Nutritional value of amaranth (genus *Amaranthus* L.) grain in diets for broiler chickens

B. Písaříková[1], Z. Zralý[1], S. Kráčmar[2], M. Trčková[1], I. Herzig[1]

[1]Veterinary Research Institute, Brno, Czech Republic
[2]Mendel University of Agriculture and Forestry, Brno, Czech Republic

ABSTRACT: The following characteristics were determined in raw and popped amaranth grain: crude protein (158.1 and 168.5 g/kg), ether extract (71.5 and 69.4 g/kg), neutral detergent fibre (NDF) (99.2 and 111.8 g/kg), cellulose (86.6 and 60.0 g/kg) and essential amino acids (Cys 4.2 and 4.1, Thr 6.0 and 6.5, Ala 8.8 and 9.2, Val 6.8 and 7.4, Ile 5.2 and 5.6, Lys 9.2 and 8.8, Arg 12.8 and 14.2 g/kg). *In vitro* protein digestibility was 68.1 and 50.6% in raw and popped amaranth grain, respectively. In balance experiments with broiler chickens ROSS 308 the following coefficients of apparent digestibility (%) were determined for control and experimental diets containing 0, 10% raw and 10% popped amaranth: crude protein 85.4, 86.5 and 83.0, ether extract 88.3, 88.2 and 86.1, NDF 21.2, 27.6 and 15.9, cellulose 25.0, 38.4 and 36.3, nitrogen free extractives 76.1, 82.6 and 81.1, organic matter 77.3, 81.8 and 80.6, gross energy 77.5, 80.6 and 78.2.

Keywords: amaranth grain; nutrients; amino acids; digestibility; chromium oxide; heat treatment

The genus *Amaranthus* (L.) belongs to the family *Amaranthaceae* and includes more than 60 species (Kalač and Moudrý, 2000). *Amaranthus cruentus*, *A. hypochondriacus*, and *A. caudatus* are the essential grain species. The plants are characterized by great diversity of species and forms, and green parts of some species are used as a vegetable. In the Czech Republic cultivation of amaranth was introduced in the early 1990s (Jarošová et al., 1999). The yields, chemical composition and nutritional value of amaranth grain (Bressani et al., 1987a,b; Dodok et al., 1997; Andrasofszky et al., 1998 and others) confirm its high potential for the use in both human and animal nutrition.

Amaranth species grown in the Czech Republic (*Amaranthus cruentus*, *A. hypochondriacus* and *A. caudatus*) are used for human nutrition in the form of whole-meal amaranth flour, crackers, pasta without eggs, brown bread without gluten, biscuits, cookies, etc. Besides the products for human nutrition, raw materials of high nutritional value, registered at the Central Institute for Supervising and Testing in Agriculture in the Czech Republic, are available. These products are used as supplements of conventional feedstuffs in feed mixtures and include amaranth grain, dry aboveground biomass, brown amaranth flour, and amaranth grain treated by extrusion or popping.

This study was conducted to determine the nutritional value (chemical composition, amino acid content, *in vitro* protein digestibility) of raw and heat-treated amaranth grain and apparent digestibility of nutrients in feed mixtures for broiler chickens with raw or popped amaranth grain compared to a cereal feed mixture without amaranth.

MATERIAL AND METHODS

We determined the content of nutrients (Horwitz, 2001) and *in vitro* protein digestibility of raw and popped amaranth grain using the method by Tilley and Terry (1963). The samples of raw and popped amaranth grain were adjusted using acidic and oxi-

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Table 1. Composition of diets fed to chickens (%)

Ingredient	Control (Diet 1)	Raw amaranth (Diet 2)	Popped amaranth (Diet 3)
Amaranth grain	–	10	10
Wheat	67.2	60.2	60.2
Extracted soybean meal	24	21	21
Sunflower oil	4	4	4
Limestone	1.31	1.28	1.28
UK VD (vitamin and mineral premix)	2.5	2.5	2.5
Indicator (chromium oxide)	1	1	1

