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Growth, Biomass and Nutrient Production of Brown Midrib Sorghum Mutant Lines at Different Harvest Times

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Abstract: Brown midrib sorghum (BMR) is a potential crop as forage because of lower lignin content than that of non-BMR sorghum. The aim of this research was to observe the growth and production of brown midrib sorghum mutant lines at different harvest times. This research was conducted at SEAMEO BIOTROP, Bogor, Indonesia using factorial in completely randomized block design (7 x 3) with three replicates. The first factor was the BMR sorghum mutant lines of Patir 3.1 (non-BMR/control), Patir 3.2, Patir 3.3, Patir 3.4, Patir 3.5, Patir 3.6 and Patir 3.7, the second factor was the harvest times (flowering, soft and hard dough phases). Measurement on agronomic parameters were fresh and dry matter biomass production, plant height, stem diameter, leaf width length and ratio of leaves, stems and panicles. While nutrient parameters were crude protein, crude fiber, ash dan crude fat production. Analysis of variance followed by Duncan Multiple Range Test (DMRT) was done. The results showed that the BMR of P 3.7 and P 3.2 produced the highest fresh and dry matter production among the BMRs, but their dry matter production were lower than P 3.1 (control). Harvesting at hard dough phase produce the highest fresh and dry matter production and as well as produced the highest crude protein, ash and crude fat production ($p<0.01$).

Key words: Brown midrib sorghum, mutant lines, growth, biomass production

INTRODUCTION

Sorghum is a food crop that may also be used as forage source and as material for industrial bioethanol energy (Rooney *et al*., 2007; Djanaguiraman and Ramesh, 2013). As forage, sorghum provides several advantages, some of which include high biomass production and nutrient content, palatability, easy maintenance and its ability to be rationed. Furthermore, sorghum has good economic value in all plant parts and grows well in dry, acid, alkaline and marginal soil (Sanchez *et al*., 2002; Ritter *et al*., 2007). However, sorghum also has some disadvantages, including a high lignin content that causes a decrease in digestibility. As a result, plant breeders are seeking to identify new varieties of sorghum using applications such as nuclear technology with gamma ray irradiation to generate brown midrib sorghum mutant lines.

Brown Midrib (BMR) sorghum has a lower lignin content than that of non-BMR sorghum (Casler, 2001; Sattler *et al*., 2010). The modification of the cell wall structure in the mutation process causes a decrease in the lignin content and an increase in the cellulose content. The modification of lignin content to cellulose causes discoloration on the midrib and stem from green to brown. A lignin decrease in BMR causes a more efficient energy conversion and an increase in nutrition content (Gressel, 2008). Therefore, BMR sorghum is expected to be used as a ruminant feed due to this genetic improvement.

Generally, this genetic improvement decrease cell wall concentration and increase water-soluble carbohydrates (Casler, 2001). Lignin is the main anti-nutrient component in grasses, has a high concentration of fibre and lignin accelerates plant ageing (Chaves *et al*., 2002). Lignin decreases cell wall digestibility (fibre) because of physical and chemical barriers against rumen microorganisms. The cell wall is the most indigestible portion of a forage plant and the indigestibility and composition of the cell wall may be the most limiting factor to producing livestock high forage diets (van Soest, 1994). Factors that influence the quality of the forage include the species type and the plant maturity stage at the time of harvesting (Arthington and Brown, 2005).

Harvesting at the optimum maturity stage is required to produce both high-quality and abundant forage (Mc Donald *et al*., 2002; Salamone *et al*., 2012). There are two primary growth phases in the plant life cycle. The fist stage includes, vegetative growth, which is the development of leaf structures and the formation of the stem, as an accumulation of photosynthetic processes. Next, the second stage is the generative phase, where

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excess assimilate produced during the vegetative process translocated for seed growth. The maturation process, including the increased stem to leaf ratio and the decreased amount of cell content, usually results in a decreased protein concentration in grasses (Wickstrom, 2010).

The maturity stage of a plant is an aspect that is closely related to the growth phase of the plant, thus an optimum harvest time is highly relevant to both the quality and quantity of forage produced. Based on these ideas, it is essential to know the optimum harvest times of BMR sorghum mutant lines to produce high quality forage with maximum forage production to be used as ruminant feed. The objective of this study was to determine the potential growth and biomass production and nutritional production in BMR sorghum mutant lines at different harvest times.

