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Crop Production, Plant Fractions and *In situ* Degradability of Silages from Different Sorghum Hybrids

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Abstract: The objective of this study, was to evaluate 3 different sorghum hybrids for whole plant silage on crop production, morphological composition and silages *in situ* degradability. Two Double Purpose (DP) hybrids (AG 200 and Nutritop) and one for grain production (G, Vdh 303) were sown in Azul, Argentina. Yield, plant fractions and chemical composition of plant fractions and silages were determined. Silage samples were incubated *in situ* for 0, 4, 15, 24 and 48 h and the effective dry matter degradation (ED) was calculated assuming a fractional passage rate of 2, 4 and 8%/h. Data were adjusted to the exponential equation of: $p = a + b\ (1\text{-}e^{-ct})$ and analyzed as a complete randomized block design considering field plots as experimental unit. The G hybrid yielded more (55%) than the other two DP hybrids, although the head content in the plant was not different between hybrids, being in average 42%. Heads presented higher CP and lower FDN content than leaf and stalks and also presented higher *in vitro* organic matter degradability (OMD, 729 g kg^{-1} DM) than leaves (605 g kg^{-1} DM). Silage *in vitro* OMD (average 558 g kg^{-1} DM) and chemical composition did not differ among hybrids. Soluble fraction (a) was higher in the DP silages, but degradable fraction (b) was higher in the G sorghum Vdh 302 than in AG 200 but not differed from the Nutritop. Potential degradability (a + b) was no different among hybrids (72% in average), neither rate of DM degradability. Silage EDs were not different at a kp of 2% h^{-1} (54.5% in average), but differed at higher rumen outflow rates.

Key words: Sorghum silage, hybrids, *in situ* degradability

INTRODUCTION

Traditionally, whole plant maize silage has been use in Argentina. However, in many areas where environmental conditions are not suitable for maize production, sorghum is becoming a convenient alternative. The aim of good silage is to keep high dry matter quantity with the best nutritive quality. In this context, sorghum is a high production annual crop able to grow under drought conditions (Lemaire *et al*., 1996) and of good ensiling characteristics (Bolsen *et al*., 2003). The main factors determining whole plant silage nutritional value are stage of maturity at harvest and hybrid characteristics (Bolsen *et al*., 2003). Many authors have reported a decline in crops digestibility with increasing maturity (Jensen *et al*., 2005; Molina *et al*., 2002). However, while FDN and lignin contents increase in cereal crops, starch content also increases and whole plant silage digestibility remains stable (Arias *et al*., 2003a; McDonald *et al*., 1991). It is well documented that sorghum must be harvested at dough stage, when dry matter, grain content and digestibility are suitable for good silage (Bolsen *et al*., 2003). The choice of the hybrid type may also affect silage quality through its morphological and chemical composition. Fodder hybrids are tall and rich in FDN, grain hybrids are shorter and rich in starch content, while double purpose hybrids recommended for ensiling are a combination between them. This is important, because metabolizable energy of sorghum silage depends on its digestibility, which in turn depends on the digestibility of its morphological components. In this regards, the digestibility of sorghum grain is low, although it can be increased by anticipating harvest to physiological maturity, by processing during ensiling or by ensiling conditions (Jensen *et al*., 2005). On the other hand, stems and leaves containing high levels

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of cell wall constituents are of variable vdigestibility (Tonani *et al*., 2001; Rocha *et al*., 2000b). In this way, studies about the performance of hybrids for silage used nowadays are still lacking. The objective of this experiment was to compare yield, plant morphological and chemical composition and silage nutritive value among three different sorghum hybrids.

MATERIALS AND METHODS

Growing conditions and experimental design: Three sorghum hybrids (*Sorghum bicolor* L. Moench) were sown on October 20th, 2006, in Azul, Buenos Aires Province, Argentina (36°48'S, 59°45`W). The area has average annual maximum and minimum temperatures of 20.5 and 8°C, respectively (30 years mean, data from Azul Meteorological Station). During the sorghum growing season (from October 15th-April 15th), total rainfall was 529 mm. Two hybrids double purpose recommended for ensiling (DP): AG SILO 200 (Sagra Seed®) and Nutritop (Advanta Seeds®) and one hybrid for grain production (G): Vdh 302 (Advanta Seeds®) were studied. Crop were sown in plots (5 rows, 0.7 m apart and 12 plants m^{-1}) in a randomized complete block design with 3 replications, fertilized with diammonium phosphate (60 kg ha^{-1}) at sowing date and insects and weeds controlled throughout the production cycle.

