Research Article

Sorghum *Bmr6* and *Bmr12* Lines May Provide New Forage Opportunities in West Africa

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Abstract

Sorghum stover consisting of stalks and leaves collected from production fields after grain harvest is a significant source of feed for livestock across West Africa. Improving the dry matter yield and the nutritional value of stover from locally-adapted sorghum varieties may contribute to mitigation of animal feed shortages that are common in this region. The *Brown midrib* (*Bmr*) *Bmr6* and *Bmr12* genes were introgressed in two Nigerien elite sorghum varieties for stover improvement. The parental lines and derived progenies were tested in replicated field trials for differences in agronomic performance including grain and stover production. The stover samples were characterized for differences in nutritional characteristics including dry matter, NDF (Neutral Detergent Fiber), ADF (Acid Detergent Fiber), ADL (Acid Detergent Lignin). Statistical analyses indicated highly significant differences among entries for grain yield, fresh stover yield, dry matter yield, and nutrients content. The *Bmr* genotypes performed well compared with the conventional varieties. El Mota *Bmr12* produced 3.0-3.5 tonnes ha-1 for grain yield. Sepon-82 *Bmr6* produced 16.5 tonnes ha-1 fresh stover yield and 16.4 tonnes ha-1 dry matter yield. The *Bmr* genotypes showed improved nutritional values. Promising lines were identified using the Baker's Standard Deviation method. The introgression of the *Bmr* genes enhanced the nutritional values of sorghum lines for dual purpose uses for local farmers.

Keywords: Sorghum, Dual purpose, Feed, *Brown midrib*, Nutritional potential.

INTRODUCTION

Forage crop production plays a key role in agricultural productivity in Africa with more than 340 million tons of fibrous crop residues produced each year (Kossila et al., 1985). Sorghum is an important forage crop in the semiarid tropics, especially in drought prone areas where it is hot or dry to grow other crops (Lima et al., 2005). In Niger, cereals stover are a significant source of feed for livestock during the long and dry season, which coincides with shortage of feed for small scale farmers, particularly in the context of limited availability of natural pasture (Diakite et al., 2017).

The stover market is a growing business in Niger (Diakite et al., 2019). Improving stover production and nutritional quality might therefore constitute an additional source of income for local farmers. The CGIAR (2011) estimated that crop residues, especially stover and straw, are increasingly important commodities that significantly increase the overall value of dryland cereals. Stover markets are expanding in the drier, more densely populated areas of West Africa. Furthermore, as the demand for livestock and livestock

products increases, so too does the importance of fodder and feed markets.

Crop improvement programs have been initiated in West Africa in increase forage production and quality. The FAO declared that the cereals residues are major forages and sorghum residues were qualified as a valued feed, especially if cut and dried immediately after the heads have been harvested for grain (www.fao.org). In small-scale farming systems, stover is usually harvested and dried after grain harvest. The unchopped stover is further stored and used as livestock feed. FAO (2012) reported that in tropical countries, dairy animals are primarily fed on crop residue based diets with very little green fodder/hay/silage, which may only be available for a limited time. A participatory rural appraisal conducted in 2016 in three localities in Niger revealed that milking cows, bullocks and then draught animals were the main beneficiaries of sorghum stovers (Diakité et al., 2017). However, those stovers were qualified as having low nutritional values by farmers and stover traders. Suharti et al., (2011); Veatch-Blohm, (2007) asserted that low cattle production in developing countries may be caused by inadequate nutrient supply in high-forage based rations. Moreover, Sultan et al., (2011) reported that crop residues as dry roughages from cultivated grain are rich in fiber and low in nitrogen, minerals and vitamins. Decreased nitrogen and digestibility and increased fiber and lignin contents are common in forages harvested after grain production (Sultan et al., (2011).

Several studies have reported on the digestibility of stovers. Akinola et al., (2015) affirmed that the cereal crop residues' potential as livestock feed is enormous if appropriate methods of improving their nutritive value are used. Gerhardt et al., (1994). & Oliver et al., (2004) reported that forage sorghum digestibility can be significantly improved with the use of *Bmr* genes.