MATERIALS AND METHODS

The study was conducted in the area of ±1500 m^2 at SEAMEO BIOTROP Bogor, Indonesia. The materials used include BMR and non-BMR sorghum mutant line seeds, manure, Nitrogen fertilizer (urea), Triple Super Phosphate (TSP), Kalium Chloride (KCl), scales, measuring instruments, a refractometer, cutting scissors and calipers. The prevention of a birds attack was accomplished using hollowed-out plastic bags (1 kg), while pesticides were used to prevent other pests and diseases.

This factorial study used completely randomized block design (7 x 3) with three replicates. The first factor tested was BMR sorghum mutant lines (Patir 3.1 (as control), 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7), while the second factor tested was harvest time (flowering, soft and hard dough phase). If significant effects were detected, further analysis was performed using the Duncan Multiple Range Test (DMRT).

Parameters: The agronomic parameters measured (fresh and dry matter biomass production, plant height, stem diameter, leaf width and length and ratio of leaves, stems and panicles). Nutritional parameters were measured on the top three promising sorghum mutant lines with the highest production of crude protein, crude fibre, ash and crude fat.

Land preparation and planting: Land preparation was performed manually, follow by soil amendment with 2 tons/ha of manure. Seeds were sown in 20 x 60 cm planting area and each hole was sown with 4-5 sorghum seeds at 5 cm depth. Thinning was performed to facilitate two stalk sorghum plants at each planting hole (following normal growth after seeding).

Maintenance: At 14 days post planting, fertilizers (urea, TSP and KCl) were applied in a ratio of 4:3:2 (g/g/g) at 270 kg/ha. To stimulate flowering, at second fertilizer application was performed at 50 days post-planting with urea, TSP and KCl in a ratio of 2:4:2 (g/g/g) at 200 kg/ha (Supriyanto, 2010).

Harvesting times: Harvesting was carried out when sorghum entered the flowering periode, exhibiting phases of soft and hard dough. The flowering phase begins when yellow anthers appear after emerging panicles. The soft dough phase occurs when seeds may be squeezed with fingers and little or no milk like liquid is extruded. The hard dough phase occurs when seeds may not be squeezed by fingers at all (Gerik *et al*., 2003). The sorghum plants were cut at the first stem node above the ground surface or approximately 10 cm above the ground. The sorghum plants were then separated into-stems, leaves and panicles in order to determine their fresh weight and other parameters.

Sample preparation: In order to determine dry weight, stems, leaves and panicles were placed into individual paper bags and dried at 60°C for 48 h. Samples were then grinded at <1 mm mash and prepared for nutritional analysis.

RESULTS AND DISCUSSION

Sorghum fresh and dry matter production: Table 1 shows that there was no interaction between the sorghum lines and the time of harvest on fresh and dry matter production. Production of fresh biomass sorghum crop was affected by sorghum mutant lines ($p<0.01$), the highest fresh biomass yield was produced by non-BMR (P 3.1), BMR (P 3.7 and P 3.2) with 46.80, 45.19 and 44.16 tons/ha, respectively. Harvest time also affected the fresh sorghum production ($p<0.01$), with the hard dough phase producing the highest fresh biomass (43.79 tons/ha), followed by the soft dough phase (42.96 tons/ha) and the lastly, flowering phase (37.75 tons/ha). The average production of fresh biomass sorghum mutant lines was ranged from 32.00-50.12 ton/ha, with similar values obtained by Shoemaker and Bransby (2010) where production of sweet sorghum biomass was 20-50 ton/ha.

Production of dry matter sorghum was also influenced by the individual sorghum mutant line, although the fresh production of BMR sorghum mutant lines (P 3.7 and P 3.2) did not differ from the control. However, dry biomass production was lower ($p<0.01$) than the control/non-BMR sorghum mutant line (P 3.1). The results of this study support those of Pedersen *et al*. (2005), Oliver *et al*. (2005) who found that BMR sorghum causes a decrease in dry matter production. However, the result from this study, differ from those of Miron *et al*. (2005), Kurniawan (2014) who found that the dry matter production of BMR sorghum did not differ from non-BMR sorghum.

