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Head and stover contribution to digestible dry matter yield on grain and dual-purpose sorghum crop

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Abstract

Sorghum is becoming an important forage crop in many regions of Argentina due to its productivity and ability to utilize water more efficiently. The use of new grain sorghum hybrids, including dual-purpose types, has generated a need for information on hybrid choice and time of harvest. We studied the yield and quality changes during the grain filling period of grain and dual-purpose sorghums intended for whole-plant forage. Four commercial sorghum hybrids were evaluated in four rainfed environments of Buenos Aires milk basin, Argentina. Forage yield and quality traits were determined on head, stover and whole-plant. Quality measurements were performed by NIRS. No interactions were detected for all variables of forage yield, except for harvest index, in which the environment interacted with maturity. Effects of maturity and hybrid were detected in most variables of forage yield. Particularly, stover dry matter (DM) content had a maximum value at early milk stage and then declined, but whole-plant and head DM content increased throughout maturity. Regarding to quality, head *in vitro* DM digestibility, head digestible energy and digestible whole-plant DM yield were affected by maturity×hybrid interaction. Effects of maturity and hybrid were observed for most quality traits; however the environment did not influence any of them, except for head crude protein. Both grain and dual-purpose hybrids presented a window for harvest starting at early milk and concluding before physiological maturity. However, whole-plant DM yield and whole plant digestibility reached a maximum at hard dough stage, without changes up to physiological maturity.

Keywords: forage quality; forage yield; maturity stage; hybrid; whole-plant forage.
Abbreviations: CP-Crude protein; DE-Digestible energy; DIG-*In vitro* dry matter digestibility; DM-Dry matter content; DWY-Digestible whole plant dry matter yield; EN-Environment; EM-Early milk; H-Head; HB-Hybrid; HD-Hard dough; HI-Harvest index; LM-Late milk; MB-Mid-bloom; MS-Maturity stage; PM-Physiological maturity; S-stover; SD-Soft dough; W-Whole-plant; Y-Dry matter yield.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is becoming an important forage crop in many regions of Argentina due to its high productivity, ability to utilize water efficiently and adaptability to be planted following wheat, as a second crop (Zerbini and Thomas 2003; Ali *et al*. 2009). After a drought stress, sorghum recovers faster than maize, and it is therefore a more successful crop in areas with low and uncertain rainfall distribution (Bramel-Cox *et al*. 1995). Maize directed for silage is the most widely used crop but sorghum produces more dry matter yield in marginal conditions (Barrière *et al*. 2003; Gul *et al*. 2008). Expanding the use of sorghum as a forage crop obliges to overcome the tendency to lodging that characterizes the tall types, as well as their insufficient accumulation of DM content (Miron *et al*. 2006). A body of research had focused on forage sorghum or tall-growing varieties, but information about the use of grain sorghum or dual-purpose hybrids as forage source is scarce. Because of their potential dual destination, both grain and dual-purpose sorghum crops are very attractive in template marginal areas where agriculture and livestock production coexist in the same farm. In good seasons, the sorghum grain can be collected, but in dry years the crop can be fed directly with a very low cost of dry matter harvest. Dual-purpose sorghum cultivars are taller than grain-cultivars and more adapted to direct graze because their plant architecture includes a high dry matter production of vegetative fraction and a high a proportion of grain (Blümmel *et al.* 2003). The use the sorghum head as forage source makes imperative to carefully control the grain maturity stage at harvest because it influences very strongly on yield and quality (Abdelhadi and Tricarico 2009). Crop maturation is a highly complex process involving numerous changes in plant composition and architecture which, in turn, may influence forage quality. Maturity stage at harvest may influence quality of forage sorghum varieties (Pedersen *et al*. 1983; Snyman and Joubert 1996). Sorghum grain filling process involves an intense re-mobilization of both mineral nutrients and dry matter stored in the stem (Vanderlip 1993). The sorghum plant may senesce, dry and become brown, or leaves and stems may stay green long time after the grain matures. Sorghum grain fraction increases the crude protein and decreases the acid detergent fiber concentration of the feed, but stover can be as important as the head fraction of the plant (Young *et al*. 1995). Stover contributes approximately half of the total dry matter yield and its quality strongly influences the nutritive value of the whole-plant fodder (Pedersen 1996). Sorghum breeding efforts have been successful to improve grain yield, including some biological mechanism for biotic and abiotic