Sorghum constitutes an important forage crop for grazing dairy cows. Some studies have demonstrated that silage from *Bmr* sorghum, with or without protein supplements, significantly increases the milk production of lactating cows (Cherney et al., 1991; Oba & Allen, 1999) and animal performance. These properties make the use of *Bmr* sorghum for cattle feeding very attractive in many countries. A trial using *Bmr* sorghum for feeding dairy cows in Costa Rica, El Salvador, Nicaragua, Honduras, Guatemala, Panama and Haiti demonstrated superior feed value and contributed to the rapid spread of *bmr* forage sorghum throughout Central America (INTSORMIL, 2013).

In this study, the *Bmr*6 and *Bmr*12 genes were introgressed in two Nigerien elites sorghum varieties by conventional plant breeding (Oliver et al., 2005; Diakité et al., 2018). The main objective of this study was to assess the potential of the new lines for further forage opportunities in Niger. The parent lines and derived progenies were tested in replicated field trials for differences in agronomic performance and nutritional characteristics of the stover.

MATERIALS AND METHOD

Sorghum Genotypes

The *Bmr*6 and *Bmr*12 mutations (Porter et al., 1978); Singh et al., (2011) were crossed to open pollinated varieties El Mota and Sepon-82 from Niger to produce breeding populations. *Brown midrib* progeny in each population were self-pollinated and advanced by pedigree breeding to the F6 generation with selection for the *Brown midrib* trait. Ten *Bmr*12 progeny from the El Mota population (BCS1), six *Bmr*6 progeny from the Sepon-82 (BCS2) population, Two *Bmr*12 progeny from the Sepon-82 (BCS3) and six checks including the recurrent and *Bmr* donor parents and one local landrace variety were evaluated in field trials in 2021.

Field Trial

The field trial was conducted during the rainy season in 2021 at the INRAN research farm at Kollo, NIGER 2°18'07.8'' East; 13°20'09.3'' North. The experimental design was an alpha lattice with three replications. Every entry was sown on 3 rows. The row length was 3 m and the sowing density was 0.80 m between rows and 0.50 m between hills on the row (0.80 m x 0.50 m). The standard cultural practices were performed. All phenotypic data were collected on plants in the middle row. After thinning, three plants were retained in every planting hill. Grain yield, fresh stover yield, and dry stover yield were determined on the center row of every plot for every family. Stover samples (leaves + stems) of every entry were collected at maturity after the panicles were harvested for nutrient content analysis. Sorghum plants were cut at ground level, and the collected stover samples were dried for two months on shelves in a shaded areas. The stover quality analyses included dry matter, NDF (Neutral Detergent Fiber), ADF (Acid Detergent Fiber), and ADL (Acid Detergent Lignin) contents using the sequential filter bags method of the ankom technology for the last three elements (Table 1).

Table 1: Phenotypic and nutrient content variables.

Phenotypic data	Nutritional data
Grain yield	Dry matter
Fresh stover yield	Neutral Detergent Fiber
Dry matter yield	Acid Detergent Fiber
	Acid Detergent Lignin

Statistical Analysis

Analyses of Variance (ANOVA) were performed with R 3.4.1 environment for statistical computing using PBIB. test function (package 'agricolae') for the alpha design analysis of variance and the least significant difference (LSD) using the linear model as follow:

$$Y_{ijl} = \mu + t_i + r_j + b_{i(j)} + e_{ijl}$$

Where; Y_{ijl} = value of the observed trait; t_i = treatment effect and (I = 1…100); r_j = replication effect and (j = 1..3); b = block within replicate effect and (j = 1…10); e = random error

Elites lines selection was performed using the Baker's Standard Deviation for multi traits selection method (BSD). Grain, fresh stover and dry matter yields were estimated according to Mark and Todd (1986) using the below formula:

$$BSD = \sum X_1 / \sigma_{pi} :$$

Where $\sum \bar{X}_1$ is the sum of mean of the ith trait and σ_{pi} is the phenotypic standard deviation of the ith mean