Contents of additives per 1 kg of diet: vitamin A (i.u.) 14 000; vitamin D3 (i.u.) 5 000; vitamin K (mg) 2.45; vitamin E (mg) 52.5; vitamin B1 (mg) 2.45; vitamin B2 (mg) 6.75; vitamin B6 (mg) 3.75; vitamin B12 (mg) 0.022; niacin (mg) 30; folic acid (mg) 0.8; calcium pantothenate (mg) 9.75; choline chloride (mg) 750; biotin (mg) 0.088; L-lysine HCl (g) 2.12; D,L-methionine (g) 1.85; L-threonine (g) 1.25; cobalt (mg) 0.262; iodine (mg) 0.375; selenium (mg) 0.13; copper (mg) 7.00; manganese (mg) 82.5; zinc (mg) 45; iron (mg) 80; sodium (g) 0.5; phosphorus (g) 0.15; calcium (g) 2.5; avilamycin (mg) 10

dative acidic hydrolysis of HCl (c = 6 mol/l) prior to amino acid determination. Chromatographic analysis of sample hydrolysates was performed using the analyser AAA 400 (INGOS Prague, CR) and Na-citrate buffers and ninhydrin detection (Official Journal, 1978; Kráčmar et al., 1998).

The control and experimental feed mixtures contained wheat, extracted soybean meal, sunflower oil, mineral and vitamin supplements (Diet 1). In the experimental feed mixtures, extracted soybean meal and wheat were partly supplemented with 10% of raw amaranth grain (Diet 2) or 10% popped grain (Diet 3) (Table 1).

Apparent digestibility of nutrients in the control and experimental diets was determined in chicken broilers by the indicator method using chromium oxide (Cr_2O_3). A total of 105 10-day-old male broiler chickens ROSS 308 were included in the experiment. The chickens were weighed and divided into three groups of 35 birds each and fed diets 1, 2 and 3. At the age of ten days the weight of chickens fed diet 1–3 was equal (214.6 ± 21.0, V 9.78%; 216.1 ± 23.6, V 10.9%; 217.3 ± 22.8 g, V 10.5%, respectively). Each balance cage housed 7 chickens. The experiments were carried out in accredited experimental stables with controlled light and temperature regime. A 24-hour light regime was applied and the temperature was adjusted according to the age of broiler chickens; relative humidity ranged between 50 and 60%. Health status was monitored daily in regular intervals.

In a 10-day preparatory period (11 to 20 days of age), the chickens were adapted to the environment and feed mixture intake; in a 5-day balance period (21 to 25 days of age) excreta were collected twice a day, which were then preserved by chloroform and kept in a refrigerator until further analysis. After termination of the balance experiment, the contents of dry matter and crude protein were determined in homogenized excreta. For further analysis, the excreta were dried at 60°C and ground.

The following characteristics were determined in the feeds and excreta: crude protein, ether extract, crude fibre, crude ash, nitrogen free extractives, organic matter (Horwitz, 2001), gross energy values using an adiabatic bomb calorimeter (Kacerovský et al., 1990), NDF, ADL and cellulose (Goering and Van Soest, 1970), and chromium oxide (Mandel et al., 1960). The content of uric acid was determined according to Ekman et al. (1949). When calculating coefficients of apparent digestibility, the content of urine was expressed as the content of uric acid; contents of other uric components were not taken into account. After determination of energy digestibility from excreta, 11.476 KJ were subtracted from the combustion heat of excreta per g of uric acid (Kacerovský et al., 1990). The obtained results were evaluated using basic statistical characteristics, analysis of variance and Tukey's test (Matoušková et al., 1992).

RESULTS AND DISCUSSION

The contents of nutrients in raw and popped amaranth grain are consistent with the values mentioned in the literature (Bressani et al., 1987a; Andrasofszky

et al., 1998 and others). Raw and popped amaranth grain is characterised by a higher content of crude protein (158.1 and 168.5 g/kg), ether extract (71.5 and 69.4 g/kg) and favourable composition of fibre compared to conventional cereals. The content of NDF was 99.2 and 111.8 g/kg, cellulose (ADF) 86.6 and 60.0 g/kg in raw and popped amaranth grain, respectively (Table 2). No ADL was found in amaranth grain in our experiment.

