The content of insoluble fibre and crude protein value of the aboveground biomass of *Amaranthus cruentus* and *A. hypochondriacus*

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ABSTRACT: Twenty samples of the aboveground biomass of *Amaranthus cruentus* (varieties Olpir, Amar 2 RR-R 150, and A 200 D) and *A. hypochondriacus* (variety No. 1 008) were analysed to determine their nutritional value during the experimental period covering five growth stages from inflorescence emergence till full ripening of grain. During plant growth, from day 80 to day 120 of cultivation, the nutritional value decreased. This was demonstrated by an increase in insoluble fibre and a reduction in crude protein content. The content of neutral detergent fibre (NDF) in the dry matter increased from 356 to 420 g/kg ($P < 0.01$); acid detergent fibre (ADF) from 238 to 286 g/kg ($P < 0.01$); acid detergent lignin (ADL) from 22.9 to 53.4 g/kg ($P < 0.01$). The content of crude protein in the dry matter of the investigated amaranth varieties decreased from 174 to 109 g/kg ($P < 0.01$). In the Czech Republic the aboveground biomass of the cultivated *A. cruentus* and *A. hypochondriacus* could be used as a good source of fibre and protein in animal diets when harvested in the period from day 80 to 90 of cultivation.

Keywords: amaranth varieties; vegetation stage; NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin

Species of the genus *Amaranthus* (L.) are herbaceous plants distributed throughout the world. Both the seeds and vegetative parts have been used for food. Yield and chemical composition data and nutritional evaluation of forage amaranth (Alfaro et al., 1987) indicate a high potential for use in animal and human diets. Under conditions of the Czech Republic, three grain species *Amaranthus cruentus*, *A. hypochondriacus*, and *A. caudatus* are important. The plants are characterised by the great diversity of species and forms; green parts of some species are used as vegetable. In the Czech Republic 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.

Digestibility deteriorates with increased fibre content. However, this does not relate to crude fibre alone but to the decreased utilization of other nutrients. During the growing season all plants are subject to changes in composition and consequently in nutritional value and digestibility. Whilst high levels of nitrogen substances are recorded in young plants, these levels drop throughout the plant growth. On the other hand, the level of nitrogen free extractives increases, especially that of fibre. However, these increases do not apply to pentosans. Pure cellulose content also remains stable, but lignin concentration increases distinctly (Nehring, 1955).

Fibre is an inseparable part of feeds of plant origin. It is composed of various components such as lignin, cellulose, hemicelluloses, pectic substances, gums, waxes, and indigestible oligosaccharides (Van Soest and McQueen, 1973; Trowell, 1974). Fibre is not digested by enzymes in the gastrointestinal tract of mammals but it is digested, to a gre-

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ater or lesser extent, by enzymes of the microflora of the gastrointestinal tract. The effect of individual fibre components is specific in the gastrointestinal tract, with the ability to bind various organic and mineral substances (Stratil, 1993).

Hemicelluloses and pectin substances with water binding and swelling capability are called soluble fibre. The other hemicelluloses, cellulose, and lignin, which bind water to a lesser extent, are called insoluble fibre. Fibre induces a mechanical sensation of glutting and promotes peristalsis in animals. In ruminants it participates in the regulatory activity of rumen. Lignin from the woody parts of plants is an undesirable substance; it is partially digested by intestinal bacteria into toxic phenols (Kalač and Míka, 1997).

The levels of crude fibre in amaranth grain range from 3 to 8% according to Pedersen et al. (1990), being predominantly formed of lignin and cellulose. Fibre content in the dry matter of grains of *A. hypochondriacus* K 343 and *A. cruentus* R 149 was 12.9 and 15.0%, respectively, according to Alfaro (1987). Bressani et al. (1987) found a 7.1% mean content of crude fibre in grain samples from Guatemala compared to 3.9 and 3.0% in samples obtained from Peru and Mexico, respectively. Singhal and Kulkarni (1988) analysed the grain of five amaranth species from India and found crude fibre values to range from 4.9% to 12.9%.

