Yield and Quality of Forage Sorghum and Different Amaranth Species (*Amaranthus* spp.) Biomass

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Summary

The objective of investigations carried out on the experimental field of the Faculty of Agriculture, Zagreb, in 2002, 2003 and 2004 was to compare green mass and dry matter yields of forage sorghum and amaranth, and the nutritional value of these two crops at several development stages. Investigations included two amaranth cultivars: '1008' (*Amaranthus hypochondriacus* L.) and 'Koniz' (*Amaranthus hypochondriacus* L. x *Amaranthus hybridus* L.), and forage sorghum, hybrid Grazer N (*Sorghum bicolor* x *S. sudanense*). In all three trial years, forage sorghum gave the highest green mass and dry matter yield at the tasselling stage. In 2003, also amaranth, cultivar 1008, gave a high green mass yield at the flowering, which was in the same rank as forage sorghum. Decline of biomass quality was observed at later development stages due to a decrease in the concentration of crude and digestible proteins and an increase in NDF (neutral detergent fibre) and ADF (acid detergent fibre) concentrations. High quality of amaranth biomass was determined. Higher concentrations of crude and digestible proteins were found in amaranth aboveground biomass compared to forage sorghum while sorghum had a higher NDF concentration.

Key words

sorghum, amaranth, dry matter yield, fodder quality

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Introduction

Use of amaranth seed and leaves is quite common in human nutrition. It is less known, however, that green mass of some amaranth species can be used as good quality animal feed. Amaranth characteristics such as rapid growth, efficient water utilization and high protein content of the whole plant make it a suitable crop for animal nutrition. Amaranth seed is known to have a very favourable chemical composition (Žajová et al., 2001; Pospišil et al., 2008). Investigations have, however, revealed high nutritional value of amaranth biomass in animal nutrition (Stordahl et al., 1999; Pisarikova et al., 2007). Amaranth genotypes with high yields of dry matter and higher percentage of leaves are suitable for forage production (Kaul et al., 1996). Forage quality also depends on the development stage of amaranth. Stordahl et al., (1999) observed a decrease in the quality of amaranth green mass from bud formation to flowering. The same authors reported the highest protein concentration at the vegetative stage (230 g kg^{-1}), which later dropped appreciably (130 g kg^{-1}), while the stalk concentrations of NDF and ADF increased.

High yield of forage sorghum green mass, its possible use in several cuttings during the growing season as well as its good adaptation to different agroecological conditions make sorghum a very important forage crop. Green mass and dry matter yields and nutritional value of forage sorghum depend on the development stage at which cutting was carried out. Németh and Izsáki (2005) reported that about 70 % of total dry matter is produced in the second part of sorghum growing season, namely, from day 59 to 103. In dependence on the cultivar, Fontaneli et al., (2001) determined a 134 to 150 g kg^{-1} concentration of crude proteins in sorghum.

The aim of these investigations was to compare green mass and dry matter yields of forage sorghum and amaranth and the nutritional value of these two crops at several development stages.

Material and methods

Investigations were carried out in field trials set up in the experimental field of the Faculty of Agriculture, Zagreb, in 2002, 2003 and 2004. Two amaranth cultivars were studied: '1008' (*Amaranthus hypochondriacus* L.) and 'Koniz' (*Amaranthus hypochondriacus* L. x *Amaranthus hybridus* L.), and forage sorghum, hybrid Grazer N (*Sorghum bicolor* x *S. sudanense*). Forage sorghum was sown at a density of 100 germinated seeds m^{-2}, and amaranth 7 kg/ha.

The trial was laid out according to the randomized block scheme with four replications. The main plot size at sowing was 12 m^2 (4 rows x 0.60 m row spacing x 5 m row length). Chemical analyses of plant material were done in three replicates.

Samples were taken three times: 1st stage: sorghum - 100 cm high, amaranth - 50 cm high; 2nd stage: sorghum - 150 cm high, amaranth - inflorescence appearance; 3rd stage: sorghum - tasselling, amaranth - flowering.

Plant samples were taken from two middle rows of 1 m length. Green mass yield was determined and after drying at 70 ^{o}C dry matter yield was estimated.