The levels of amino acids in raw and popped amaranth grain confirmed the favourable amino acid composition as reported by Bressani et al. (1992), Jarošová et al. (1997) and Gorinstein et al. (2002). Raw and popped amaranth contained higher levels of essential amino acids (g/kg) compared to conventional cereals, e.g. wheat (Müller, 1969): Cys 4.2 and 4.1 vs. 3.3, Thr 6.0 and 6.5 vs. 3.6, Ala 8.8 and 9.2 vs. 4.4, Val 6.8 and 7.4 vs. 5.2, Ile 5.2 and 5.6 vs. 4.3, Lys 9.2 and 8.8 vs. 3.3 and Arg 12.8 and 14.2 vs. 5.7 (Table 3); no significant differences were observed between raw and popped grain. In contrast, Gamel et al. (2004) recorded the lowering of Tyr, Phe and Met levels due to popping, and Písaříková et al. (2005) found a lower index of essential amino acids (EAAI) in popped grain compared to raw grain (85.4 vs. 90.4%).

Some authors (Bressani et al., 1987b; Imeri et al., 1987) reported the same or increased nutritional value of amaranth grain after heat treatment in the form of autoclaving, extrusion, atmospheric cooking, toasting, popping, which can be explained by a limited effect of heat-labile anti-nutritive compounds; however, the results of our study showed the higher nutritional value in raw amaranth.

In vitro digestibility of protein was higher in raw amaranth grain (68.1%) compared to popped grain (50.6%). This lower level in popped grain might be related to a decreased biological value of protein which occurs at temperatures higher than 100°C (Pant, 1985; Tovar et al., 1989). Correa et al. (1986) determined *in vitro* protein digestibility of raw amaranth grain in the range from 61 to 76%.

Chemical composition (crude protein, crude fat, NDF, cellulose, nitrogen free extractives and organic matter) and gross energy in control and experimental diets fed to broiler chickens in a balance experiment confirmed an even content of crude protein, crude fat and gross energy which can be considered as isoproteinaceous and isoenergetic (Table 2). The supplement of 10% raw amaranth grain in feed mixture (Diet 2) resulted in a highly significant increase ($P < 0.01$) in gross energy, NDF, cellulose, nitrogen free extractives and organic matter compared to cereal feed mixture without amaranth (Diet 1), however, there was no effect on crude protein digestibility and ether extract digestibility (Table 4). These results are in accordance with insignificantly higher live weight of chickens after termination of the balance experiment at 25 days of age (591.8 ± 84.9 g vs. 570.9 ± 74.7 g).

The supplement of 10% popped amaranth grain in feed mixture (Diet 3) resulted in a significant decrease ($P < 0.01$) in crude protein digestibility, ether extract, NDF, and in an increase ($P < 0.01$) in digestibility of cellulose, nitrogen free extractives and organic matter compared to feed mixture without amaranth (Diet 1). Comparison of diets with popped grain (Diet 3) and raw amaranth grain

Table 2. Chemical composition of diets fed to chickens (dry matter) (g/kg)

	Control (Diet 1)	Raw amaranth[a] (Diet 2)	Popped amaranth[b] (Diet 3)
Crude protein	206.0	203.3	202.1
Ether extract	70.9	70.2	70.0
NDF	91.9	95.8	105.0
Cellulose	63.3	63.7	61.0
Nitrogen free extractives	606.9	613.0	609.2
Organic matter	914.8	928.5	928.5
Gross-energy (MJ/kg)	20.27	20.29	20.06

[a]raw amaranth grain analysis (g/kg): dry matter 892.6, crude protein 158.1, ether extract 71.5, NDF 99.2, cellulose 86.6, crude ash 30.2, nitrogen free extractives 600.1, organic matter 862.4

