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Sorghum Grain Quality as Influenced by Plant Density, Nitrogen Nutrition and Cultivar

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ABSTRACT

Background: Grain sorghum [*Sorghum bicolor* (L.) Moench] is a staple cereal crop in the semiarid regions of the world, notably in sub-Saharan Africa due to its ability to withstand drought. However, poor soil fertility is one factor that limits its production in small farmers' fields.

Methods: Field experiments were conducted at two locations in the North-West province of South Africa during the 2016/17 and 2017/18 planting seasons. The objective of this study was to determine the effects of plant density, nitrogen (N) fertilizer rates and cultivar on sorghum grain quality. Ash, fiber, oil, protein and starch content were analysed.

Result: N fertilizer rate had a significant effect ($P \leq 0.05$) on sorghum ash content during the 2017/18 season. Sorghum without N application had significantly higher ash content (4.438%) than those fertilized with 100 and 150 kg N/ha. Cultivar had a significant effect ($P<0.001$) on protein content during the 2017/18 season. Sorghum cultivar PAN 8816 had a significantly higher protein content (8.87%) than PAN 8625. Location had a significant effect ($P<0.001$) on starch content during the 2016/17 season. Sorghum planted at Mafikeng had a significantly higher starch content (38.50%) than sorghum planted at Taung.

Key words: Cultivar, Grain quality, Nitrogen, Plant density, Sorghum.

INTRODUCTION

Sorghum is a major source of carbohydrates and protein in the diet of rural communities in sub-Saharan Africa (Hikeezi, 2014). Sorghum is high in starch, while some cultivars contain high dietary fiber (Jimoh and Abdullahi, 2017). Typical analytical figures for sorghum grains are; ash 2%, fat 3%, fiber 2%, food energy 394 calories, moisture 11-12%, protein 10-15% and starch 68-80% (Jimoh and Abdullahi, 2017).

N fertilization is one factor limiting grain quality, as variable responses to the application of N fertilizer have been observed in sorghum and maize (Kaufman *et al*., 2013). The effect of N fertilizers on the grain quality of many cereals has also been investigated extensively (Sedlář *et al*., 2011; Valkama *et al*., 2013). Some experiments on wheat have indicated that increasing N levels lead to an increase in the wheat protein content and similar effects have been found in sorghum and maize (Kaufman *et al*., 2013; Silva *et al*., 2019).

Plant density has no effect on the ash content of sorghum (Mahmood *et al*., 2013). On the other hand, sorghum planted under high plant densities show an increase in protein content. Generally, grain quality varies among different cultivars of sorghum and influenced by the prevailing environmental conditions under which the plants are cultivated (Oyier *et al*., 2017). Reports by Tang *et al.* (2018) indicated that high protein content was observed in early maturing cultivars of wheat.

Since nitrogen is a critical nutrient for cereals, its deficiency may limit grain yield and quality (Diallo, 2012). On the other hand, over-fertilization tends to decrease the quality of grains. Therefore, the objective of this study was to determine the influence of cultivar, N fertilizer rates and plant density on sorghum grain quality.

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MATERIALS AND METHODS

Site description

This study was conducted during the 2016/17 and 2017/18 planting seasons at the Department of Agriculture Experimental Station, Taung, and the North-West University Research Farm, Mafikeng, South Africa. The soils at the sites had different chemical and physical properties (Table 1), and the environmental conditions also differed (Table 2). The North-West University Research Farm is situated at 25°48′S and 45°38′E. This region receives a mean annual rainfall of 571 mm in summer (Kasirivu *et al*., 2011).

The Department of Agriculture's experimental station at Taung is situated at 27°30′S and 24°30′E. The experimental site is situated in a grassland savannah region with a mean rainfall of 1061 mm, and the rainy season usually starts in October (Pule-Meulenberg *et al*., 2010).

