green matter on day 25 after planting the content of crude protein was 29.5%, and that of crude fibre was 11.1%; on day 40 the content of crude protein was 22.7% and the crude fibre content increased to 14.3%; on day 60 the protein content was the lowest (14.4%) and the crude fibre content was 17.0%.

Pond and Lehmann (1989) reported the following values in the dried biomass of the Zimbabwe cultivar PI 482049 of *A. cruentus,* which was harvested 1 week after anthesis: dry matter 94.0%, crude ash 18.4%, cell contents 64.3%, NDF 33.7%, ADF 24.0%, ADL 5.2%, crude protein (N × 6.25) 16.2%, compared to the first cutting lucerne hay, when the following values were obtained: dry matter 87.2%, cell contents 40.5%, NDF 59.5%, ADF 47.1%, cellulose 38.1%, ADL 10.0%, crude protein (N × 6.25) 13.6%.

The recorded content of crude protein in *A. hypochondriacus* No.1008 was higher compared to the level mentioned by Riveros and Cristi (1988) in *A. cruentus* (20.6 - 9.7%) from the start of vegetative growth to the harvest time.

The chemical composition of amaranth suggests difficult ensiling. Škultéty et al. (1991) investigated in bulls the digestibility of green, dried and ensilaged amaranth *A. hypochondriacus* No. 1008, whose crude protein ranged from 25.3 to 15.7%, depending on the growth stage at harvest. A very low ensilage digestibility was observed, suggesting its low quality.

Conclusions

The obtained results showed a significant dependence of nutritional value of the above-ground biomass of amaranth on the plant growth stage. During plant growth, the nutritional value decreased, which was presented especially by a significant linear decrease of the crude protein content and a significant increase of crude fibre. From the viewpoint of the crude protein content and satisfactory production of the above-ground biomass at the same time, the period from day 80 to 90 of cultivation, i.e. the inflorescence emergence and onset of flowering, appears as the most suitable for harvest. Of the four variants under investigation, A 200 D (*A. cruentus*) and No. 1008 (*A. hypochondriacus*) proved to be better sources of nutrients, having higher protein content. This relatively high content of crude protein shows that the above-ground biomass of amaranth can be used as a nutrient substitute for conventional forages in the form of dry biomass.

Nutriční hodnota sušené nadzemní biomasy amarantu - *Amaranthus cruentus* a *A. hypochondriacus*

Ke zjištění živinového složení bylo analyzováno 40 vzorků suché nadzemní biomasy rostlin dvou druhů a čtyř odrůd amarantu: *A. cruentus* (Olpir, Amar 2 RR-R 150, A 200 D) a *A. hypochondriacus* (No. 1008). Během pěti růstových fází od stadia nasazování květu do plné zralosti zrna mezi 80. a 120. dnem vegetace u sledovaných odrůd signifikantně poklesl obsah dusíkatých látek (ze 158,2 ± 1,20 až 185,4 ± 2,33 g/kg na 103,8 ± 1,20 až 113,1 ± 0,01 g/kg) a obsah popela (ze 169,9 ± 0,14 až 192,2 ± 0,42 g/kg na 129,7 ± 0,14 až 138,4 ± 0,21 g/kg). Naopak signifikantně narůstal obsah tuku (z 12,2 ± 0,14 až 15,9 ± 0,28 g/kg na 28,0 ± 0,28 až 36,4 ± 0,14 g/kg), vlákniny (ze 144,9 ± 2,12 až 170,0 ± 3,68 g/kg na 183,6 ± 7,00 až 276,0 ± 1,20 g/kg) a *brutto* energie (z 16,6 ± 0,03 až 17,2 ± 0.07 MJ/kg na 18,1± 0,14 až 18,4 ± 0,01 MJ/kg) mezi 80. a 120. dnem vegetace. Relativně vysoký obsah živin nadzemní biomasy amarantu v období od 80. do 90. dne vegetace predeterminuje možnost jejího využití k náhradě konvenčních krmiv.

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