[b]popped amaranth grain analysis (g/kg): dry matter 938.7, crude protein 168.5, ether extract 69.4, NDF 111.8, cellulose 60.0, crude ash 31.4, nitrogen free extractives 633.4, organic matter 907.3

Table 3. Content of amino acids in raw and popped amaranth grain compared to wheat (g/kg)

Amino acid	Raw amaranth	Popped amaranth	Wheat*
Cys	4.2	4.1	3.3
Asp	13.2	13.8	6.2
Met	2.2	2.5	2.1
Thr	6.0	6.5	3.6
Ser	11.0	12.3	6.1
Glu	25.0	24.9	40.1
Pro	4.1	4.1	13.1
Gly	20.0	19.1	5.1
Ala	8.8	9.2	4.4
Val	6.8	7.4	5.2
Ile	5.2	5.6	4.3
Leu	7.9	8.4	8.4
Tyr	0.3	0.2	–
His	2.8	3.0	2.8
Lys	9.2	8.8	3.3
Arg	12.8	14.2	5.7

*Müller (1969)

Table 4. Apparent digestibility of dietary constituents in chickens fed diets with raw and popped amaranth grain (%)

	Control (Diet 1) $n = 5$	Raw amaranth (Diet 2) $n = 5$	Popped amaranth (Diet 3) $n = 5$
Crude protein	85.4 ± 0.45	86.5 ± 0.35	$83.0 \pm 1.60^{b*c**}$
Ether extract	88.3 ± 0.92	88.2 ± 0.50	$86.1 \pm 0.34^{b**c**}$
NDF	21.2 ± 1.14	$27.6 \pm 0.38^{a**}$	$15.9 \pm 1.25^{b**c**}$
Cellulose	25.0 ± 0.88	38.4 ± 1.35a**	$36.3 \pm 1.11^{b**}$
Nitrogen free extractives	76.1 ± 0.27	82.6 ± 0.33a**	$81.1 \pm 0.56^{b**c**}$
Organic matter	77.3 ± 0.29	81.8 ± 0.31a**	$80.6 \pm 0.23^{b**c**}$
Gross energy	77.5 ± 0.66	80.6 ± 0.32a**	$78.2 \pm 0.17^{c**}$

*$P < 0.05$; **$P < 0.01$

a = control : raw; b = control : popped; c = raw : popped

(Diet 2) showed significantly lower ($P < 0.01$) digestibility coefficients of crude protein, ether extract, NDF, gross energy, nitrogen free extractives, and organic matter (Table 4). This is in accordance with insignificantly lower live weight of chickens after termination of the experiment (566.3 ± 72.6 g vs. 591.8 ± 84.9 g).

Lower digestibility of crude protein, ether extract and NDF in Diet 3 with popped amaranth might be explained by a decreased nutritional value of amaranth grain by popping. Heat treatment can even result in damage to essential amino acids with consequently decreased content of amino acids or conversion to a racemic mixture (Tovar et al., 1989). Several authors also mentioned quantitative changes of insoluble fibre components after heat treatment (Reistad and Frolich, 1984; Jorgensen et al., 1996 and others) and formation of indigestible

complexes of fibre components with protein and amino acids (Mendez et al., 1993). Heat treatment can also result in disruption of the fat component. Singhal and Kulkarni (1990) reported a decreased level of unsaturated fatty acids from 75.5 to 62.3%, and a significant decrease in the linoleic acid level from 46.8 to 27.0% in popped grain of *Amaranthus cruentus*.

CONCLUSIONS

High content of crude protein, favourable composition of amino acids and fibre of raw amaranth grain and high coefficients of apparent digestibility of nutrients in a diet with 10% amaranth grain predetermine raw amaranth grain to be a suitable supplement of conventional feeds in feed mixtures for broiler chickens.

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Corresponding Author

Ing. Bohumila Písaříková, Veterinary Research Institute, Hudcova 70, 621 32 Brno, Czech Republic
Tel. +420 533 331 616, fax +420 541 211 229, e-mail: pisarikova@vri.cz