Experimental design

The experimental design was a split-split plot arrangement fitted into a randomized complete block design (RCBD) with four replicates. The experiment considered high plant density (33333 plants/ha) with 1 × 0.3m spacing and low plant density (22222 plants/ha) with 1.5 × 0.3m spacing; as the main plot factor. N fertilizer rates of 0, 100 and 150 kg N/ha, were the sub-plot factor, while two sorghum cultivars; PAN 8625 (late-maturity) and PAN 8816 (medium-late-maturity), were the sub-sub plot factor. The field area measured 60m × 36m (2160 m^2) and the experiment was a total of 48 plots per site.

Agronomic practices

Seedbeds were prepared through disc ploughing and harrowing. Sorghum cultivars were purchased from PANNAR Seed Company. Each plot measured 6m × 4m, with five rows under low plant density and seven rows under high plant density. Urea (46% N) supplied nitrogen, and single superphosphate (60 kg/ha) supplied phosphorus. Fertilizers were mixed and applied through banding at planting. Thinning was carried out three weeks after emergence, leaving one plant per stand.

Data collection

Field dried sorghum panicles were hand-harvested from a harvesting area of 9.6 m^2. The panicles from the harvesting area were threshed and winnowed. Approximately 500 g of

Table 1: The results of soil chemical (mg kg^{-1}) and the physical properties of samples collected before planting at two locations during the 2016/17 and 2017/18 seasons.

Location	Chemical/physical properties	2016		2017	
		0-15 (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)
Mafikeng	$N\text{-}NO_3$	4.24	8.66	8.50	10.00
	$N\text{-}NO_4$	0.75	1.40	1.75	1.95
	P (Bray-1)	54	54	19	33
	K	268	268	198	195
	% Sand	82	80	81	82
	% Silt	4	6	4	4
	% Clay	14	14	15	14
	pH (KCl)	6.26	6.07	5.28	5.24
Taung	$N\text{-}NO_3$	11.06	5.39	28.50	26.75
	$N\text{-}NO_4$	0.50	0.80	1.35	1.55
	P (Bray-1)	9	6	9	8
	K	235	203	188	198
	% Sand	84	82	85	86
	% Silt	3	4	3	3
	% Clay	13	14	12	11
	pH (KCl)	5.79	5.39	5.65	5.74

Table 2: The mean temperatures and rainfall at Mafikeng and Taung for the duration of the experiment.

Location	Season	Climate data	Dec	Jan	Feb	Mar	Apr	May
Mafikeng	2016/17	Rainfall (mm)	117.2	147.8	282.8	21.0	77.6	0
		Max T (°C)	31.5	28.5	27.2	29.4	26.5	24.5
		Min T (°C)	18.8	17.7	17.4	13.9	11.8	6.6
	2017/18	Rainfall (mm)	48.6	71.8	108.8	90.0	27.6	26.0
		Max T (°C)	32.4	33.8	29.7	29.6	27.0	25.2
		Min T (°C)	16.9	18.0	17.4	15.4	12.5	7.0
Taung	2016/17	Rainfall (mm)	145.6	241.6	155.4	13.0	42.6	0.6
		Max T (°C)	36.1	30.6	29.3	31.0	27.3	25.6
		Min T (°C)	18.2	16.9	17.8	13.2	9.2	4.7
	2017/18	Rainfall (mm)	31.2	41.8	49.6	126.8	107.8	1.6
		Max T (°C)	34.8	36.0	33.1	31.0	26.2	24.8
		Min T (°C)	16.8	17.8	17.9	15.4	12.7	4.4

Max T (°C) = Maximum temperature in degree Celsius, Min T (°C) = Minimum temperature in degree Celsius, mm = millimeters.
Source: South African Weather Service (SAWS), 2018.

grain samples were sub-sampled per plot and used for grain analysis. A total of 48 samples per location were analysed for protein, oil, starch, ash and fiber content using the Spectra Star XL near Infrared Analyser (NIR) machine.