Table 1. Rainfall distribution (mm) in LL (2002/03), VC (2003/04), SC (2004/05) and EZ (2004/05) and the average for 30 years for each environment

Month	LL		VC		SC		EZ	
	2002/03	30-yr	2003/04	30-yr	2004/05	30-yr	2004/05	30-yr
Oct	170.2	120.1	172.0	117.7	85.0	115.0	97.1	111.7
Nov	101.4	102.0	130.4	109.2	189.0	115.1	214.0	100.9
Dec	87.4	107.3	51.0	100.0	121.1	101.0	108.2	95.4
Jan	101.2	104.0	71.4	108.4	35.2	109.7	41.1	108.9
Feb	139.8	118.1	82.6	107.6	190.0	97.8	220.3	106.6

tolerance; however, a potential desirable trait for forage use, the stay green, which delays stover senescence, has been developed (Rooney 2005). Stay-green sorghum cultivars maintain their leaves alive up to advanced stages of maturity (Singh *et al*. 2009) and they are expected to mature slowly with gradual decline in whole-plant quality. It is not clear how stover changes across the grain filling period affect the dry matter quantity and quality contribution on normal and stay green grain sorghum hybrids. So, an examination of dry matter accumulation pattern and plant fractions (head/stover) quality changes across maturity stages would be useful to identify an optimum window to harvest and assist to select new grain and dual-purpose sorghum cultivars. This work was conducted in an attempt to study the dynamics of dry matter accumulation and quality changes across the grain filling period, on grain and dual-purpose sorghum hybrids. Thus, the objectives were: i) to determine the dynamic of head and stover dry matter accumulation across maturation stages, ii) to evaluate the quality changes of head and stover across maturation process, and iii) to evaluate how each fraction (head and stover) contributes to the digestible whole-plant dry matter yield.

Materials and methods

Four field experiments were conducted during 2002 to 2005 growing seasons at representative environments of Buenos Aires milk basin, Argentina. The sites included: "La Lomada" (LL) (2002/2003), on an Argilic argiudoll thapto argilic soil, "Vicente Casares" (VC) (2003/2004), on a Typical argiudoll soil, "Santa Catalina" (SC) (2004/2005) and "Ezeiza" (EZ) (2004/2005), both on Aquic argiudoll soils. The trials were seeded the last week of November. Phosphorus was preplant applied at 40 kg P ha^{-1} rate and nitrogen was side dressed at the six-leaf stage at a rate of 50 kg N ha^{-1}. Weed control was achieved by applying 3.5 L ha^{-1} of atrazine [6-chloro-*N*-ethyl-N'-(1-methlyethyl)-1,3,5-triazine-2,4-diamine] as a pre-plant treatment. Carbofuran [2,3-dihydro-2,2-(dimethyl)-7-benzofuranyl ethylcarbamate] was applied in-furrow to prevent soil insect damage. The genetic material comprised four well adapted sorghum commercial hybrids. This included the early-maturity hybrid P8419, the intermediate-maturity NK412 and late-maturity hybrids P8232 and A9904. Both P8232 and A9904 can be considered as dual-purpose hybrids carrying the stay-green trait, but the former is the only cultivar free of condensed tannins. The experimental plots in each environment were arranged in randomized complete blocks with three replications. Each plot consisted on six rows, 5.2 m long and 0.7 m apart. After emergence, on five-leaf stage (E2) (Vanderlip 1993), plants were hand thinned to a space of 10 cm apart within rows. Ten plants were harvested from the inner four rows at six successive maturity stages (MS): mid-bloom (MB), early milk (EM), late milk (LM), soft dough (SD), hard dough (HD), and physiological maturity (PM). Head (H) and stover (S) were separated and fresh weight of each component was measured. A representative sub-sample of each plant fraction was dried at 60ºC up to constant weight in a forced-air oven to estimate dry weight and then to calculate dry matter content (HDM, SDM and WDM; %). The dry matter yield (Y; Mg ha^{-1}) was measured on head (HY) and stover (SY), both contributing to whole-plant dry matter yield (WY), and then harvest index (HI; %) was calculated. The dried samples of both plant components were ground to pass a 1 mm screen in a mill (FRITSCH Co., Germany). The near infrared reflectance spectroscopy (NIRS) was used for forage quality determinations using a NIRS 6500 Foss (Foss NIRS systems Inc., Silver Spring, MD, USA), collecting the spectra of the ground samples located on a mini dish (100×60 mm). The NIRS calibration equations were determined using a sub-group of head and stover samples previously analyzed by routine laboratory methods. For NIRS calibration, all data were analyzed using partial-least squares (PLS) regression. The criteria used to select prediction equations were the maximization of the coefficient of determination (R^2) and the minimization of the standard error of calibration and cross validation, following the guide of Shenk and Westerhaus (1994). An enzymatic technique (pepsin-cellulase) was used to determine *in vitro* DM digestibility (DIG). Samples were incubated in pepsin (in 0.1 N HCL, 39.5ºC) for 24 h (Jones and Hayward 1975), followed by incubation in cellulase preparations (Trichoderma viride, 39.5ºC) (Gabrielsen 1986) for 48 h. A treatment for starch hydrolysis at high temperature digestion (80ºC) for 45 min was included and performed in a Daisy II incubator (ANKOM technology Corp., Fairport, NY). Total N was determined by rapid combustion (850º) in a LECO N analyzer (LECO FP-528, Leco Co., St. Joseph, MI) (Wiles *et al*. 1998), then crude protein percentage (CP) was calculated as N × 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) determinations were performed using the ANKOM^{220} fiber analyzer (ANKOM technology Corp., Fairport, NY) (Vogel *et al*. 1999). Additionally, 2 ml of a 2% (w/v) α-amylase (Sigma Chemical Co., St. Louis, MO) solution were added to head samples, at the mid-point of refluxing during the NDF procedure (Van Soest and Robertson 1980). Gross energy content was determined using a calorimeter bomb (LECO AC-350, Leco Co., St. Joseph, MI). Quality traits determined in head and stover included: *in vitro* DM digestibility (HDIG and SDIG), crude protein (HCP and SCP), NDF (HNDF and SNDF), ADF (HADF and SADF), ADL (SADL, only in