Harvesting and ensiling: Thirty plants of each hybrid (ten from each block) were hand-cut (0.10 m above surface) at soft dough stage of grain maturity (Vanderlip and Reeves, 1972). Nine additional samples (3 lineal meters from each block) of each hybrid were harvested for crop production estimation. Plants were fresh weighed and dissected into leaves, stalk and head. All fractions and crop production samples were oven-dried (at 60°C for 48 h) and weight for plant morphological composition and yield estimation. Other plants were hand harvested, chopped at theoretical chop length of 2 cm and ensiled in plastic recipients (0.5 m high and 0.4 m diameter). Two micro silages of each hybrid for block were made removing the air by a vacuum pump. After sixty days of ensiling recipients were opened, silage samples were oven-dried (at 60°C for 48 h) and used for chemical and *in situ* analysis.

Chemical analysis and *in situ* dry matter degradability: Plant morphological fractions and silage samples were ground to pass 1 mm screen mill in a Willey type mill to perform the following analysis: *In vitro* dry matter degradability (OMD, Theodoru *et al*., 1994), neutral detergent fibber (NDF, Van Soest *et al*., 1991), using an Ankom Fiber Analyzer (Ankom Technology Corporation, Fairport, NY), Crude Protein (CP) was calculated as N×6.25, Water Soluble Carbohydrates (WSC) by anthrone method (Bailey, 1958) and starch (MacRae and Armstrong, 1968).

For the *in situ* analysis, silages samples were ground to pass 2 mm screen and dry matter degradability was measured in three Holstein steers (400±30 kg) fitted with permanent ruminal canulae. Animals were kept in individual pens with fresh water always available and were fed Lucerne hay at maintenance of body weight. Silages samples (5±0.05 g DM) were placed in dacron bags (10×20 mm and 50 μm mean pore size) and incubated by duplicate for 0, 4, 15, 24 and 48 h (Mehrez and Ørskov, 1977). The zero time was an incubation of 5 min to determine the soluble fraction. Before incubating, bags were hydrated in warm water (39°C) for 15 min. After incubation bags were hand-washed with tap water until the water run clear and oven dried at 60°C for 48 h. The *in situ* values from a single animal (set of 10 bags, 5 incubation times replicated) were adjusted to the exponential equation of Ørskov and McDonald (1979): $p = a + b(1-e^{-ct})$, where p is DM degradation (%) at time t, a is the soluble fraction, b the insoluble but gradually degradable fraction and c the fractional rate of degradation. The effective DM degradability (ED) was calculated at a rumen outflow rate of 2, 4 and 8%/h (Ørskov and McDonald, 1979).

Statistical analysis: Data were analyzed by the General Linear Model procedure of SAS (1998) for a complete randomized block design considering field plots as experimental unit. Digestion kinetic parameters were estimated by the Marquardt method with NLIN option of General Linear Model procedure of SAS (1998). Hybrids mean differences were compared by Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

Dry matter content at harvest was not different among hybrids (33.1%, in average), but dry matter yield and stover composition differed ($p<0.05$) between G and DP hybrids. The G hybrid (Vdh 302) yielded 24420 kg DM ha^{-1}, while the DP hybrids (Nutritop and AG silo 200) yielded 13480 kg DM ha^{-1}, without differences between them (Table 1). It is expected than forage hybrids yield more than those for ensiling, which in turn might be higher than those for grain production (Rocha *et al*., 2000a; Molina *et al*., 2000). On the contrary, in this study, the grain sorghum yielded more (55%) than the other two DP hybrids. In spite of the 55% difference in DM yield, the head content in the plant was not different between

Table 1: Dry matter, dry matter production and morphological composition of three sorghum hybrids