RESULTS

Phenotypic variables

The ANOVA revealed significant variation in grain yield, fresh stover yield, and dry matter yield among the varieties (Table 2). Comparisons of performance among the *Brown midrib* progenies and checks indicated that the El Mota *Bmr*12 progenies were similar or performed slightly better than the Sepon-82 *Bmr*6 progenies and check genotypes for GY (Table 3). The performance of the Sepon-82 *Bmr*6 progenies was more competitive with the El Mota *Bmr*12 progenies for FSY and DSY (Table 3) with most of the *Brown midrib* progeny exhibiting similar performance.

Nutrients Content

The ANOVA revealed significant variability between the varieties for dry matter and nutrient contents for ADF and ADL (Table 4) (Figure 1).

Elites Lines Selection

The application the Baker's Standard Deviation for multi

Table 2: Mean squares of *bmr* families, parental lines and the check.

Variables	SOV	Df	Mean Sq	Pr(>F)	
Grain_Yield	VAR	23	1612700	0.000	***
	Replicates	2	1556977	0.017	*
	Replicates/Blocks	4	470479	0.268	
	Residuals	42	349300		
Fresh stover yield	VAR	23	296777572	0.000	***
	Replicates	2	457871046	0.000	***
	Replicates/Blocks	4	238716966	0.005	**
	Residuals	42	55641562		
Dry matter yield	VAR	23	4,2345	0.000	***
	Replicates	2	4,6522	0.014	*
	Replicates/Blocks	4	5,7123	0.000	***
	Residuals	42			

0.05=*; **=0.01; ***=0.001: significant at probability level; ns=not significant; Df =Degree of freedom; GY=Grain Yield; FSY=Fresh Stover Yield; DM=Dry Matter Yield.

Table 3 : *bmr*, parental lines and check performance par variable.

VAR	GY (t/ha)	Groups	VAR	FSY (t/ha)	Groups	VAR	DMY (t/ha)	Groups
El Mota *bmr12*-88	3,505	a	Local check	52,167	a	Local	17,611	a
El Mota *bmr12*-102	3,430	ab	Sepon-82 *bmr6*-138	46,528	ab	Sepon-82 *bmr6*-138	16,399	ab
El Mota bmr12-92	3,373	ab	Sepon-82 *bmr6*-201	39,722	abc	El Mota *bmr12*-102	12,644	abc
El Mota *bmr12*-95	3,335	abc	El Mota *bmr12*-102	37,778	abcd	EL Mota	12,593	abc
El Mota *bmr12*-60	3,331	abc	El Mota *bmr12*-66	36,528	abcd	Sepon-82 *bmr12*-210	12,338	abc
El Mota *bmr12*-82	3,163	abc	Sepon-82 *bmr6*-199	36,389	abcd	Sepon-82 *bmr6*-199	12,009	abc
El Mota *bmr12*-71	3,113	abcd	El Mota *bmr12*-71	34,306	abcd	Sepon-82 *bmr12*-192	11,817	abcd
El Mota *bmr12*-18	3,036	abcd	Sepon-82 *bmr6*-145	33,944	abcd	El Mota *bmr12*-66	11,698	abcd
Sepon-82 *bmr6*-203	2,854	abcd	Sepon-82 *bmr12*-210	33,750	abcd	Sepon-82 *bmr6*-201	11,256	abcd
El Mota *bmr12*-66	2,533	abcd	EL Mota	33,222	abcd	El Mota *bmr12*-82	11,229	abcd
El Mota *bmr12*-68	2,465	abcd	El Mota *bmr12*-18	32,222	abcd	El Mota *bmr12*-68	11,201	abcd
Sepon-82	2,413	abcd	Sepon-82 *bmr12*-192	32,139	abcd	Sepon-82 *bmr6*-145	11,199	abcd