Total nitrogen was determined by the method after Kjeldahl (AOAC, 2002) and recalculated into proteins by multiplying it by a factor of 6.25. Digestible protein concentration was determined by *in vitro* hydrolysis with pepsin. The feed sample was incubated with a pepsin containing solution under acidic conditions and the amount of digested and therefore dissolved protein was determined with the Kjeldahl method and this was considered as the digestible protein concentration of biomass. Crude fat was determined by the Soxhlet method, crude fibers and crude ash were determined by standard methods (AOAC, 2002).

Neutral detergent fibres (NDF) and acid detergent fibres (ADF) were determined by the method of van Soest et al. (1991).

Results of seed chemical analyses were recalculated to absolute dry matter and processed by the analysis of variance using the MSTAT-C program (Michigan State University, 1990).

The trial was set up on eutric cambisol, of acid reaction, in the plough layer (pH in 1 M KCl = 5.30). The soil was poorly supplied with humus (2.9 %) and well supplied with nitrogen (0.21 %), available phosphorus (21.1 mg/100 g soil) and potassium (30.0 mg/100 g soil).

Results and discussion

Green mass and dry matter yield

In all three trial years, forage sorghum gave the highest green mass and dry matter yield at the tasselling stage (Table 1). In 2003, also amaranth, cultivar 1008, gave a high green mass yield, 31.7 t/ha, at the third development stage (flowering), which was in the same rank as forage sorghum. The achieved green mass and dry matter yields of forage sorghum and amaranth point to high potentials of these two crops.

Lower green mass and dry matter yields were achieved in 2003 compared to the other two trial years. This is attributed to inclement weather conditions, primarily lack o precipitation over the whole growing season. Lack of moisture was recorded in all the growing-season months with the exception of September. The 2003 growing season had 149.7 mm less precipitation compared to the long-term average. At the same time, temperatures were higher compared to the long-term average, which had an adverse effect on green mass and dry matter yields of forage sorghum and amaranth. Nonetheless, even under such unfavourable conditions, green mass and dry matter yields were satisfactory. At the same time, the overall dry matter yields of natural and cultivated grasslands (4.8 and 3.01 t/ha, respectively) were in 2003 lower than the yields of forage sorghum and amaranth, cultivar 1008, at the third development stage (Leto et al., 2005; Bošnjak et al., 2006).

The obtained green mass and dry matter yields of forage sorghum and amaranth partially agree with the results of Štafa (2004) and Gregorova (1999).

Table 1. Forage sorghum and amaranth green mass (GM) and dry matter (DM) yield in three development stages in 2002, 2003 and 2004 (t/ha)

Stage	Species	2002		2003		2004	
		CP	DP	CP	DP	CP	DP
1st stage	Forage sorghum	138 b	94 c	146 c	94 cd	125 c	98 cd
	Amar., cv. 1008	203 a	150 b	163 b	104 c	152 b	117 b
	Amar., cv. Koniz	216 a	166 a	204 a	148 a	171 a	137 a
2nd stage	Forage sorghum	99 de	68 de	128 e	82 e	96 e	66 e
	Amar., cv. 1008	125 be	97 c	138 d	94 cd	118 cd	87 d
	Amar., cv. Koniz	135 b	97 c	166 b	122 b	117 cd	85 d
3rd stage	Forage sorghum	71 f	51 f	92 g	65 f	64 f	43 f
	Amar., cv. 1008	85 ef	60 ef	106 f	66 f	113 d	91 cd
	Amar., cv. Koniz	110 cd	77 d	138 d	87 de	120 cd	103 bc

Values followed by the same letter within the year are not significantly different at the 5 % level of probability

Table 2. Crude (CP) and digestible (DP) proteins concentrations in aboveground biomass of forage sorghum and amaranth in three development stages in 2002, 2003 and 2004 (g kg^{-1} on dry matter basis)