Hybrid	DM (%)	Production DM ha^{-1}	Leave	Stalk	Head	Leave: Stalk
			--------g kg^{-1} DM---------			
Vdh 302	34.20	24420[a]	298[a]	251[b]	451	1.30[a]
Nutritop	33.80	13890[b]	194[b]	424[a]	382	0.46[c]
AG 200	34.20	13390[b]	229[b]	356[a]	415	0.66[b]
MEE	3.28	2400	1.44	2.48	356	0.10

[ab]Different letters in the same row are significantly different, Tukey (p<0.05)

hybrids, being in average 42%. This harvest index was higher than those reported previously for grain and DP sorghum (Neuman *et al*., 2002; Brito *et al*., 2000), although similar values have been obtained in our area (Abdeladhi and Santini, 2006; Arias *et al*., 2003b). The stover fraction of the DP hybrids had less (p<0.05) proportion of leaves and more stalks than the G hybrid, consequently, G hybrid presented a higher leaf to stalk ratio than DP sorghums (Table 1). The individual organs distribution is important since they have different nutritive value. The heads containing grains are the organs of highest DM digestibility of the plant (Miron *et al*., 2005; Serafim *et al*., 2000), while the stalks are the most lignificated and less degradable fraction (Flaresso *et al*., 2000).

In previous studies researchers have stated that DM production and stalk proportion increase, while head proportion decreased with plant size (Gontijo Neto *et al*., 2004; Rocha *et al*., 2000b; Molina *et al*., 2000). Nevertheless, there is a wide variation between hybrids morphological composition even though within sorghum types (grain, forage and double purpose). Important is to note that in spite of its higher production, G hybrid Vdh 302, had similar grain proportion and higher leaf to stalk ratio than those recommended for ensiling.

Chemical composition of morphological components from the different hybrids was determined. No interactions hybrid x fraction were found, so only the main factor means are present in Table 2. As shown, in all hybrids heads presented higher CP and lower FDN content than leaf and stalks. Heads also presented higher *in vitro* OMD (729 g kg^{-1} DM) than leaves (605 g kg^{-1} DM), while stalks (684 g kg^{-1} DM) were in an intermediated position. Lower values of stalk digestibility have been observed in earlier studies in which stalk have been stated like the worst part of the plant and heads like the best one (Flaresso *et al*., 2000). The lack of difference between hybrids in DMD of stalk and leaves in this experiment may be explained by the high WSC (235 vs. 89%) and similar FDN content (581 g kg^{-1}, in average) of stalks as compared with leaves. In concordance with our results Miron *et al*. (2005) reported lower WSC content and higher values of NDF in leaves than in stalks. The same authors found in all four varieties studied that heads had the highest DM digestibility (730-810 g kg^{-1} DM), while stems had

Table 2: Chemical composition of morphological components of three sorghum hybrids. (g kg^{-1} DM)

	OMD	NDF	CP	WSC	Starch[1]
Fraction					
Leaf	605b	599a	51b	89b	---
Stalk	684ab	563a	15c	235a	---
Head	729a	231b	76a	---	549
Hybrid					
Vdh302	696	454	66a	146	558
Nutritop	678	472	53b	193	554
AG200	644	467	54b	148	535
MEE	2.37	2.72	0.40	2.9	---
Effects					
Fraction	**	***	***	**	
Hybrid	0.31	0.88	***	0.59	0.92
FxH	0.74	0.74	0.71	0.55	

[ab]Different letters in the same column refers to significant differences (Tukey, p<0.05) within each factor (fraction or hybrid); [1]starch in heads

Table 3: Chemical composition of three ensiled sorghum hybrids (g kg^{-1} DM)

Hybrid	OMD	NDF	WSC	Starch	CP	pH
Vdh 302	559	547	60.0	227	58.00	4.04
Nutritop	564	556	47.0	207	54.00	4.14
AG 200	553	542	41.0	214	55.00	4.16
SEM	1.01	0.88	0.79	2.07	0.52	0.08

[ab]Different letters in the same row are significantly different, Tukey (p<0.05)

intermediate values (630-730 g kg^{-1} DM) and leaves were the lowest digestible organ (540-610 g kg^{-1} DM).