Table 1: Influence of sorghum mutant lines and harvest times on fresh and dry matter biomass production (ton/ha)

	---------- Harvest times ----------			
Sorghum mutant lines	Flowering	Soft dough	Hard dough	Mean
Fresh production				
Patir 3.1	41.61±2.35	48.67±7.44	50.12±2.15	46.80±3.98^{A}
Patir 3.2	43.97±2.18	44.83±6.74	43.67±4.20	44.16±4.37^{A}
Patir 3.3	35.13±0.83	38.02±6.89	41.20±1.75	38.11±3.16^{B}
Patir 3.4	32.00±1.58	41.44±2.41	40.73±5.57	38.06±3.19^{B}
Patir 3.5	35.10±1.93	40.55±6.88	39.50±3.34	38.39±4.05^{B}
Patir 3.6	37.44±3.32	38.96±3.06	43.02±2.95	39.81±3.11^{B}
Patir 3.7	38.99±4.15	48.26±4.65	48.32±5.49	45.19±4.76^{A}
Mean	37.75±2.33^{B}	42.96±5.44^{A}	43.79±3.64^{A}	
Dry matter production				
Patir 3.1	7.23±0.54	11.27±2.03	16.74±0.73	11.74±1.10^{A}
Patir 3.2	7.07±0.21	9.68±1.25	12.73±1.65	9.83±1.04^{BC}
Patir 3.3	5.97±0.27	8.98±1.50	12.61±0.43	9.18±0.73^{C}
Patir 3.4	6.24±0.45	9.46±0.70	12.31±1.47	9.34±0.87^{C}
Patir 3.5	6.42±0.42	9.53±1.66	12.65±0.88	9.54±0.99^{BC}
Patir 3.6	6.60±0.38	9.20±0.55	13.23±1.37	9.67±0.77^{BC}
Patir 3.7	7.05±0.18	10.54±1.30	13.81±2.22	10.47±1.23^{B}
Mean	6.65±0.35^{C}	9.81±1.28^{B}	13.44±1.25^{A}	

Uppercase letter in the same rows and columns indicates highly significant influence ($p<0.01$). Patir 3.1 = non-BMR sorghum mutant line (control). Patir 3.2-Patir 3.7 = BMR sorghum mutant lines

Table 2: Influence of sorghum mutant lines and harvest times on height (cm) and stem diameter (mm)

	---------- Harvest times ----------			
Sorghum mutant lines	Flowering	Soft dough	Hard dough	Mean
Plant height				
Patir 3.1	205.49±2.81	219.46±4.73	213.90±0.51	212.95±2.68
Patir 3.2	207.04±3.10	215.71±6.13	212.08±9.56	211.61±6.26
Patir 3.3	218.87±5.50	216.89±0.89	214.46±8.13	216.74±4.84
Patir 3.4	213.62±0.27	220.75±3.08	213.37±0.92	215.91±1.42
Patir 3.5	217.05±4.62	217.18±2.57	215.09±5.74	216.44±4.31
Patir 3.6	220.20±3.50	217.83±3.43	215.28 1.43	217.77±2.79
Patir 3.7	214.18±4.21	214.20±4.04	214.76±8.83	214.38±5.69
Mean	213.78±3.43	217.43±3.55	214.13±5.12	
Stem diameter				
Patir 3.1	13.7±1.32^{GH}	14.72±1.02^{CDEFG}	15.6±0.3^{BCDE}	14.53±0.88
Patir 3.2	17.41±0.70^{AB}	14.32±1.76^{DEFG}	15.43±1.32^{CDEF}	15.72±1.26
Patir 3.3	12.16±1.68^{H}	13.85±0.78^{DEFGH}	14.97±0.29^{CDEFG}	13.66±0.92
Patir 3.4	12.4±2.40^{H}	13.03±0.29^{GH}	15.37±1.41^{CDEF}	13.6±1.37
Patir 3.5	14.83±0.32^{CDEFG}	13.5±1.39^{FGH}	14.9±0.26^{CDEFG}	14.41±0.66
Patir 3.6	15.63±0.21^{BCDE}	14.6±0.75^{CDEFG}	16.4±0.72^{ABC}	15.54±0.56
Patir 3.7	17.35±0.49^{A}	15.93±0.41^{BCD}	16.2±1.3^{ABCD}	16.49±0.74
Mean	14.72±1.01	14.28±0.91	15.55±0.80	

Uppercase letter in the same rows and columns indicates highly significant interaction ($p<0.01$). Patir 3.1 = non-BMR sorghum mutant line (control). Patir 3.2-Patir 3.7 = BMR sorghum mutant lines