Data analysis

An analysis of variance was performed on the data generated using the GenStat: 11th edition (2008). The least significant difference (LSD) was used to separate the means, and a probability level of less than 0.05 was considered statistically significant (Gomez and Gomez, 1984). The high factor interactions were considered under each measured parameter.

RESULTS AND DISCUSSION

The effects of cultivar, nitrogen fertilizer rate, plant density and location on the sorghum ash content

Cultivar had a significant effect ($P<0.001$) on the sorghum ash content during the 2016/17 planting season, as indicated in Fig 1. Sorghum cultivar PAN 8625 had a significantly higher ash content of 4.47% than PAN 8816 (3.54%). The difference between the two cultivars in terms of ash content could be attributed to the genetic constitution. This corroborates the findings by Telleng *et al*. (2016), who reported an increase in the ash content among one of the varieties of sorghum planted.

Nitrogen fertilizer rate and location had a significant effect ($P\leq0.05$) on the sorghum ash content during the 2017/18 planting season, as indicated in Fig 2 and 3, respectively. Sorghum without nitrogen fertilizer application had a significantly higher ash content of 4.438% than sorghum fertilized with 100 (4.32%) and 150 kg (4.31%) N/ha. These findings are contradictory to the findings by Hassan *et al.* (2014), who reported increased ash content with increased nitrogen application.

Sorghum planted at Taung had a significantly higher ash content of 4.40% than sorghum planted at Mafikeng (4.31%). These results could be attributed to the difference in soil type, its soil nutrient status and the variable rainfall recorded at the two locations. This corroborates the findings by Jimoh and Abdullahi (2017), who reported that an increase in ash content of sorghum could be attributed to the nature of the soil and the amounts of nutrient in the soil. During the 2017/18 planting season, the interactions of nitrogen fertilizer rate x plant density x location had a significant effect ($P = 0.009$) on the sorghum ash content.

The effects of cultivar, nitrogen fertilizer rate, plant density and location on the sorghum fiber content

Cultivar had a significant effect ($P < 0.001$) on the sorghum fiber content during the 2016/17 and 2017/18 planting seasons, as indicated in Fig 1. Sorghum cultivar PAN 8625 had a significantly higher fiber content of 10.60% and 9.67% than PAN 8816, with fiber content of 7.35% and 7.13% during the 2016/17 and 2017/18 planting seasons. Ayub *et al*. (2010) also reported significant differences in fiber content among eight cultivars tested.

Location had a significant effect ($P = 0.005$) on the sorghum fiber content during the 2016/17 planting season, as indicated in Fig 3. Sorghum planted at Taung had a significantly higher fiber content of 9.80% than sorghum planted at Mafikeng (8.14%). Variations in the crude fiber contents of various sorghum cultivars were also reported by Telleng *et al*. (2016) and Hunsigi *et al*. (2010). Higher fibre content obtained at Taung could also be attributed to better rainfall during growing season as reported by Islam and Sebetha (2020).

During the 2017/18 planting season, the interaction of nitrogen fertilizer rate × plant density × location had a significant effect ($P = 0.027$) on the sorghum fiber content.

The effects of cultivar, nitrogen fertilizer rate, plant density and location on the sorghum oil content

Cultivar had a significant effect ($P < 0.001$) on the sorghum oil content during the 2017/18 planting season, as indicated in Fig 1. Sorghum cultivar PAN 8816 had a significantly higher oil content of 5.45% than PAN 8625 (4.1%). The