In addition and as a consequence of the similar plant morphological composition reported here in, all hybrids were not different in whole plant chemical composition with the exception of CP that was higher in the hybrid Vdh 302 as shown in Table 2. Thereafter, the most significant factor, which determines plant nutritive value is the organs proportion in the plant which, as demonstrated above, had different nutritional quality.

Table 3 shows data of silage chemical composition. All silages presented pH values (<4) and organoleptic characteristics that indicated an appropriate fermentation process (McDonald *et al*., 1991). *In vitro* OMD (average 558 g kg^{-1} DM) and chemical composition did not differ among hybrids, in accordance with their lack of differences in heads and stover proportions, as well as in plant chemical composition. Silage average chemical composition was: 216 g kg^{-1} DM of starch, 49 g kg^{-1} DM of WSC, 56 g kg^{-1} DM of CP and 548 g kg^{-1} DM of NDF. Although, the silage NDF content could vary from that of fresh plants due to the loss of effluents (Van Soest, 1994) or the hydrolysis of part of NDF components during ensiling process (Neuman *et al*., 2002), in our experiment the silage NDF was numerically higher than that of fresh plant shown in Table 2. Neuman *et al*. (2002) also observed an increase in some hybrids but a decrease in others. The WSC decreased from fresh plant to silage (162-49 g kg^{-1} DM), which indicated that they were fermented during the ensiling process (Miron *et al*., 2005, 2007). This was also observed by Ribeiro *et al*. (2007),

Table 4: *In situ* kinetic parameters of dry matter degradability

Hybrid	a (%)	B (%)	a+b	c (h^{-1})
Vdh 302	21.3c	54.3a	75.70	0.036
Nutritop	26.4b	45.5ab	71.90	0.037
AGsilo 200	30.3a	38.8b	69.00	0.035
MEE	0.49	3.36	3.34	0.004

[ab]Different letters in the same row are significantly different, Tukey ($p<0.05$)

who reported that the soluble carbohydrates degradation was intense during de first ten days after ensiling and then they were stabilized in very low values (0.08-1.43% at 56 days post ensiling). Silages NDF content was similar to that observed by other authors. For example, Neuman *et al.* (2002) using forage and double purpose hybrids reported results from 543-583 g kg^{-1} and Miron *et al.* (2005) presented values, which ranged from 530-610 g kg^{-1} DM. On the other hand, Borges *et al.* (1999) found smaller values of this parameter (446-491 g kg^{-1}) when short hybrids were evaluated but also similar NDF content with taller hybrids (566-598 g kg^{-1}). It should be noticed here that the decrease in NDF content is a consequence of a higher grain content and the corresponding decrease in the stover proportion in short hybrids.