Fibre content (in %) in commonly cultivated amaranth species was summarized by Bressani (1994):

Fibre	*A. cruentus*	*A. hypochondriacus*	*A. caudatus*
Insoluble	5.5	7.0	4.6–13.5
Soluble	1.5	6.5	2.3–3.6
Total	7.0	13.5	7.6–16.4
Proportion of insoluble fibre	78.6	51.8	60.5–82.4

Crude fibre content in the aboveground biomass of amaranth ranges from 11.1% to 24.4% (Alfaro et al., 1987; Škultéty et al., 1991; Zeman et al., 1995) depending on the physiological stage of plants. The dietary fibre content in "vegetable" white Malaysian amaranth (*A. viridis*) and red spinach (*A. gangeticus*) ranges between 3.6 and 4.1 g/100 g according to Osman (1990). Nutritional value and yield of the aboveground biomass depend on the age of plants. Riveros and Cristi (1988) monitored *in vitro* the nutritional value of single parts of *A. cruentus* plants from the beginning of growth until harvest. Chemical and nutritional properties of the wild species *A. muricatus* were assessed by determination of the general chemical composition of flour from leaves and stems according to Escudero et al. (2000).

The objective of our study was to determine the nutritive value of dried aboveground biomass of *A. cruentus* and *A. hypochondriacus* in dependence on growth stage from day 80 to day 120 of cultivation, based on the content of structured insoluble fibre (NDF, ADF, ADL) and crude protein.

MATERIAL AND METHODS

Samples of dry biomass of two amaranth species, *A. cruentus* (varieties Olpir, Amar 2 RR-R 150, and A 200 D) and *A. hypochondriacus* (variety No. 1008), were analysed. Amaranth plants were grown in experimental fields of the Department of Plant Production, Agricultural Faculty, České Budějovice in 1999, with the seeds being sown in May. Plant density was 36 plants per m^2. When the plants were 15 cm high, ammonium nitrate with limestone fertilizer was applied (LOVOFERT LAV 27, Lovochemie a.s., Lovosice, Czech Republic) at a dose of 50 kg N/ha. The plants were harvested during August and September.

Plant samples (20 samples were taken from 4 cultivars, 5 harvest times) were collected on day 80, 90, 100, 110, and 120 of cultivation. According to the macrophenological assessment of growth stages, the following stages can be observed: from day 80

Macrophenological assessment in selected varieties cultivated in the Czech Republic (Jarošová et al., 1999):

Days of cultivation/ growth stages (DC)	57	68	78	89	99	109	120
Olpir	24–30	30	30–39	40	61–68	70–80	90
Amar 2 RR-R150	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

– rapid elongation and stem branching, and inflorescence emergence; from day 90 – apex formation in the main panicle, onset of flowering; from day 100 – flowering, pollination, and onset of seed formation; from day 110 – milk and dough development of seeds; and from day 120 – full ripening of seeds (Jarošová et al., 1999). Samples were taken in representative quantities (Anonymous, 2001).

Biomass samples collected during the above stages of the growing season were analysed for the dynamics of changes in selected indicators. After harvesting, the plants were dried at room temperature and the dry matter of the plants was determined. Analyses of NDF, ADF and ADL of two parallel samples were carried out according to a modified procedure described by Van Soest et al. (1991). NDF modification included the elimination of decalin and the addition of 2 ml of a 2% solution of heat-stable α-amylase during refluxing. The cellulose content was obtained after subtraction of ADL from ADF, and hemicelluloses after subtraction of ADF from NDF. The content of dry matter and crude protein (CP) (N × 6.25) was determined by procedures laid down in AOAC (2001) for a laboratory testing of feeds. To allow comparison, the results are presented in dry matter.

Statistical characteristics were obtained using the program Stat Plus (Matoušková et al., 1992). The dependence of single components of fibre and crude protein (CP) on the plant growth stage was established using linear regression and correlation coefficients (*r*).