Table 2. Significance of main effects and their interactions in analysis of variance

SV	Forage yield							Forage quality												
	HDM	SDM	WDM	HY	SY	WY	HI	HDIG	HCP	HDE	HNDF	HADF	SDIG	SCP	SDE	SNDF	SADF	SADL	WDIG	DWY
Environment (EN)	ns	*	ns	ns	*	ns	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Maturity stage (MS)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hybrid (HB)	ns	*	*	*	*	*	ns	*	*	*	*	*	*	ns	*	*	ns	ns	*	*
EN×MS	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
EN×HB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
MS×HB	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
EN×MS×HB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* and ns: Significant and non significant at 5% probability level, respectively

Table 3. Dry matter content (DM) and dry mater yield (Y) of fractions (H-Head; S-Stover; W-Whole plant) across the grain filling period (means averaged across hybrids and environments) and values for hybrids (means averaged across maturities and environments)

Effect	DM (%)			Y (Mg ha^{-1})		
	HDM	SDM	WDM	HY	SY	WY
Maturity						
Mid-bloom	33.8 f	27.8 b	28.5 e	2.1 f	11.9 a	13.9 bc
Early milk	35.7 e	32.0 a	32.2 d	3.5 e	11.2 b	14.7 b
Late milk	43.9 d	28.4 b	32.4 cd	4.7 d	8.8 c	13.5 c
Soft dough	52.0 c	24.2 d	32.9 c	6.3 c	7.4 d	14.0 c
Hard dough	59.3 b	24.3 d	35.1 b	8.3 b	7.7 d	15.9 a
Physiological Maturity	67.1 a	25.2 c	38.7 a	9.3 a	7.6 d	16.9 a
Hybrid						
P8232	48.9 a	28.0 a	33.8 a	5.5 bc	9.8 a	15.4 a
NK412	48.2 a	27.1 b	33.7 a	6.2 a	9.1 b	15.3 a
A9904	49.1 a	27.3 ab	33.5 a	5.8 b	9.7 ab	15.5 a
P8419	48.4 a	25.5 c	32.2 b	5.3 c	7.7 c	13.1 b