Stage	Species	2002		2003		2004	
		GM	DM	GM	DM	GM	DM
1st stage	Forage sorghum	27.5 cd	5.3 de	9.6 e	2.1 ef	18.3 d	2.4 ef
	Amar., cv. 1008	23.9 de	3.7 f	11.9 e	2.0 ef	18.9 d	1.8 fg
	Amar., cv. Koniz	18.8 e	3.5 f	10.2 e	1.8 f	10,6 e	1.4 g
2nd stage	Forage sorghum	37.7 b	7.7 b	17.7 cd	3.3 c	23.8 c	3.6 cd
	Amar., cv. 1008	25.6 cd	4.0 f	23.3 b	3.1 cd	24.6 c	2.8 de
	Amar., cv. Koniz	25.2 d	4.7 ef	16.7 d	2.5 de	16.3 d	2.1 efg
3rd stage	Forage sorghum	56.5 a	13.1 a	32.5 a	6.5 a	48.0 a	7.0 a
	Amar., cv. 1008	42.3 b	7.3 bc	31.7 a	4.9 b	40.1 b	4.5 b
	Amar., cv. Koniz	31.0 c	6.0 cd	21.5 bc	3.7 c	25.4 c	3.8 bc

Values followed by the same letter within the year are not significantly different at the 5 % level of probability

Concentration of crude and digestible proteins

In all three trial years, both amaranth cultivars achieved a significantly higher concentration of crude and digestible proteins compared to forage sorghum (Table 2). An exception was the dry 2003 when the digestible protein concentration of the amaranth cultivar 1008 was similar to that of forage sorghum. Significantly highest concentration of crude proteins was recorded at the first development stage, ranging in amaranth from 152 to 216 g kg^{-1} in dependence on the cultivar and trial year. At the same time, crude protein concentration of forage sorghum ranged from 125 to 146 g kg^{-1}. Concentration of digestible proteins at the first development stage ranged from 104 to 166 g kg^{-1} in amaranth, and from 94 to 98 g kg^{-1} in forage sorghum, which is in agreement with the results of Štafa et al. (2004).

In all trial years, the concentration of crude proteins significantly decreased at later development stages, which is in agreement with the results of Stordahl et al. (1999) and Gregorova (1999). Stordahl et al. (1999) determined the highest concentration of crude proteins at the vegetative stage of amaranth (230 g kg^{-1}). Sorghum concentration of crude proteins was similar to the results of Štafa et al. (2004), while Moyer et al. (2003) found 124 to 178 g kg^{-1} of crude proteins in the aboveground mass, in dependence on sorghum type.

Crude fat concentration

Crude fat concentration in the aboveground biomass of forage sorghum and amaranth declined in all investigation years parallel with plant development; thus the highest fat concentration was recorded at the first stage. In 2002 and 2004, in the 1^{st} and 2^{nd} stage, forage sorghum had a significantly higher crude fat concentration compared to both amaranth cultivars (Table 3). In 2003, the amaranth cultivar Koniz produced a similar concentration of crude fat as forage sorghum (32 and 33 g kg^{-1} respectively). The achieved crude fat concentration is quite high and indicates the high quality of forage sorghum and amaranth biomass. The obtained values are close to the maize grain values but are higher than the fat concentration in wheat grain (Grbeša, 2004).

Crude fibres concentration

Crude fibers concentration increased with plant development, which is in agreement with the results of Gregorova (1999). Forage sorghum produced a significantly higher concentration of crude fibers compared to both amaranth cultivars (Table 4). Crude fibers concentration of forage sorghum at tasselling stage ranged from 295 to 329 g kg^{-1} in dependence on the trial year, which is in agreement with the results of Štafa et al. (2004).

Table 3. Crude fat concentration in aboveground biomass of forage sorghum and amaranth in three development stages in 2002, 2003 and 2004 (g kg^{-1} on dry matter basis)

Stage	Species	2002	2003	2004
1st stage	Forage sorghum	33 a	33 a	34 a
	Amaranth, cv. 1008	22 bc	22 c	24 c
	Amaranth, cv. Koniz	25 b	32 a	28 b
2nd stage	Forage sorghum	20 c	27 b	28 b
	Amaranth, cv. 1008	15 d	18 d	23 c
	Amaranth, cv. Koniz	15 d	23 c	24 c
3rd stage	Forage sorghum	21 c	19 d	20 d
	Amaranth, cv. 1008	13 d	14 f	20 d
	Amaranth, cv. Koniz	21 c	16 e	24 c

Values followed by the same letter within the year are not significantly different at the 5 % level of probability