RESULTS AND DISCUSSION

The content of NDF, ADF, ADL, CP, hemicelluloses and cellulose in samples of the aboveground biomass in the varieties Olpir, Amar 2 RR-R 150, A 200 D and No. 1008 are presented in Tables 1–4, mean levels and the dependence of single components on the plant growth (*r*) are shown in Table 5.

During the investigated period from day 80 to day 120 of cultivation, the content of crude protein statistically decreased ($P < 0.01$), ($r = –0.9115$). The content of NDF, ADF and ADL statistically increased ($P < 0.01$), ($r = 0.6135$, 0.6888, and 0.8850 respectively). An increase in the particular fibre components and a decrease in CP levels throughout the investigated period are evident from Figure 1.

Hemicellulose levels ranged from 118 to 134 g/kg while cellulose levels were in the range of 215 to 233 g/kg (Table 5). The obtained levels of hemicelluloses and celluloses did not exhibit any dependence on the growth stage of plants, but a marked increase in lignin content was confirmed, which

Table 1. Levels of single components of fibre and crude protein (g/kg) in *A. cruentus*, Olpir variety

Days of cultivation	80	90	100	110	120
NDF	337	347	358	373	399
ADF	234	248	258	266	270
ADL	24.6	33.5	46.8	50.0	63.5
Hemicelluloses	103	99	100	107	129
Cellulose	209	214	211	216	206
CP[1]	170	162	122	122	104

NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP[1] – crude protein (N × 6.25)

Table 2. Levels of single components of fibre and crude protein (g/kg) in *A. cruentus*, Amar 2 RR–R 150 variety

Days of cultivation	80	90	100	110	120
NDF	343	413	428	450	473
ADF	247	257	287	311	317
ADL	23.1	27.2	29.4	35.4	48.3
Hemicelluloses	96	156	141	139	156
Cellulose	224	230	258	276	269
CP[1]	158	144	119	112	110

NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP[1] – crude protein (N × 6.25)

Table 3. Levels of single components of fibre and crude protein (g/kg) in *A. cruentus*, A 200 D variety

Days of cultivation	80	90	100	110	120
NDF	356	369	373	377	387
ADF	222	228	232	244	259
ADL	20.4	35.6	45.9	46.6	47.6
Hemicelluloses	134	141	141	133	128
Cellulose	202	192	186	197	211
CP[1]	185	150	115	110	109

NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP[1] – crude protein (N × 6.25)

Table 4. Levels of single components of fibre and crude protein (g/kg) in *A. hypochondriacus*, variety No. 1 008

Days of cultivation	80	90	100	110	120
NDF	387	386	394	404	419
ADF	246	257	262	282	298
ADL	23.6	27.6	46.0	47.2	54.0
Hemicelluloses	141	129	132	122	121
Cellulose	222	229	216	235	244
CP[1]	184	150	118	117	113

NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP[1] – crude protein (N × 6.25)

is in accordance with data from the literature (Nehring, 1955).

The above-mentioned data correspond with those obtained by Alfaro et al. (1987), who recorded the following values in green matter of *A. hypochondriacus*: on day 25 after planting, the content of crude protein was 29.5%, that of crude fibre was 11.1%; on day 40, the content of crude protein was 22.7% and crude fibre content increased to 14.3%; on day 60, the protein content was lowest (14.4%) and crude fibre content was 17.0%. Pond and Lehmann (1989) reported in Zimbabwe cultivar PI 482049 of *A. cruentus* the following values: dry matter 94.0%, crude ash 18.4%, cellulose contents 64.3%, NDF 33.7%, ADF 24.0%, ADL 5.2%, crude protein (N × 6.25) 16.2%.