Means within a column followed by the same letters are not significantly different at 5% probability level according to LSD test

stover fraction) and digestible energy (HDE and SDE). The HDE and SDE contents, both as Mcal kg^{-1}, were calculated multiplying gross energy content of each fraction by digestibility values. The digestible whole-plant dry matter yield (DWY), expressed in Mg ha^{-1}, was calculated as follows:

$$DWY = (HY \times HDIG) + (SY \times SDIG).$$

The whole-plant digestibility (WDIG), expressed in %, was determined by the formula:

$$WDIG = (DWY / WY) \times 100$$

Data were statistically analyzed by analysis of variance which included environment, maturity stage, hybrid and their interactions as variation sources. Each environment was considered as random effect, whereas hybrid and maturity stage were fixed effects. Mixed model was performed according to McIntosh (1983) and significance was considered at 0.05 level of probability. When statistically significant, multiple comparisons were made using Fisher's protected LSD. Data were analyzed using SAS (Statistical Software Package 2004).

Results and discussion

Climatic conditions

Table 1 shows rainfall distribution for the four environments. The EZ site registered the highest cumulative precipitations for all the season. During January to February (the most critical period), rainfall varied from 225 to 261 mm at LL, SC and EZ environments. However, only 154 mm were registered at VC in the same period. Particularly, rainfall was 21% above the 30-yr mean at EZ, while 28% below the historical mean was recorded at VC, as extremes values.

When averaged across environments, the earliest maturing hybrid (P8419) reached mid-bloom stage (E6) 78 days after sowing, while the later maturing hybrid (P8232) required 91 days. In average, 39 days elapsed between the first (MB) and the last (PM) maturity stages at LL, VC and SC, but this period was extended to 43 days at EZ environment. Plant height varied from averages of 140 cm (P8419) up to 175 cm (A9904).

Forage yield

The significances of main effects and their interactions in the analysis of variance for each trait of forage yield are shown in Table 2. No interactions were detected for all the traits, except for HI, in which the environment interacted with the maturity stage. Of special interest is that, although precipitation pattern and amount differed among sites, the environment had lower impact than the other two main effects. In this sense, maturity and hybrid affected most variables involved in forage yield. Thus, means of such variables within maturities (averaged across environments and hybrids) and hybrids (averaged across environments and maturities) are presented in Table 3. Close examination of Table 3 reveals that stover DM content increased up to EM and then decreased to SD, indicating the mobilization and translocation of non-structural carbohydrates from stover towards the developing head. The head and the whole plant dry matter content increased throughout the grain filling period, reaching a maximum value at physiological maturity (Table 3). Particularly, at LL, the more productive environment, during EM to PM of grain filling period, head DM content increased about five fold faster than whole-plant DM (data not shown). During the grain filling period the harvest index showed a tendency to increase, due to the dry matter stover decreased and the head dry matter continuous increasing (Fig. 1). Although no maturity × hybrid interaction occurred, a slight increase in the variable SDM was observed on P8232 and A9904 cultivars after HD, so stay-green may have probably contributed to this fact. According to Thomas and Howarth (2000) classification, these two hybrids could be classified as “A” type stay-green, within which stover senescence is initiated late but then proceeds at a normal rate. As it is shown in Table 3, no great variation among hybrids for head and whole plant DM content was observed, except for the whole plant DM content of P8419 which was lower than those of the others. Moreover, the hybrid P8419 had almost 9% lower stover DM content than P8232. Due to the lack of maturity × hybrid interaction (Table 2) for SDM, our results partially agree with the findings of McBee *et al*. (1983) who noted that no senescing cultivars contained significantly more carbohydrates at early maturity stages than the senescing ones. Díaz *et al*. (2001) also found a similar range of values for this trait in silage samples. Head yield increased from MB to PM, when it peaked at 9.3 Mg ha^{-1} (Table 3). Averaging across maturities, NK412 had the greatest ($p<0.05$) head yield, producing 14.5% more than the lowest yielding P8419, although both of them registered similar values for harvest index (data not shown). In all environments, MB stage had the highest values for SY. Afterwards, the stover yield decreased until SD stage, and then it stabilized at almost 7.5 Mg ha^{-1} (Table 3). Dual-purpose hybrids P8232 and A9904 had the highest ($p<0.05$) stover yield, almost 21% more than P8419, the lowest yielding hybrid, possibly due to a different plant architecture that includes a lower total leaf area. The SY trait was affected by the environment, which could be partially explained by rainfall at critical growth stages. With respect to whole-plant yield, its maximum value was reached at PM stage, but without significant differences with the previous HD stage. The maturity stage seemed to strongly affect HI values, increasing across grain filling and reaching a maximum at physiological maturity (Fig. 1). The observed environment × maturity interaction suggests that HI registered in each environment depended upon stages of maturity. In this sense, in the first two maturity stages (MB and EM), SC environment produced among the lower values of HI, being intermediate at LM stage, while it reached among the higher values at the last stage of maturity. In general, the best performance for HI was registered in EZ environment in all stages of grain filling (Fig. 1). Apparently, the highest rainfall recorded at EZ during the season might have contributed to such enhanced HI production.