Sepon-82 *bmr6*-138	2,403	abcd	Sepon-82	31,528	abcde	El Mota *bmr12*-71	11,032	abcd
EL Mota	2,335	abcd	El Mota *bmr12*-82	30,139	abcde	El Mota *bmr12*-18	11,010	abcd
Sepon-82 *bmr6*-145	2,328	abcd	El Mota *bmr12*-68	29,583	abcde	El Mota *bmr12*-60	10,648	abcd
Sepon-82 *bmr6*-199	2,301	abcd	El Mota *bmr12*-95	29,444	abcde	El Mota *bmr12*-92	10,636	abcd
Sepon-82 *bmr12*-192	2,239	abcd	El Mota *bmr12*-92	28,889	abcde	Sepon-82	10,401	abcd
Local check	2,205	abcd	Sepon-82 *bmr6*-172	28,583	abcde	El Mota *bmr12*-95	10,029	abcd
Sepon-82 *bmr12*-210	1,792	abcd	El Mota *bmr12*-60	28,194	abcde	Sepon-82 *bmr6*-172	9,561	abcd
Sepon-82 *bmr6*-172	1,535	abcd	El Mota *bmr12*-88	23,056	bcde	El Mota *bmr12*-88	8,074	bcd
Tx630 *bmr12*	1,514	bcd	Sepon-82 *bmr6*-203	17,417	cde	Sepon-82 *bmr6*-203	5,982	cd
Sepon-82 *bmr6*-201	1,362	cd	Tx630 *bmr12*	16,389	cde	Redlan *bmr6*	5,465	cd
Wheatland *bmr12*	1,357	cd	Redlan *bmr6*	13,722	de	Tx630 *bmr12*	5,426	cd
Redlan *bmr6*	1,132	d	Wheatland *bmr12*	6,667	e	Wheatland *bmr12*	2,574	d

GY=Grain Yield; FSY=Fresh Stover Yield; DM=Dry Matter Yield.

Table 4: Mean squares of *bmr* families, parental lines and the check for their nutrient content.

Variables	SOV	DF	Mean Sq	Pr(>F)	
DM	VAR	23	0.78665	0.000	***
	Rep	1	0.03853	0.506	
	Block/Rep	1	0.32200	0.063	
	Residuals	22	0.08430		
NDF	VAR	23	3.1562	0.475	
	Rep	1	8.3667	0.113	
	Block/Rep	1	2.0301	0.424	
	Residuals	22	3.0704		
ADF	VAR	23	1.32975	0.006	**
	Rep	1	2.21880	0.037	
	Block/Rep	1	0.46803	0.319	
	Residuals	22	0.45058		
ADL	VAR	23	0.40244	0.002	**
	Rep	1	0.00521	0.834	
	Block/Rep	1	0.01950	0.685	
	Residuals	22	0.11586		

0.05=*; **=0.01; ***=0.001: significant at probability level; ns=not significant; Df =Degree of freedom; DM=Dry matter; NDF= Neutral detergent fiber; ADF=Acid detergent fiber; ADL=Acid detergent lignin.
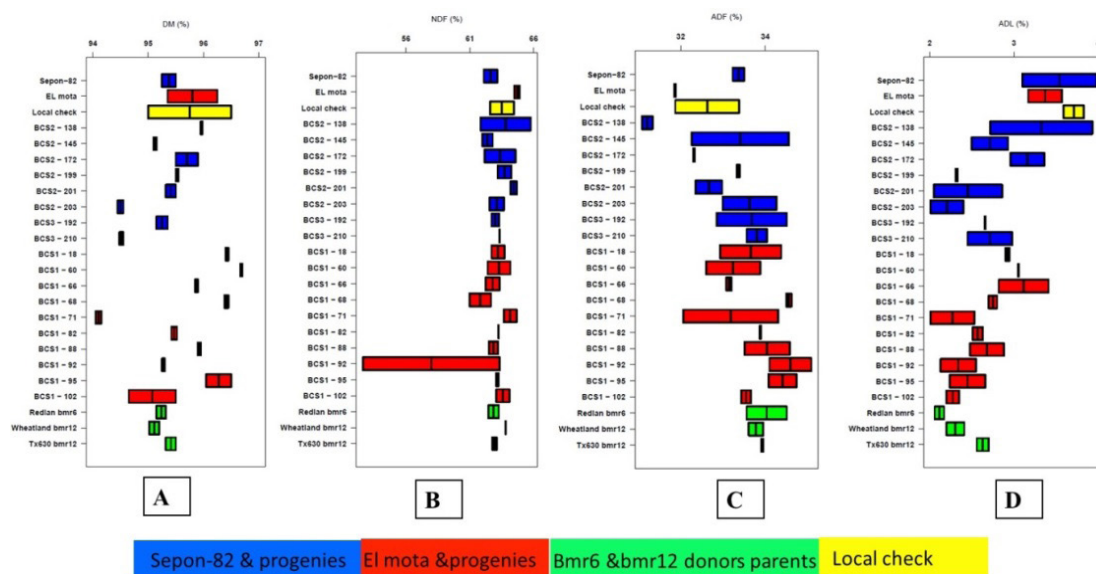