Dry matter production was also affected by harvest time ($p<0.01$) in this study. The highest dry matter production occurred during the hard dough phase, followed by the soft dough and flowering phases, with values of 13.44, 9.81 and 6.65 tons/ha, respectively. In general, the increased maturity of a plant will increase its production of fresh and dry matter of sorghum (Atis *et al*., 2012), which is in contrast to results obtained by Miron *et al*. (2006), who found that dry matter production decreases with increasing maturity stage of a plant. The hard dough and soft dough phase produced higher output than the flowering phase. This is likely due to the soft dough and hard dough phases being grain filling phases so that the weight of the seeds will increase, causing a generally increase in the weight of fresh plants (Pacific seeds yearbook, 2009; Vanderlip, 1993).

Plant height and stem diameter: Observations of plant height and stem diameter are presented in Table 2. There was no interaction between the sorghum mutant lines and harvest times on the sorghum plant height. Both the time of harvest and the sorghum mutant lines had no significant effect ($p>0.05$) on plant height. The height of sorghum plants was not affected by sorghum mutant lines and the height of BMR and non-BMR sorghum was not significantly different ($p>0.05$). Similar, results were also reported by Miron *et al.* (2005); Carmi *et al.* (2006); however, Beck *et al.* (2007) and Atis *et al.* (2012) who found that the non-BMR sorghum plants grew higher than BMR sorghum plants in their respective studies.

In this study, the harvest time did not differ according to plant height. Carmi *et al.* (2006) also found no differences in plant height after flowering, while Xie *et al.* (2012), Qu *et al.* (2014) and Li *et al.* (2015) all found that sorghum plant height increases along with the ageing of the plant. Sorghum height in this study ranged from 205.49 to 220.75 cm, which is higher than the result of Sihono (2009) where the average height of sorghum mutant plants was 188.44 cm.

There was a significant interaction ($p<0.01$) between the sorghum mutant lines and harvest time on stem diameter. The highest stem diameter was found in P 3.2 at the flowering phase (17.41 mm), followed by P 3.7 at the flowering phase (17.35 mm). The mean diameter of the sorghum stems in this study from the flowering to the hard dough phase ranges from 12.16 to 17.41 mm, while Li *et al.* (2015) found no difference in the stem diameter from the flowering phase to dough phase with a range of 16.6 to 17.4 mm.

Leaf, stems and panicle proportions: The dry weight proportion of leaves, stems and panicles are presented in Table 3. There were interactions ($p<0.05$) between sorghum mutant lines and harvest time on leaves and stems dry weight proportions, as well as a significant interactions ($p<0.01$) of proportion on panicles dry weight. The combination that produced the highest proportion of leaves was in P 3.6 at the soft dough phase (29.50%). In the flowering and soft dough phases, leaf proportion was 27.8 and 28.1%, but upon entering the hard dough phase, the leaf proportion lowered to $\leq$25%. Ball *et al.* (2001) suggested that the proportion of leaves in forage will decrease as a function of increasing maturity stage of the plant.

The highest proportion of stem was produced in P 3.1 at the soft dough phase (25.55%) and the lowest proportion of stem was produced in P 3.6 at the hard dough phase. As with the leaves, the stems proportion increased from the flowering phase to the soft dough phase and then decreased upon entering the hard dough phase, with values of 19.4, 23.5 and 14.9%, respectively. The decrease in the proportion of leaves and stems on the generative phase was likely due to the movement of nutrients from the leaves and stems to the grain produced (Gerik *et al.*, 2003; Vanderlip, 1993).

In this study, the highest panicle proportion produced by all sorghum mutant lines was at the hard dough phase, similar to result obtained by Atis *et al.* (2012). The proportion of the panicle at the flowering phase was 51.8% and increased to 60% at the hard dough phase. The increase of panicle proportion is correlated closely

Table 3: Influence of sorghum mutant lines and harvest time on ratio of leaves, stems and panicles by total dry weight (%)