The *in situ* kinetic parameters of the three sorghum silages are presented in Table 4. The soluble fraction (a) was higher in the S hybrids, although G hybrid had more WSC, which is one of the most important components of this fraction (Tonani *et al.*, 2001). Serafin *et al.* (2000) and Tonani *et al.* (2001) studying silage *in situ* degradability of three sorghum hybrids (grain, double purpose and forage sorghum) found no differences in soluble fraction (23.6 and 22.9 in average, respectively) even though hybrids differed in morphological and chemical composition. On the contrary, Molina *et al.* (2003) reported values ranging from 13.6-21.0% for different hybrids. It is normally assumed that soluble fraction is immediately and completely fermented in the rumen but some small insoluble particles can escape from the bag at zero time (Woods *et al.*, 2002). Cone *et al.* (2006) showed that individual starch granules may pass the pores and leave the bags undegraded. Further studies, should be performed to determine this fact because the loss of particles through the pores may lead to overestimating soluble fraction and consequently cause a bias in the other fractions estimations (Woods *et al.*, 2002; Dewhurst *et al.*, 1995). The degradable fraction (b) is basically the result of starch and FDN ruminal degradation. While, the starch is almost completed degraded, FDN degradation depends on its intrinsic quality, which is closely related to maturity stage. The b fraction was higher in the G sorghum Vdh 302 than in AG 200 but not differed from the Nutritop, which was similar to both of them. In a previous study, Tonani *et al.* (2001) found that degradable fraction was higher in those hybrids with high grain proportion. The potential degradability (a + b) was no different among hybrids (72% in average). This finding is a consequence of the differences observed for a and b fractions, because those hybrids presenting a higher a fraction also present lower b fraction and potential degradability in average was not different between sorghums. Molina *et al.* (2003) reported potential degradability from 83.3-73.3%, the lower values corresponding to those hybrids with high tannin level in their grains. Rate of DM degradability data showed no differences between hybrids, which was 0.036 h^{-1}, in average. This value is higher than those obtained by Tonani *et al.* (2001), who reported a rate of DM degradability of 0.017 h^{-1} for DP hybrids and 0.023 h^{-1} in average for G and fodder sorghums. Similarly, Serafim *et al.* (2000) reported 0.012 h^{-1} for DP hybrid and 0.014 h^{-1} for the others (G and fodder). Nevertheless, the truly degraded substrate, which will be available for the animal (effective DM degradability) depends on both the rate of degradability and the rate of passage. The last one was no measured, so effective DM degradability was estimated at 3 different rumen outflow rates (2, 4 and 8%/h). Silage EDs were not different at a kp of 2% h^{-1} (54.5% in average), but differed at higher rumen outflow rates as shown in Table 5. Serafin *et al.* (2000) found higher EDs in G hybrid than in fodder and DP at every rate of passage, which was associated with a higher rate of degradability. They concluded that the results showed a positive influence of a higher grain proportion in the silage on fiber and protein degradability. On the contrary, Tonani *et al.* (2001) found no differences in EDs between hybrids, but the double purpose ones tended to show higher ED although they had a lower rate of degradability than the others (G and fodder). However, despite the above-mentioned results, differences found in EDs are small and of minor practical importance. Overall, it might be suggested that when hybrids had similar head content and since the most digestible components of stover fraction are lost during the ensiling process, we have not to expect differences in silage nutritive value.

Table 5: Effective DM degradability at three rumen outflow rate 2, 4 and 8 % h^{-1}

Hybrid	DE (2%h^{-1})	DE (4%h^{-1})	DE (8%h^{-1})
Vdh 302 (G)	55.10	46.0b	37.5c
Nutritop (S)	54.20	46.7b	39.7b
AGsilo 200 (S)	54.20	47.7a	41.6a
MEE	0.59	0.38	0.46

[ab]Different letters in the same row are significantly different, Tukey ($p<0.05$)

CONCLUSION

The results obtained from the present study indicated that heads are the most important part of the plant since, it is the organ of highest nutritive value. The hybrids evaluated presented nodifferences on head content and they also presented no differences on potential degradability, which was 72% in overage. Finally, from a practical point of view, the better choice will be the hybrid of higher head content and higher DM production.

REFERENCES

Arias, S., O.N. Di Marco and M.S. Aello, 2003a. Effect of Hybrid and maturity on Maize stover ruminal degradability in cattle fed different diets. Asian-Aust. J. Anim. Sci., 16: 1619-1624. http://www.ajas.info/manuList.asp.

Arias, S., A.J. Freddi, O. Sánchez and M. Arzadún, 2003b. Dry matter yield and morphological composition of sorghum and maize hybrids for whole plant silage. Rev. Arg. Prod. Anim., 23: 221-222 (abstract). http://www.aapa.org.ar/congresos/2003/PpPdf/Pp90.PDF.

Abdelhadi, L.O. and F.J. Santini, 2006. Corn silage *versus* grain sorghum silage as a supplement to growing steers grazing high quality pastures: Effects on performance and ruminal fermentation. Anim Feed Sci. Technol., 127: 33-43. DOI: 10.1016/j.anifeedsci.2005.08.010. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232006%23998729998%23618017%23FLA%23&_cdi= 4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=8a3dcee0a699832b366517362134b696.

Bailey, R.W., 1958. Reactions of pentoses with anthrone. Biochem. J., 68: 669-672. PMID: 13522678. PMCID: PMC1200415.