Figure 1: Variation in DM, NDF, ADF, and ADL among brown midrib progeny, parental lines and check genotypes.

VAR	GY	VAR	FSY	VAR	DMY	GY	FSY	DMY	BSD	Weight of GY	Weight of FSY	Weight of DMY	Selection Index	Ranking
El Mota *bmr12*-88	3505,003	Local check	52166,667	Local	17611,206	5,779	6,273	6,420	18,472	1,043	2,463	2,387	5,893	1
El Mota *bmr12*-102	3429,583	El Mota *bmr12*-102	37777,778	El Mota *bmr12*-102	12644,139	5,654	4,543	4,609	14,807	0,919	0,733	0,576	2,228	2
El Mota *bmr12*-92	3373,056	El Mota *bmr12*-66	36527,778	El Mota	12593,039	5,561	4,392	4,591	14,544	0,826	0,582	0,557	1,965	3
El Mota *bmr12*-95	3334,582	El Mota *bmr12*-71	34305,556	El Mota *bmr12*-66	11698	5,498	4,125	4,264	13,887	0,762	0,315	0,231	1,309	4
El Mota *bmr12*-60	3330,972	El Mota	33222,222	El Mota *bmr12*-82	11229,361	5,492	3,995	4,094	13,580	0,757	0,185	0,060	1,001	5
El Mota *bmr12*-82	3163,333	El Mota *bmr12*-18	32222,222	El Mota *bmr12*-68	11201,361	5,215	3,875	4,083	13,174	0,480	0,064	0,050	0,595	6
El Mota *bmr12*-71	3113,194	El Mota *bmr12*-82	30138,889	El Mota *bmr12*-71	11032,472	5,133	3,624	4,022	12,779	0,397	-0,186	-0,012	0,200	7
El Mota *bmr12*-18	3035,694	El Mota *bmr12*-68	29583,333	El Mota *bmr12*-18	11010,389	5,005	3,557	4,014	12,576	0,270	-0,253	-0,020	-0,003	8
El Mota *bmr12*-66	2532,639	El Mota *bmr12*-95	29444,444	El Mota *bmr12*-60	10648,431	4,176	3,541	3,882	11,598	-0,560	-0,270	-0,152	-0,981	9
El Mota *bmr12*-68	2465,417	El Mota *bmr12*-92	28888,889	El Mota *bmr12*-92	10636,278	4,065	3,474	3,877	11,416	-0,671	-0,336	-0,156	-1,163	10
EL Mota	2334,722	El Mota *bmr12*-60	28194,444	El Mota *bmr12*-95	10028,944	3,849	3,390	3,656	10,896	-0,886	-0,420	-0,377	-1,683	11
Local check	2205	El Mota *bmr12*-88	23055,556	El Mota *bmr12*-88	8074,361	3,635	2,772	2,943	9,351	-1,100	-1,038	-1,090	-3,228	12
Tx630 *bmr12*	1514,304	Tx630 *bmr12*	16388,889	Tx630 *bmr12*	5426,194	2,497	1,971	1,978	6,446	-2,239	-1,839	-2,055	-6,133	13
Average GY	2872,115308	Average FSY	31685,89746	Average DMY	11064,16731									
Std dev GY	606,5271247	Std dev FSY	8315,949414	Std dev DMY	2743,21169									
VAR	GY	VAR	FSY	VAR	DMY	GY	FSY	DMY	BSD	Weight of GY	Weight of FSY	Weight of DMY	Selection Index	Ranking
Sepon-82 *bmr6*-203	2854,163	Local check	52166,667	Local	17611,206	4,960	4,185	4,333	13,478	1,381	1,511	1,603	4,495	1