Table 4. Crude fibres concentration in aboveground biomass of forage sorghum and amaranth in three development stages in 2002, 2003 and 2004 (g kg^{-1} on dry matter basis)

Stage	Species	2002	2003	2004
1st stage	Forage sorghum	272 c	233 c	257 c
	Amaranth, cv. 1008	132 e	134 e	150 f
	Amaranth, cv. Koniz	119 e	126 e	142 f
2nd stage	Forage sorghum	312 ab	258 b	305 b
	Amaranth, cv. 1008	206 d	171 d	205 e
	Amaranth, cv. Koniz	208 d	163 d	227 d
3rd stage	Forage sorghum	323 a	295 a	329 a
	Amaranth, cv. 1008	290 bc	239 c	258 c
	Amaranth, cv. Koniz	270 c	228 c	245 cd

Values followed by the same letter within the year are not significantly different at the 5 % level of probability

NDF and ADF

Forage sorghum had in all three trial years a higher concentration of NDF and ADF in its aboveground biomass than both amaranth cultivars (Table 5). The highest NDF and ADF concentrations were achieved at the second and third development stages (height to 150 cm and tasselling, respectively). At these stages, the NDF concentration ranged from 636 to 693 g kg^{-1} in dependence on the trial year, which is in agreement with the results of Moyer et al. (2003), who found 569 to 714 g kg^{-1} NDF in forage sorghum aboveground biomass at tasselling.

NDF and ADF concentrations in both amaranth cultivars increased with plant development; the highest concentrations were recorded at the flowering. NDF concentration ranged from 423 to 478 g kg^{-1} and ADF concentration from 274 to 366 g kg^{-1} in dependence on the cultivar and trial year. The obtained values are in agreement with the values that Chamberlain and Wilkinson (1996) recommend for good quality silage. Also Stordahl et al. (1999) observed that the amaranth biomass quality declined with the progress of the growing season due to the increase in NDF and ADF concentration. Depending on the amaranth cultivar, Sleugh et al. (2001) obtained 330 to 390 g kg^{-1} NDF, while the concentration in different amaranth cultivars increased from 260 % to 470 g kg^{-1} with the progress of the growing season. The same authors determined an increase in ADF concentration from 168 to 354 g kg^{-1} as the growing season progressed.

Conclusions

In all three trial years, forage sorghum gave the highest green mass and dry matter yield at the tasselling stage. In 2003, also amaranth, cultivar 1008, gave a high green mass yield at the flowering, which was in the same rank as forage sorghum. Decline of the biomass quality of forage sorghum and amaranth at later development stages is associated with the decrease in the concentration of crude and digestible proteins and with the increase in NDF and ADF concentrations. High quality of amaranth biomass was determined. Concentrations of crude and digestible proteins were higher in both amaranth cultivars than in forage sorghum while forage sorghum had a higher NDF concentration. Depending on the development stage, forage sorghum had a higher ADF concentration as well; however, at sorghum tasselling stage and amaranth flowering stage, amaranth cultivar 1008 also was in the same rank as forage sorghum.

Table 5. NDF and ADF concentrations in aboveground biomass of forage sorghum and amaranth in three development stages in 2002, 2003 and 2004 (g kg^{-1} on dry matter basis)

Stage	Species	2002		2003		2004	
		NDF	ADF	NDF	ADF	NDF	ADF
1st stage	Forage sorghum	634 b	314 cd	603 b	289 c	576 c	337 cd
	Amar., cv. 1008	313 e	217 e	322 e	206 f	339 g	229 g
	Amar., cv. Koniz	300 e	185 e	298 f	187 g	319 h	210 g
2nd stage	Forage sorghum	693 a	385 a	639 a	302 b	636 b	359 bc
	Amar., cv. 1008	396 d	313 cd	359 d	225 e	402 f	298 ef
	Amar., cv. Koniz	416 d	288 d	351 d	219 ef	408 f	291 f
3rd stage	Forage sorghum	659 ab	384 a	637 a	352 a	657 a	389 a
	Amar., cv. 1008	478 c	364 ab	423 c	301 bc	431 e	366 ab
	Amar., cv. Koniz	475 c	341 bc	428 c	274 d	452 d	325 de

Values followed by the same letter within the year are not significantly different at the 5 % level of probability

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