Borges, A.L.C.C., L.C. Goncalves, F.S. Nogueira, N.M. Rodriguez1 and I. Borges. 1999. Forage sorghum silage with different tannin concentration and moisture in the stem. II-Variation on carbohydrates during fermentation. Arq. Bras. Med. Vet. Zootec., 51: 491-497. DOI: 10.1590/S0102-09351999000500016. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102- 09351999000500016&lng=pt&nrm=iso>.

Bolsen, K.K., K.J. Moore, W.K. Coblentz, M.K. Siefers and J.S. White, 2003. Sorghum Silage. Silage Science and Technology. In: Al-Amoodi, L. (Ed.). ASA-CSSA-SSSA, Madison, USA., 927: 609-632. ISBN: 0-89118-151-2. http://lccn.loc.gov/2003109369.

Brito, A.F., L.C. Gonçalves, J.A.S. Rodrigues, V.R.R. Júnior, I. Borges and N.M. Rodriguez, 2000. Evaluation of silages from seven sorghum genotypes (*Sorghum bicolor* (L.) Moench). I. Agronomical traits. Arq. Bras. Med. Vet. Zootec., 52: 391-396. DOI: 10.1590/S0102-09352000000400018. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102-09352000000400018&lng=en&nrm=iso>.

Cone, J.W., A.H. Van Gelder and W.Z. Chai, 2006. Fermentation behavior of the nylon bag washout and degradable fractions determined with the gas production technique. Anim. Feed Sci. Technol., 127: 319-326. DOI: 10.1016/j.anifeedsci.2005.09.008. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232006%23998729996%23618880%23FLA%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=0a7d14f1c4670affd6546ab2bce52e33.

Dewhurst, R.J., D. Hepper and A.J.F. Webster, 1995. Comparison of *in situ* and *in vitro* techniques for estimating the rate and extent of rumen fermentation of a range of dietary ingredients. Anim. Feed Sci. Technol., 51: 211-219. DOI: 10.1016/0377-8401(94)00692-3. http://www.sciencedirect.com/science? _ob=PublicationURL&_tockey=%23TOC%234962%231995%23999489996%23189112%23FLP%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=0521c93922438798811e803cf91e02d3.

Gontijo Neto, M.M, J.A. Obeid, O. Gomes Pereira, P.R. Cecon, A.C. De Queiroz, C.P. Zago, M.J.D. Candido and L. Ferreira Miranda, 2004. Sorghum (*Sorghum bicolor* (L.) Moench) Hybrids Cultivated under Increasing Fertilization Levels. Agronomic Characteristics, Soluble and Structural Carbohydrates of the Plant. R. Bras. Zootec., 33: 1975-1984. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982004000800008&lng=en&nrm=iso. http://www.scielo.br/scielo.php?pid=S1516-35982004000800008&script=sci_abstract&tlng=pt.

Flaresso, J.A., C.D. Gross and E.X. Almeida, 2000. Evaluation of Corn (*Zea mays* L.) and Sorghum (*Sorghum bicolor* (L.) Moench.) Cultivars for Silage Production in the High Valley do Itajaí Region, Santa Catarina State, Brazil. R. Bras. zootec., 29: 1608-1615. DOI: 10.1590/S1516-35982000000600003. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982000000600003&lng=es&nrm=iso.

Jensen, C., M.R. Weisbjerg, P. Nørgaard and T. Hvelplund, 2005. Effect of maize silage maturity on site of starch and NDF digestion in lactating dairy cows. Anim. Feed Sci. Technol., 118: 279-294. DOI: 10.1016/j.anifeedsci.2004.10.011. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232005%23998819996%23554355%23FLA%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=074d5d7de9b58fdeeb9001fd3895bf02.

Lemaire, G., X. Charrier and Y. Hébert, 1996. Nitrogen uptake capacities of maize and sorhum crops in different nitrogen and water supply conditions. Agronomie, 16: 231-246. http://cel.isiknowledge.com/CEL/CIW.cgi?CustomersID=Highwire&Func=Links&PointOfEntry=FullRecord&PublisherID=Highwire&ServiceName=TransferToWos&ServiceUser=Links&UT=A1996UW18000003&e=zVWtF0LwhFrg9Av03IVACRK_.bxstrE.E2KLVfTx2n2n_U9AxBh580PCbdHU6y8U.