Forage quality

The Table 2 summarizes the significances of main effects and their interactions in the analysis of variance for different traits contributing to forage quality. While significant main effects of maturity and hybrid were observed for most measured traits, the environment did not influence any of them, except for HCP. Thus, Table 4 shows the means for maturities (averaged across environments and hybrids) and hybrids (averaged across environments and maturities). The two-way interaction maturity × hybrid reached significance only in HDIG, HDE and DWY. No three-way interaction occurred in any variables. In general, both head and stover forage quality of sorghum hybrids changed across the grain filling period (Table 4). Immature heads could produce a lower quality than heads harvested between soft dough and hard dough. This agrees partially with results found by Sonon and Bolsen(1996), who reported decreasing whole-plant CP, NDF, and ADF and increasing digestibility during grain filling phase. Head fiber content (NDF and ADF) and head CP decreased from MB to SD and then stabilized up to PM. The head NDF was 11.2% greater in NK412 than A9904 as extremes values, but all genetic material had a similar tendency across maturation process (Table 4). Although significant differences of hybrid (Table 4) and environment (not shown) for head CP were registered, the magnitudes could be considered small and probably of little practical importance. Significant maturity × hybrid interaction observed in some attributes related to head quality (HDIG and HDE (Table 2).

Table 4 Quality traits of head (H) and stover (S), and whole-plant (W) digestibility across the grain filling period (means averaged across hybrids and environments) and values for hybrids (means averaged across maturities and environments)

Effect	H			S						W
	HCP (%)	HNDF (%)	HADF (%)	SDIG (%)	SCP (%)	SDE (Mcal kg^{-1})	SNDF (%)	SADF (%)	SADL (%)	WDIG (%)
Maturity										
Mid-bloom	11.8 a	66.4 a	30.3 a	49.5 a	4.1 b	1.9 a	65.6 e	41.4 d	7.7 c	50.6 d
Early milk	11.2 b	60.6 b	23.0 b	46.8 b	3.9 c	1.8 b	66.3 d	42.2 c	8.0 bc	52.8 c
Late milk	10.2 c	53.6 c	18.5 c	41.9 c	4.1 b	1.6 c	68.2 c	44.1 b	8.1 b	53.9 c
Soft dough	9.4 d	49.0 d	15.6 d	34.4 d	4.1 b	1.3 d	71.6 b	46.6 a	8.3 a	55.2 b
Hard dough	9.4 d	49.1 d	14.6 e	33.6 d	4.2 a	1.2 d	72.5 a	46.4 a	8.1 b	57.5 a
Physiological Maturity	9.6 d	49.8 d	15.3 de	31.7 e	4.2 a	1.1 e	72.6 a	46.2 a	8.1 b	56.7 a
Hybrid										
P8232	9.8 b	59.9 a	19.5 c	38.4 b	4.2 a	1.4 b	70.6 a	45.0 a	8.0 a	53.5 c
NK412	10.3 a	61.4 a	22.2 a	40.0 a	4.1 a	1.5 ab	69.0 b	44.3 a	8.1 a	54.3 bc
A9904	10.5 a	54.5 c	19.3 c	40.2 a	4.1 a	1.6 a	68.3 c	43.9 a	8.0 a	55.3 a
P8419	10.3 a	56.5 b	20.5 b	39.9 a	4.0 a	1.5 ab	69.9 a	44.8 a	8.1 a	54.7 ab