Riveros and Cristi (1988) presented the highest quality of *A. cruentus* plants from the start of vege-

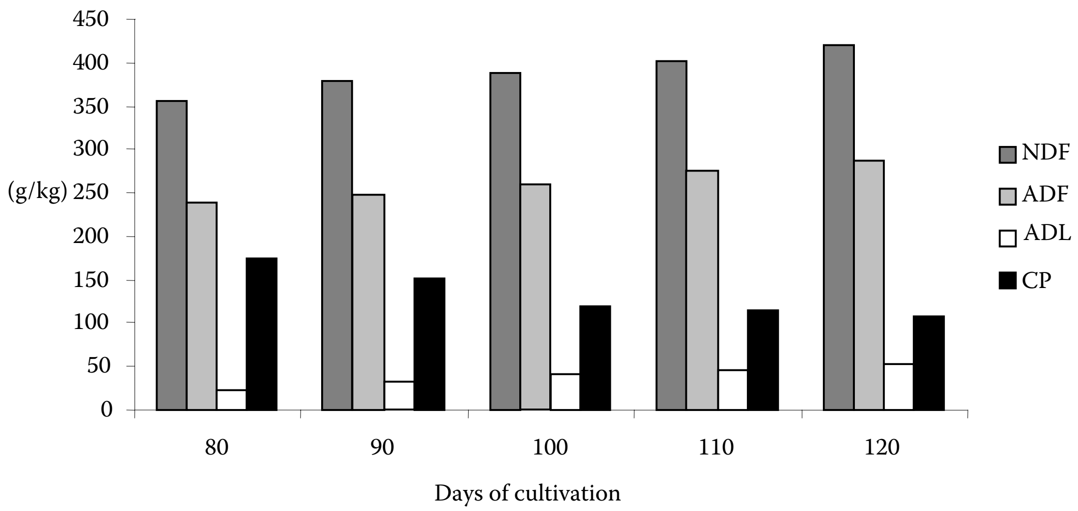

Figure 1. The increase in particular fibre components and decrease in CP levels throughout the investigated period

Table 5. Mean levels of single components of fibre and crude protein (g/kg) in the aboveground biomass of four varieties of *A. cruentus* and *A. hypochondriacus*

Days of cultivation	80	90	100	110	120	*r*
NDF	356	379	388	401	420	0.6135**
ADF	238	248	260	276	286	0.6888**
ADL	22.9	31.0	42.0	44.8	53.4	0.8850**
Hemicelluloses	118	131	128	125	134	NS
Cellulose	215	217	218	231	233	NS
CP[1]	174	152	119	115	109	–0.9115**

NDF – neutral detergent fibre; ADF – acid detergent fibre; ADL – acid detergent lignin; CP[1] – crude protein (N × 6.25)
r = correlation coefficient; significance of linear regression**($P < 0.01$); NS = non-significant

tative growth to harvest time. Organic matter (OM) content fluctuated between 85.3 and 96.7%, crude protein (CP) between 9.7 and 20.6%, NDF between 21.5 and 56.2%. Leaf OM, CP and NDF fluctuated from 69.9 to 87.8, from 8.0 to 16.3, and from 27.2 to 41.0%, respectively. Stem OM, CP, and NDF ranged between 75.6 and 85.9, 2.5 and 5.6, and 51.1 and 67.5%, respectively.

Escudero et al. (2000) indicated a nutritive potential for the flour of aerial parts of *A. muricatus* based on their results. Protein concentration of amaranth flour was 15.7 g/100 g and total dietary fibre content was high (53.8 g/100 g), with 79% coming from insoluble dietary fibre.

CONCLUSIONS

The results showed a significant dependence of the nutritional value of the aboveground biomass of amaranth on the growth stage of plants. During plant growth, from day 80 to day 120 of cultivation, the nutritional value decreased, which was presented by an increase in insoluble fibre, especially ADL, and by a decrease in crude protein content. The obtained levels of hemicelluloses and cellulose did not exhibit any dependence on the growth stage of plants. As far as digestibility, crude protein content, and at the same time satisfactory production of the aboveground biomass are concerned, the period from day 80 to 90 of cultivation, i.e. rapid vegetative growth and heading, appears the most suitable time for harvest.

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