MacRae, J.E. and D.G. Armstrong, 1968. Enzyme method for determination of α-linked glucose polymers in biological materials. J. Sci. Food. Agric., 19: 578-581. http://www3.interscience.wiley.com/journal/112606648/abstract?CRETRY=1&SRETRY=0.

McDonald, P., A.R. Henderson and S.J.E. Heron, 1991. The Biochemistry of Silage. 2nd Edn. ISBN: 0-948617-22-5. Chalcombe Publications, Aberystwyth, UK, pp: 339. URL: http://www.fao.org/agris/search/display.do?f=./1994/v2015/GB9135229.xml;GB9135229.

Mehrez, A.Z. and E.R. Ørskov, 1977. A study of the artificial fibre bag technique for determining the digestibility of feeds in the rumen. J. Agric. Sci. (Camb.), 88: 645-650.

Miron, J., E. Zuckerman, G. Adin, M. Nikbachat, E. Yosef, A. Zenou, Z.G. Weinberg, R. Solomon and D. Ben-Ghedalia, 2007. Field yield, ensiling properties and digestibility by sheep of silages from two forage sorghum varieties. Anim. Feed Sci. Technol., 136: 203-215. DOI: 10.1016/j.anifeedsci.2006.09.001. URL: http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232007%23998639996%23662541%23FLA%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=0f0b755365d0814956a08c9936c52790.

Molina, L.R., L.C. Goncalves, N.M. Rodriguez, J.A.S. Rodrigues, J.J. Ferreira and V.C.P. Ferreira, 2000. Agronomic evaluation of six sorghum hibrids ((*Sorghum bicolor* L.) Moench). Arq. Bras. Med. Vet. Zootec., 52: 385-390. DOI: 10.1590/S0102-09352000000400017.

Miron, J., E. Zuckerman, D. Sadeh, G. Adin, M. Nikbachat, E. Yosef, D. Ben-Ghedalia, A. Carmi, T. Kipnis and R. Solomon, 2005. Yield, composition and *in vitro* digestibility of new forage sorghum varieties and their ensilage characteristics. Anim. Feed Sci. Technol., 120: 17-32. DOI: 10.1016/j.anifeedsci.2005.01.008. http://www. sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232005%23998799998%23591725%23FLA%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=1cf63bf4548c09eb3928b9b634e5cf74.

Molina, L.R., L.C. Gonçalves, N.M. Rodriguez, J.A.S. Rodríguez, J.J. Ferreira and A.G. de Castro Neto, 2002. *In situ* degradability of dry matter and crude protein of silages of 6 Sorghum genotipes in different stages of maturation. R. Bras. Zootec., 31:148-156.DOI:10.1590/S1516-35982002000100017. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982002000100017&lng=es&nrm=iso.

Molina, L.R., N.M. Rodriguez, L.C. Gonçalves, I. Borges and B.M. Sousa, 2003. Effect of tannin on *in situ* degradability of the dry matter and crude protein of six sorghum silage genotypes ((*Sorghum bicolor* L.) Moench), harvested at dough stage. Arq. Bras. Med. Vet. Zootech., 55: 203-208. DOI: 10.1590/S0102-09352003000200012. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102-09352003000200012&lng=en&nrm=iso&tlng=pt.

Neuman, M., J. Restle, D.C. Alves Filho, I.L. Brondani, L.G. De Pellegrini and A. Kellermann De Freitas, 2002. Nutritional Evaluation of the Plant and Silage of Different Sorghum Hybrids (*Sorghum bicolor*, L. Moench). Arq. Bras. Med. Vet. Zootec., 31: 293-301. DOI: 10.1590/S1516-35982002000200002. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982002000200002&lng=pt&nrm=iso.

Ørskov, E.R. and I. McDonald, 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci., Camb., 92: 499-503. http://www.fao.org/agris/search/display.do?f=./1979/v505/XE7907058.xml;XE7907058.