Means within a column followed by the same letters are not significantly different at 5% probability level according to LSD test

could confirm hybrid variability for these traits, partially due to panicle morphology and tannin content. The white grain sorghum free of condensed tannins (P8232) showed among the higher head digestibility values in most maturity stages (Fig. 2). Similar results were reported by Wester *et al.* (1992), O'Brien (1999), Díaz *et al*. (2001) and Montiel (2003). Contrastly, NK412 had low HDIG values throughout grain filling process (Fig. 2), which could be related to its high content in HADF (Table 4). For brevity, data of HDE regarding to maturity × hybrid interaction is not analyzed because it does not add much to this discussion. Stover fiber content (SNDF, SADF and SADL) increased across grain filling phase (Table 4). As consequence, there was a great change for stover digestibility during maturity process, e.g. SDIG and SDE decreased 17.8 and 0.8 units from MB to PM, respectively. More specifically, SDIG and SDE content decreased at a lower rate from MB to EM than from EM to HD stage. Such strong decrease of stover digestibility from EM to HD could be partially associated with the diminishing of stover DM content registered throughout such period of grain filling, as previously commented. As it is shown in Table 4, no genetic effect was observed for SCP. Although statistical differences for SCP were detected among maturities, such variability could be considered of insufficient magnitude to be of practical value. In Argentina, maize and sorghum crops are primarily grown as energy source feeds and CP concentration is not of primary concern because protein-rich pasture forages are also produced on most livestock operations. Similarly, the variables SADF and SADL did not vary among hybrids. Due to the maturity × hybrid interaction detected in DWY, data were analyzed separately within each maturity stage (Fig 3). As it is shown, at HD and PM stages, DWY for the grain P8419 was significantly lower than for the dual purpose (P8232 and A9904) and the grain NK412 hybrids. Moreover, no statistical differences were detected among such three materials in these particularly late stages of maturity, although their ranking tended to vary earlier during the grain filling phase. As consequence of the quality changes in both plant fractions, whole-plant digestibility increased across maturity stages (up to HD, and then it stabilized), which could be related to starch build-up in the head and to a decrease in whole-plant cell-wall content due to a dilution effect. Therefore, the harvest index increase and the head fiber decrease might have more influenced on whole-plant digestibility (WDIG) than the progressive reduction of stover digestibility. When sorghum crop is recommended to producers, its purpose should be considered. Although the whole-plant DM content at PM was significantly higher than at HD, the harvest of crop for silage purpose at late-hard dough maturity or later, will increase the undigested amount of the grains and decrease the nutritional value, since the over mature kernels become harder and less digestible if left unbroken (Bolsen 2002; Camps and Gonzalez 2003). All data reported in our work are from unfermented forage, however some quality inference could be made to silage. This inference from unfermented samples should be valid, except when comparing sweet vs. grain sorghum (dry stalk), which was not the case in the present study. Our results indicate that whole-plant DM content is within the recommended ensiling range (30 to 40% DM) as soon as at early-milk stage, which may be a criterion for silage harvest when an early release of the field is desired. The differences in both forage yield and quality among maturities observed in our study may be of sufficient consistency to possess practical value to forage producers. Specifically, some constraints faced by sorghum producers are to determine the optimum time to harvest and the length of the harvest window.

Evaluation of plant fractions allowed us to verify the changes in yield and quality across maturity stages and to suggest a proper time to harvest whole plants for fodder and silage purposes. Based on these criteria, grain and dual-purpose sorghum hybrids cropped under rain fed conditions had a window of maturity stages for harvest that should start at early-milk and conclude before physiological maturity. However, digestible whole-plant DM yield should be also taken into account since it seemed to reach the highest value at hard-dough stage, whitout changing later on. Finally, before recommending hybrids to producers based on their forage yield and quality, studies on animal feeding should be carried out to verify if such differences can influence on animal production.