Sepon-82 *bmr6*-138	2403,194	Sepon-82 *bmr6*-138	46527,778	Sepon-82 *bmr6*-138	16399,431	4,177	3,733	4,035	11,944	0,598	1,058	1,304	2,961	2
Sepon-82 *bmr6*-145	2328,472	Sepon-82 *bmr6*-201	39722,222	Sepon-82 *bmr6*-199	12008,583	4,047	3,187	2,955	10,188	0,468	0,513	0,224	1,204	3
Sepon-82 *bmr6*-199	2301,04	Sepon-82 *bmr6*-199	36388,889	Sepon-82 *bmr6*-201	11256,083	3,999	2,919	2,770	9,688	0,420	0,245	0,039	0,704	4
Sepon-82 *bmr6*-172	1535,497	Sepon-82 *bmr6*-145	33944,444	Sepon-82 *bmr6*-145	11198,544	2,669	2,723	2,755	8,147	-0,910	0,049	0,025	-0,837	5
Sepon-82	2413,053	Sepon-82 *bmr6*-172	28583,333	Sepon-82 *bmr6*-172	9561,286	4,194	2,293	2,353	8,839	0,615	-0,381	-0,378	-0,144	6
Sepon-82 *bmr6*-201	1361,811	Sepon-82	31527,778	Sepon-82	10400,528	2,367	2,529	2,559	7,455	-1,212	-0,145	-0,172	-1,529	7
Local check	2205	Local check	17416,667	Sepon-82 *bmr6*-203	5982,181	3,832	1,397	1,472	6,701	0,253	-1,277	-1,259	-2,282	8
Redlan *bmr6*	1131,664	Redlan *bmr6*	13722,222	Redlan *bmr6*	5464,908	1,967	1,101	1,345	4,412	-1,612	-1,573	-1,386	-4,571	9
Average GY	2059,321556	Average FSY	33333,33333	Average DMY	11098,08533									
Std dev GY	575,4021173	Std dev FSY	12465,32235	Std dev DMY	4064,21226									
VAR	GY	VAR	FSY	VAR	DMY	GY	FSY	DMY	BSD	Weight of GY	Weight of FSY	Weight of DMY	Selection Index	Ranking
Sepon-82 *bmr12*-192	2238,611	Local check	52166,667	Local	17611,206	5,252	3,221	3,249	11,722	0,557	1,292	1,229	3,078	1
Sepon-82	2413,053	Sepon-82 *bmr12*-192	32138,889	Sepon-82 *bmr12*-192	11816,867	5,661	1,985	2,180	9,826	0,967	0,055	0,160	1,182	2
Local check	2205	Sepon-82	31527,778	Sepon-82	10400,528	5,173	1,947	1,919	9,039	0,479	0,017	-0,101	0,395	3
Sepon-82 *bmr12*-210	1791,576	Sepon-82 *bmr12*-192	33750	Sepon-82 *bmr12*-210	12338,167	4,203	2,084	2,276	8,563	-0,491	0,154	0,256	-0,080	4
Wheatland *bmr12*	1356,704	Wheatland *bmr12*	6666,667	Wheatland *bmr12*	2574,139	3,183	0,412	0,475	4,069	-1,511	-1,518	-1,545	-4,575	5
Average GY		Average FSY		Average DMY										
Std dev GY		Std dev FSY		Std dev DMY										

Figure 2: Identification of elites lines per population.

traits selection method was used to identify the best performing lines in each population. El Mota *Bmr*12-88, El Mota *Bmr*12-102 and El Mota *Bmr*12-92 were identified as the best performing lines in the El Mota population. Sepon-82 *Bmr*6-203 and Sepon-82 *Bmr*6-138 were identified as the best performing lines in the Sepon-82 population (Figure 2).