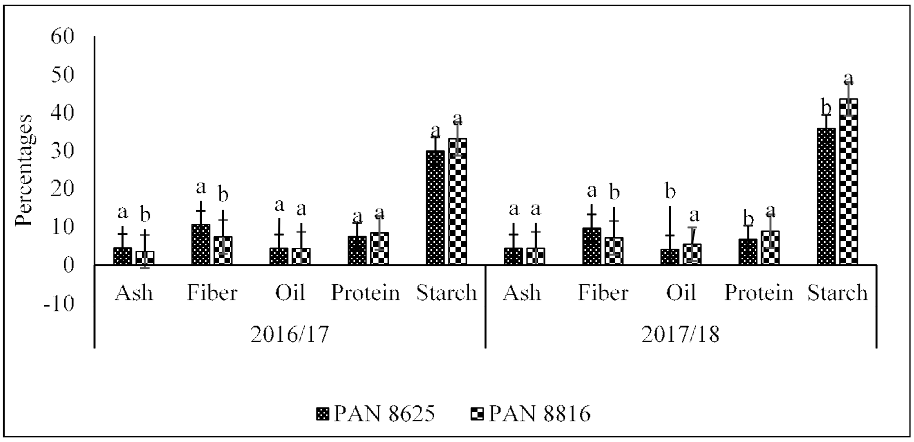

Fig 1: The main effects of cultivar on ash, fiber, oil, protein and starch content of sorghum during the 2016/17 and 2017/18 planting seasons.

observed differences in oil content could be attributed to the differences in grain size of the two sorghum cultivars. This corroborates the findings by Shen *et al*. (2010), who reported that the oil content in maize seed is influenced by the size of the seed embryo and the oil concentration in the embryo and endosperm.

Location had a significant effect (P<0.001) on the sorghum oil content during the 2016/17 and 2017/18 planting seasons, as indicated in Fig 3. Sorghum planted at Mafikeng had a significantly higher oil content of 5.01% than sorghum planted at Taung (3.69%) during the 2016/17 planting season. Sorghum planted at Mafikeng also had a significantly higher oil content of 5.01% than sorghum planted at Taung (4.54%) during the 2017/18 planting season. This could be attributed to differences in rainfall and temperature prevailed at the two locations. These result corroborate the findings by Mikulíková *et al*. (2011), who reported that starch content in cereals is significantly influenced by the prevailing weather.

During both seasons, the interactions of cultivar x location had a significant effect on the sorghum oil content.

The effects of cultivar, nitrogen fertilizer rate, plant density and location on the sorghum protein content

Cultivar and location had a significant effect (P < 0.001) on the sorghum protein content during the 2017/18 planting season, as indicated in Fig 1 and 3, respectively. Sorghum cultivar PAN 8816 had a significantly higher protein content of 8.87% than PAN 8625 (6.74%). In previous studies, Ahmad *et al.* (2016) also reported significant differences among sorghum cultivars for protein content. Sorghum planted at Taung had a significantly higher protein content of 8.31% than sorghum planted at Mafikeng (7.31%). This corroborates the findings by Sebetha *et al*. (2015), who

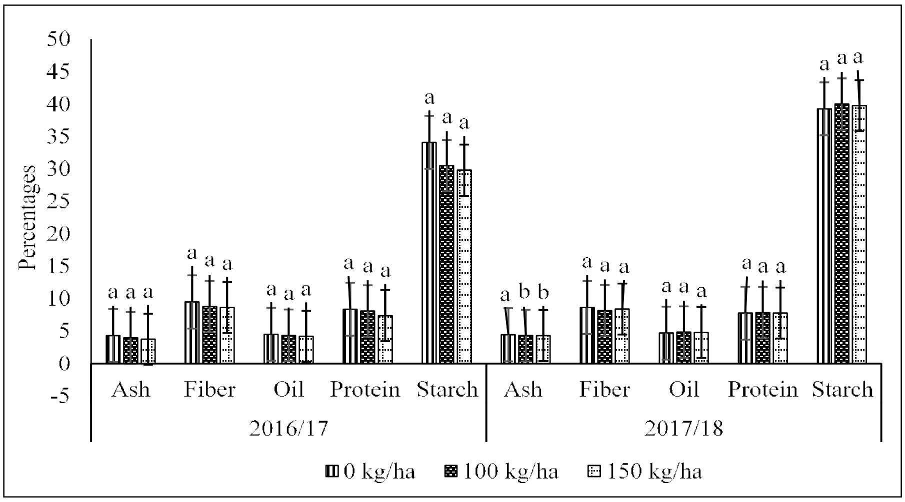

Fig 2: The main effects of nitrogen fertilizer rate on ash, fiber, oil, protein and starch content of sorghum during the 2016/17 and 2017/18 planting seasons.