		Sorgum mutant lines							
Parameter	Harvesting time	Patir 3.1	Patir 3.2	Patir 3.3	Patir 3.4	Patir 3.5	Patir 3.6	Patir 3.7	Mean
Leaf proportion	Flowering	29.2±1.4^{a}	25.4±3.0^{cd}	26±5.2^{a}	28.9±0.6^{a}	28.9±1.7^{a}	27.2±0.2^{abcd}	28.0±0.5^{ab}	27.6±1.8
	Soft dough	29.3±3.^{a}	28.5±0.7^{a}	27.4±0.2^{abcd}	25.6±1.2^{cde}	27.9±0.0^{abc}	29.50±1^{a}	28.2±0.8^{ab}	28.1±1.0
	Hard dough	24.1±0.2^{cd}	25.0±0.3^{cd}	25.4±0.4^{cd}	24.3±1.2^{cd}	25.04±0.9^{cd}	25.7±1.0^{bcde}	25.2±1.4^{cd}	25±0.6
	Mean	27.5±1.5	26.3±1.4	26.2±1.9	26.3±1	27.32±0.9	27.4±0.7	27.1±0.6	
Stalk proportion	Flowering	19.3±0.2^{d}	19.3±1.7^{d}	16.6±0.7^{e}	16.6±0.7^{e}	19.6±1.0^{d}	20.5±0.2^{d}	20.4±0.8^{d}	19.4±0.8
	Soft dough	25.5±2.8^{a}	24.4±0.6^{ab}	23.4±0.4^{abc}	23.4±0.4^{abc}	22.9±0.7^{bc}	21.4±0.8^{cd}	23.3±1.8^{abc}	23.5±1.0
	Hard dough	15±0.7^{ef}	15.2±2.3^{ef}	15.5±0.7^{ef}	15.5±0.7^{ef}	15.7±1.6^{ef}	13.8±0.1^{f}	14.4±0.8^{ef}	14.9±1.0
	Mean	19.9±1.3	19.6±1.5	18.5±0.6	19.5±0.6	19.4±1.0	18.6±0.4	19.4±1.1	
Panicle proportion	Flowering	51.4±1.6^{CDE}	52.8±3.0^{BC}	54.3±0.4^{B}	49.3±2DE	51.3±0.7^{CDE}	52.2±0.4^{BC}	51.5±0.8^{CD}	51.8±1.3
	Soft dough	45.0±0.5^{G}	46.9±0.4^{FG}	49±0.2^{EF}	50.4±1.6^{CDE}	49.1±0.3^{DEF}	49±0.7^{EF}	49.4±1.2^{DE}	48.4±0.7
	Hard dough	60.7±0.7^{A}	59.7±1.9^{A}	59±0.3^{A}	61.1±0.7^{A}	59.2±1^{A}	60.3±0.9^{A}	60.2±0.6^{A}	60±0.9
	Mean	52.4±0.9	53.1±1.8	54.1±0.3	53.6±1.4	53.2±0.6	53.9±0.6	53.7±0.8	

Uppercase letter in the same rows and columns indicates highly significant influence ($p<0.01$), while the lowercase one indicates significant influence ($p<0.05$). Patir 3.1 = non-BMR sorghum mutant line (control). Patir 3.2-Patir 3.7 = BMR sorghum mutant lines

Table 4: Influence of sorghum mutant lines and harvest time on leaf width and length (cm)

	Harvest times			
Sorghum mutant lines	Flowering	Soft dough	Hard dough	Mean
Leaf width				
Patir 3.1	7.61±0.27	7.43±0.50	7.88±0.40	7.64±0.39^{AB}
Patir 3.2	7.50±0.26	6.89±0.45	7.56±0.39	7.32±0.37^{BC}
Patir 3.3	6.99±0.20	6.84±0.72	7.93±0.21	7.25±0.39^{C}
Patir 3.4	6.64±0.33	6.82±0.24	7.68±0.63	7.04±0.40^{C}
Patir 3.5	7.16±0.01	6.77±0.51	7.36±0.24	7.10±0.25^{C}
Patir 3.6	7.35±0.21	6.76±0.21	7.67±0.29	7.26±0.24^{C}
Patir 3.7	7.56±0.20	7.68±0.36	8.04±0.54	7.76±0.37^{A}
Means	7.26±0.21^{B}	7.03±0.43^{C}	7.73±0.39^{A}	
Leaf length				
Patir 3.1	99.83±7.73^{abc}	100.98±2.69^{abc}	103.85±1.13^{a}	101.55±3.85
Patir 3.2	99.81±1.08^{abc}	97.74±2.42^{bcd}	96.56±2.78^{bcd}	98.04±2.09
Patir 3.3	97.58±1.91^{bcd}	97.61±1.98^{bcd}	93.45±1.99^{de}	96.21±1.96
Patir 3.4	96.85±4.07^{bcd}	97.36±2.64^{bcd}	95.6±3.22^{cd}	96.60±3.31
Patir 3.5	98.83±0.55^{abcd}	97.94±1.71^{bcd}	96.47±2.25^{bcd}	97.74±1.50
Patir 3.6	100.00±1.70^{abc}	98.76±0.58^{abcd}	90.67±4.78^{e}	96.48±2.35
Patir 3.7	101.49±1.94^{ab}	100.62±0.70^{abc}	101.72±3.24^{ab}	101.28±1.96
Means	99.20±2.71	98.72±1.81	96.90±2.77	