DISCUSSION

The objective of this study was enhancement of locally-adapted sorghum varieties through genetic improvement of forage quality using the *Bmr*6 and *Bmr*12 mutations. Several El Mota *Bmr*12 and Sepon-82 *Bmr*6 lines were developed and identified as having outstanding productivity and nutritional quality. Acquaah (2007) reported that the backcross method of breeding is best suited to improve established cultivars that are later found to be deficient in one or two specific traits. For the case of *Bmr* type, Oliver et al. (2005) reported that *Bmr* genes were found to have negative agronomic impact on grain and stover yields in grain sorghum lines but the yield-drag can be overcome with heterosis. Furthermore, the improvement of the stover quality due to *Bmr* genes increases the potential value of *Bmr* lines and compensate grain yield-drag. In this view, the CGIAR (2011) reported that the classical target of research has been on increasing the output of grain, while the value of the stover was of secondary interest. High grain yield combined with healthy dry matter stover yields are essential breeding traits for local small-scale farmers. Camara et al. (2006) revealed that characteristics of the variety such as early maturity, less diseases and drought resistance incidences and productivity influenced sorghum and millet adoption by farmers.

In this study, the local check performed better than all the entries for the fresh stover and dry matter yields. Many of the *Bmr*6 and *Bmr*12 progenies performed similar to the local check and exhibited excellent nutritional value. High stover yield of local landraces indicates farmers' varietal preference for varieties with high stover potential and shows the high importance of stover from cereal crops in the country. In addition, Magnan et al. (2012) reported that the importance of crop residue as feed has an implication for farmers' cereal variety choice. On the other hand, superior varieties with low biomass yield might not be selected by farmers in areas where stover value is high. Vinutha et al. (2017) considered that the important feed traits to be considered for crop improvement should include high biomass yields of good quality forage. The results of the current study are in agreement with those authors. Several *Bmr* lines performed better than their parental lines in fresh and dry matter yields. Current results are in harmony with Kotasthane et al. (2015) who evaluated *Bmr* sorghum parental lines and their derivatives for fresh and dry biomass and found some derived lines superior to their parental lines checks. The global forage quality measured by DM, NDF, ADF, and ADL showed variability.

The relative highest DM, ADF combined with the low ADL content of the *Bmr* varieties are in harmony with Dahlberg et al. (2012). In addition, Ouda et al., (2005); Diakite et al (2017) showed that *Bmr* genotypes had a better degradability and hence nutritive value than the normal genotypes. The high dry matter yields and lower lignin content of *Bmr* lines over the check and the parental lines confirmed the improvement accomplished. The results of the current study are in agreement with Porter et al. (1978); Strefeler & Wehner (1986) Grant et al. (1995) who suggested that the *Bmr* mutants of sorghum have significantly lower levels of lignin content than regular sorghum moreover *Bmr* silage were more digestible because of the lower lignin content.

CONCLUSION

Crop residues can play a strategic role in maintaining sustainable livestock production systems if high quality of stover is used for feeding. Stover from *Bmr* varieties can constitute a good alternative for the pressing demand for efficient stover for both quantity and quality to sustain livestock productivity in Niger and West Africa. The Baker's Standard Deviation for multi traits selection method allowed a clear identification of the superior lines from each genetic background. The *Bmr* sorghum type exhibited better forage quality and their cultivation in West Africa can provide new and sustainable forage opportunities for farmers.

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