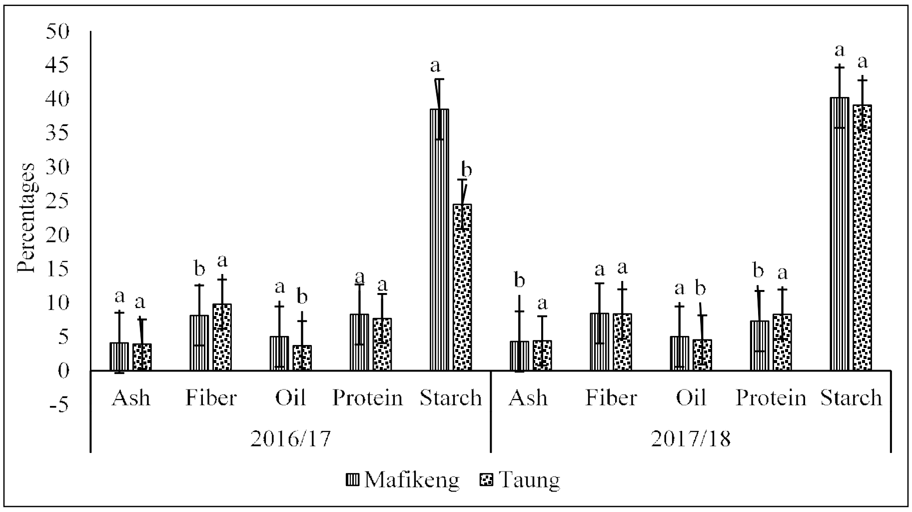

Fig 3: The main effects of location on ash, fiber, oil, protein and starch content of sorghum during the 2016/17 and 2017/18 planting seasons.

reported that maize seeds harvested from Taung had a significantly higher protein content than at Mafikeng.

During the 2016/17 planting season, the interactions of nitrogen fertilizer rate x location had a significant effect (P < 0.045) on the sorghum protein content. During the 2017/18 planting season, the interactions of cultivar x location had a significant effect (P = 0.032) on the sorghum protein content.

The effects of cultivar, nitrogen fertilizer rate, plant density and location on the sorghum starch content

Cultivar had a significant effect (P<0.001) on the sorghum starch content during the 2017/18 planting season, as indicated in Fig 1. Sorghum cultivar PAN 8816 had a significantly higher starch content of 43.55% than PAN 8625 (35.79%). These results are consistent with findings by Palavecino *et al.* (2016), who reported that sorghum cultivars differ significantly in starch content.

Location had a significant effect (P<0.001) on the sorghum starch content during the 2016/17 planting season, as indicated in Fig 3. Sorghum planted at Mafikeng had a significantly higher starch content of 38.50% than sorghum planted at Taung (24.5%). The higher starch content from sorghum planted at Mafikeng might be attributed to better environmental conditions such as rainfall and temperature. Adebayo *et al*. (2021) reported the improved in maize performance from the same location.

During both the planting seasons, the interactions of cultivar x location had a significant effect on the starch content of sorghum.

CONCLUSION

The results of the grain analysis revealed that the grain quality of sorghum was significantly affected by different treatments. Cultivar, PAN 8625, had higher ash and fiber content than PAN 8816, which showed higher oil, protein, and starch content. Nitrogen rates did not affect the quality of sorghum except ash content. However, interaction was significant among different treatments, which implied that the choice of a cultivar is important in a location, fertility status of soil and plant density to realize improved sorghum yields.

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