Uppercase letter in the same rows and columns indicates highly significant influence ($p<0.01$), while the lowercase one indicates significant influence ($p<0.05$). Patir 3.1 = non-BMR sorghum mutant line (control). Patir 3.2-Patir 3.7 = BMR sorghum mutant lines

with the decrease of stem biomass, because of the translocated of nutrients from stems to seeds (Vanderlip, 1993; Fernandes *et al*., 2014).

Leaf ratio in this study was higher than that of stems, in contrast to the finding of Jung (2012), who found that accumulation of stem biomass exceeds leaf biomass during the plant maturation process. In the case of sweet sorghum, the stem is juicier because it contains of sugar (Hoeman, 2012). The drying process caused a decrease in stem weight, making the percentage of stem lower than that of the leaf. However, based on volume, the biomass of stems is more voluminous than that of the biomass of leaves, because sorghum stem acts like sponge or cork (du Plessis, 2008; Hoeman, 2012). The proportion of leaf decreased after entering the hard dough phase, similar to result obtained by Carmi *et al*. (2005, 2006); this is due to the increase of panicles proportion during plant maturity (Atis *et al*., 2012). The highest panicle proportion, compared to the leaves and stems, occurred after flowering in the reproductive phase. This process requires very strong nutrients, which may limits the assimilated portion of the additional of the leaves and stems (Almodares and Darany, 2006).

Top of form

Leaf length and width: Leaf length and width is related to the photosynthetic area of sorghum and different sorghum mutant lines will affect the biomass production. The average width and length of leaves of the sorghum is presented in Table 4. There was no interaction between the sorghum mutant lines and harvest time on leaf width. Sorghum mutant lines significantly affected ($p<0.01$) leaf width, the largest leaf width found in this study was at P 3.7 (7.75 cm) and the smallest leaf width was found in P 3.4 (7.04 cm). Harvest time had a highly significant ($p<0.01$) effect on leaf width, where the widest leaf was found at the hard dough phase (7.73 cm). Overall, leaf widths in this study was ranged from 6.64 to 8.04cm, in comparison to Li *et al*. (2015) where sorghum leaf width ranged from 5 to 9cm.

Top of form: Table 4 also shows that leaf length was influenced by the interaction of the sorghum mutant lines with harvesting time ($p<0.01$). The longest leaves were found in P 3.1 at the hard dough phase (103.85 cm), while the shortest leaves were found in P 3.6 at the hard dough phase (90.67 cm). These values are higher than those obtained by Li *et al*. (2015), where the average leaf length ranged from 69 to 73 cm.

Nutrition production: Crude protein (CP), crude fibre (CF), ash and crude fat production were calculated from the average percentage of stems, leaves and panicles multiplied by the average percentage content of CP, CF, ash and crude fat (in stems, leaves, panicle) and then multiplied by the average dry matter (DM) production of biomass (tons/ha). The average production of CP, CF, ash and crude fat are presented in Table 5. Production of CP was more influenced by harvest time ($p<0.01$) in production while the sorghum mutant lines did not affect CP ($p>0.05$). CP production was highest at the hard dough phase (1.26 tons/ha) and the soft dough and flowering phases were lower at 0.94 tons/ha and 0.65 tons/ha, respectively. CP production was higher at advanced generative phases due to the higher dry matter production at the same phase. Balabanli *et al*. (2010) stated that the CP production of feed crops depend on DM production and CP content of plants. CP

Table 5: Influence of sorghum mutant lines and harvest time on nutrient production (ton/ha)