Ribeiro, C.G.M., L.C. Gonçalves, J.A.S Rodrigues, N.M. Rodriguez, I. Borges, A.L.C.C. Borges, E.O.S. Saliba, G.H.F. Castro1 and G.O. Ribeiro Junior, 2007. Fermentation pattern of silages from five sorghum genotypes. Arq. Bras. Med. Vet. Zootec., 59: 1531-1537. DOI: 10.1590/S0102-09352007000600028. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0102-09352007000600028&lng=en&nrm=iso&tlng=pt.

Rocha, V.R., L.C. Gonçalves, J.A.S. Rodrigues, A.F. Brito, N.M. Rodríguez and I. Borges, 2000a. Evaluation of seven sorghum genotypes ((*Sorghum bicolor* L.) Moench) for silage. I-Agronomic traits. Arq. Bras. Med. Vet. Zootech., 52: 506-511. DOI: 10.1590/S0102-09352000000500017.

Rocha, V.R., L.C. Gonçalves, J.A.S. Rodrigues, A.F. Brito, I. Borges and N.M. Rodríguez. 2000b. Evaluation of seven sorghum genotypes (*Sorghum bicolor* (L.) Moench) for silage production. III- Nutritional value. Arq. Bras. Med. Vet. Zootech., 52: 627-633. DOI: 10.1590/S0102-09352 000000600013.

SAS, 1998. Statistical Analysis Systems Institute Inc., SAS User´s Guide: Statistics, Cary N.C. http://www.sas.com/presscenter/bgndr_history.html.

Serafim, M.V., I. Borges, L.C. Gonçalves, N.M. Rodriguez and J.A.S. Rodrigues, 2000. *In situ* disappearance of dry matter, crude protein and fiber of sorghum silage (*Sorghum bicolor* (L) Moench). Arq. Bras. Med. Vet. Zootech., 52: 634-640. DOI: 10.1590/S0102-09352000000 600014.

Theodorou, M.K., B.A. Williams, M.S. Dhanoa, A.B. Mc Allan and J. France, 1994. A simple gas production method using a pressure transducer to determine fermentation kinetics of ruminant feeds. Anim. Feed Sci. Technol., 48: 185-197. DOI:10.1016/0377-8401(94)90171-6. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%231994%23999519996%23461687%23FLP%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=1cec8750649982c247264bf034d7b987.

Tonani, F.L., A.C. Ruggieri, A.C. Queiroz and P. Andrade, 2001. Ruminal *in situ* degradability of dry matter and neutral detergent fiber of sorghum (*Sorghum bicolor* L.) silages with different harversting times. Arq. Bras. Med. Vet. Zootech., 53: 100-104. DOI: 10.1590/S0102-09352001000100016.

Vanderlip, R.L. and H.E. Reeves, 1972. Growt stages of sorghum (*Sorghum bicolor* (L.) Moench). Agron. J., 64: 13-16. http://agron.scijournals.org/cgi/content/abstract/64/1/13.

Van Soest, P.J., J.B. Robertson and B.A. Lewis, 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci., 74: 3583-3597. PMID: 1660498.

Van Soest, P.J., 1994. Nutrition and ecology of the ruminant. 2nd. Edn. ISBN: -13: 9780801427725, Ithaca: Cornell University, pp: 476. ISBN 0-8014-2772-X. Accession No: 356298. http://books.google.com.ar/books?id=-mwUu6PL1UgC&lr=&source=gbs_summary_s&cad=0.

Woods, V.B., F.P. O'Mara and A.P. Moloney, 2002. The *in situ* ruminal degradability of concentrate feedstuffs in steers as affected by level of feed consumption and ratio of grass silage to concentrate. Anim. Feed Sci. Technol., 100: 15-30. DOI: 10.1016/S0377-8401(02)00147-5. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234962%232002%23998999998%23334961%23FLA%23&_cdi=4962&_pubType=J&_auth=y&_acct=C000054199&_version=1&_urlVersion=0&_userid=1677711&md5=f7400499fa191c6d4c23c697ec6dbaa8.