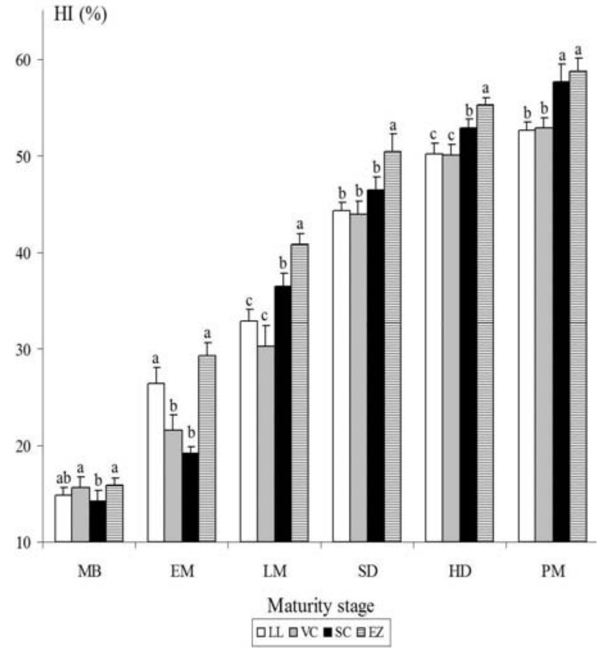

Fig 1. Harvest index (HI) of four environments during grain filling. Mean values across four sorghum hybrids (vertical bars indicate standard errors of the mean). Same small letters are not significantly different at 5% probability level according to LSD test. The LSD tests the means among environments within each maturity stage.

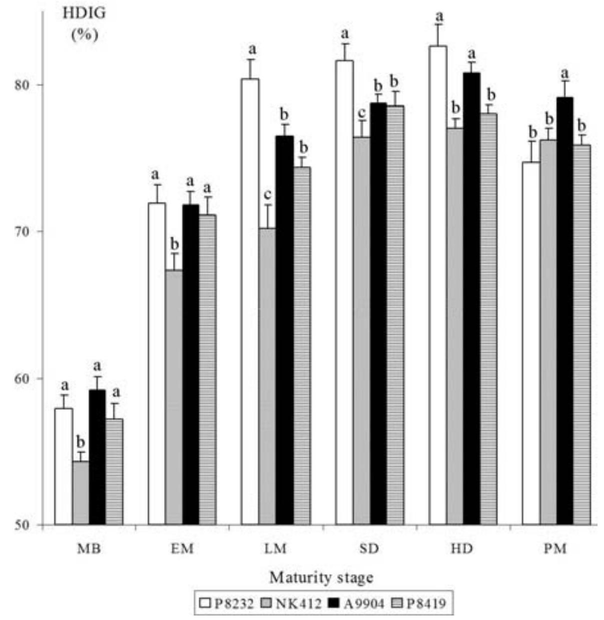

Fig 2. Head *in vitro* dry matter digestibility (HDIG) in four sorghum hybrids during grain filling. Mean values across four environments (vertical bars indicate standard errors of the mean). Same small letters are not significantly different at 5% probability level according to LSD test. The LSD tests the means among sorghum hybrids within each maturity stage.

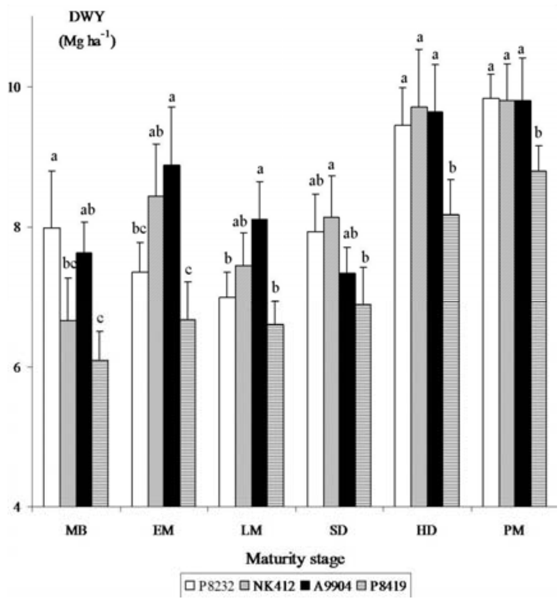

Fig 3. Digestible whole-plant dry matter yield (DWY) in four sorghum hybrids during grain filling. Mean values across four environments (vertical bars indicate standard errors of the mean). Same small letters are not significantly different at 5% probability level according to LSD test. The LSD tests the means among sorghum hybrids within each maturity stage.

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