		Harvest times			
Production	Sorghum mutant lines	Flowering	Soft dough	Hard dough	Mean
Crude protein	P 3.1	0.66±0.05	0.95±0.11	1.32±0.05	0.98±0.07
	P 3.2	0.66±0.06	0.89±0.17	1.16±0.12	0.90±0.12
	P 3.7	0.62±0.03	0.95±0.12	1.30±0.27	0.96±0.14
	Mean	0.65±0.05^{C}	0.94±0.13^{B}	1.26±0.14^{A}	
Crude fiber	P 3.1	1.88±0.20	2.03±0.36	2.44±0.12	2.12±0.23
	P 3.2	2.02±0.12	1.84±0.20	1.96±0.07	1.94±0.13
	P 3.7	1.96±0.12	1.76±0.19	1.93±0.21	1.89±0.18
	Mean	1.95±0.15	1.87±0.25	2.11±0.13	
Ash	P 3.1	0.51±0.02^{d}	0.74±0.09^{cb}	1.11±0.06^{a}	0.79±0.05
	P 3.2	0.49±0.04^{d}	0.61±0.15^{cd}	0.77±0.16^{b}	0.62±0.12
	P 3.7	0.47±0.00^{d}	0.73±0.08^{cb}	0.82±0.17^{b}	0.67±0.12
	Mean	0.49±0.02	0.69±0.11	0.90±0.13	
Crude fat	P 3.1	0.10±0.03	0.15±0.04	0.33±0.01	0.19±0.03
	P 3.2	0.08±0.02	0.16±0.01	0.24±0.07	0.16±0.03
	P 3.7	0.08±0.02	0.19±0.03	0.31±0.06	0.20±0.04
	Mean	0.09±0.02^{C}	0.17±0.03^{B}	0.29±0.05^{A}	

Uppercase letter in the same rows and columns indicates highly significant influence ($p<0.01$), while the lowercase one indicates significant influence ($p<0.05$). Patir 3.1 = non- BMR sorghum mutant line (control). Patir 3.2-Patir 3.7 = BMR sorghum mutant lines

production at the soft dough phase in this study was 0.94 tons/ha. This value is lower than the 1.62 tons/ha obtained by Atis *et al*. (2012) and is likely because production of DM in this study was also lower. In this study, CP production between BMR and non-BMR sorghum mutant lines did not differ. This was likely due to the lack of a difference in CP content of BMR and non-BMR sorghum mutant lines and according to Li *et al.* (2015) there is no difference in the content of CP between green midrib (non-BMR) and BMR-12 sorghum. CF production was not affected by sorghum mutant lines and harvest time ($p>0.05$). The average CF production ranged from 1.76 to 2.44 tons/ha. In this study, decreased CF content at the advanced generative phase (unpublished data) caused a decrease in the fibre content (ADF, NDF and lignin) and increased sugar content, particularly in the sorghum stem (Carmi *et al.*, 2006; Qu *et al.*, 2014). Although the CF content at the advanced generative phase was lower, the CF production per unit area is not different, likely due to an increase in DM production by area.

Ash production was influenced by the interaction between sorghum mutant lines and harvest time ($p<0.05$). Harvesting at the hard dough phase produced the highest ash production in P 3.1 (1.11 tons/ha), followed by P 3.7 and P 3.2 with values of 0.82 tons/ha and 0.77 tons/ha, respectively. The higher ash production in the advanced generative phase is associated with a higher production of minerals, especially calcium and phosphorus to meet the needs of livestock. This is relevant because ash consists of inorganic substances or minerals (Sudarmadji *et al.*, 2003).

Crude fat production was affected by harvest time ($p<0.01$) where harvest at the hard dough phase produced the highest fat production at 0.29 tons/ha. Harvesting at the hard dough phase had the highest potential in the provisioning of energy sources for livestock, Wahyono and Hardiyanto (2004) stated that fat is a source of energy other than carbohydrates.

Conclusion: Sorghum dry matter production was affected by the sorghum mutant lines and harvest time. Fresh production of BMR sorghum mutant lines (P 3.2 and P 3.7) was similar to the non-BMR sorghum mutant line (P 3.1). Meanwhile, the dry matter production of BMR sorghum mutant lines was lower than non-BMR sorghum mutant line. Harvesting at advanced generative phases (soft and hard dough phases) will lead to an increase in the fresh and dry matter sorghum biomass production. There were no significant effects with respect to CP, CF, ash and crude fat production on sorghum mutant lines, but harvesting at an advanced generative phase (the hard dough phase) generated the highest CP, ash and crude fat production.

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