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Sorghum Grain Quality as Affected by Different Nitrogen Fertilizer Sources, Cultivar and Field Condition

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Abstract

The source of nitrogen fertilizer applied in the soil during the development of sorghum can affect the grain quality. The objective of this study was to determine the quality of sorghum grains as influenced by different nitrogen fertilizer sources and field conditions. The experiment used incorporated a 2x5x2 factorial arranged in a split-split plot design that was fitted into a randomized complete block design. Sorghum grain samples were analyzed for ash, fiber, fat, protein, and starch contents in percentages by using a Near-infrared spectroscopy machine. Nitrogen fertilizer source and had a significant effect on sorghum crude protein content during the 2018/19 planting season. The study indicated that nitrogen fertilizer sources such as limestone ammonium nitrate and urea are suitable for improving the quality of the sorghum grain. For example, limestone ammonium nitrate significantly improved the quality of the sorghum grain since it affected protein and starch content. Urea was also found to play a significant role in the grain quality as it affected the fiber and starch content of the grain. Field condition had a significant effect on sorghum crude fiber and protein during the 2019/20 planting season. The increase in crude fiber under dryland field conditions proves that the quality of sorghum can be increased under no supplementary irrigation. This study, therefore, indicates that sorghum grain quality is influenced by the type of cultivar, the nitrogen fertilizer source, and the field conditions.
Keywords: Nitrogen source; Field condition; Sorghum; Quality; Cultivar.

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the essential grain crop grown in the arid parts of Africa on account of its hardiness, drought tolerance, and limited demand for water levels. It is the world's fifth-largest cultivated crop after wheat, maize, rice, and barley [1, 2]. Chemical composition and nutritional value if the crop is of importance and it can be affected by cultivar choice, soil type, environmental conditions and fertility status of the soil [3]. Climatic conditions such as temperature and moisture stress can limit the amount of grain filling operating through the metabolism of starch [4]. As opposed to the protein content, the accumulation of starch in wheat was found to be more sensitive to high temperatures [5].

Nitrogen plays an essential role in influencing the nutritional quality of sorghum and applications of nitrogen increase the amount of crude protein [6]. Nitrogen fertilizer was reported to reduce the oil and starch content in maize [7]. The application of the highest rated nitrogen source such as urea was reported to produce the lowest soluble carbohydrate and fibre content in maize [8]. Ammonium sulphate was reported to increase the protein content of sorghum [9]. A nitrogen source such as urea, limestone ammonium nitrate and ammonium sulphate were found to significantly increase the crude protein, fibre, ash and fat content of wheat [10].

Grains from drought-stressed crops are commonly lower in quality [11]. Water stress occurring at grain filling stage is detrimental because it can reduce the nutritional value of grains [12]. The starch content of maize is not affected by shortage of water, thus indicating that the rate of is similar for both rain-ed and irrigation treatments [13]. The use of an irrigation interval in maize was found to reduce water stress and to consequently increase the availability of mineral nutrients for higher protein, starch, oil and fibre content [14]. Irrigation is responsible for the increase of many quality properties such as the starch, fat and ash content of sorghum. Furthermore, sorghum subjected to water stress affect not only the grain yield, but also the quality parameters, such as the protein, starch, oil, cellulose and ash content, and the mineral composition of the grain [13].

The quality of the sorghum grain is affected by irrigation levels in that the highest levels reduce the protein content as opposed to that under low irrigation levels [15]. On the other hand, the lowest crude fibre content is associated with applications of ammonium sulphate nitrate as opposed to the other nitrogen sources [16]. The objective of this study was to determine the quality of sorghum grains as influenced by different nitrogen fertilizer source and field condition.

2. Materials and Methods

2.1. Description of Study Area

The experiment was conducted during the 2018/19 and 2019/20 plantings seasons. The experiment took place in the North West province of South Africa at North-West University research farm, Molelwane (25° 48′S latitude and 45° 38′E longitude and at a mean altitude above sea level of 1012 metres) outside Mafikeng city. The area receives rainfall of 571mm, and it falls into a semi-arid region according to Kasirivu, *et al.* [17]. The temperature of the region ranges from 7°C to 37°C. Molope [18] and Kasirivu, *et al.* [17] stipulated that the soil at the site belongs to the Hutton series with a sandy loam texture. According to the classification by FAO-UNESCO [19], the soil at Molelwane is categorized as a Ferric Luvisol. Table 1 shows the weather data for Molelwane for the two seasons selected for the study.

Table-1. The mean temperature and rainfall data for Mafikeng for the duration of the experimental period

Site	Season	Climate data	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mafikeng	2018/ 2019	Rainfall(mm)	5.2	5.2	90.6	30.2	113.4	36.2	122.8	7.2
		Max T (°C)	30.5	32.7	34.8	34.5	31.5	33.7	26.6	26.1
		Min T (°C)	13.1	15.9	19.6	18.9	17.5	17.1	13.7	8.4
	2019/ 2020	Rainfall(mm)	0.6	54.6	160.4	106.4	52.2	88.0	46.8	0.0
		Max T (°C)	33.6	33.3	30.2	30.7	31.1	28.4	25.8	25.7
		Min T (°C)	15.6	17.5	18.1	17.4	17.8	14.8	11.6	6.9

Max T (℃) = Maximum temperature in degrees Celsius;, Min T (℃) = Minimum temperature in degrees Celsius; mm = millimetres.
Source: South African Weather Service (SAWS), 2020

2.2. Experimental Design

The experiment used was incorporated a 2x5x2 factorial arranged in a split-split plot design that was fitted into a randomized complete block design. The main plots reflected irrigation and dryland field conditions. The subplots reflected the nitrogen sources (LAN, urea, ammonium sulphate, ammonium sulphate nitrate, and control) and the sub-sub plots reflected the cultivars (Titan and Avenger). There was a total of 10 combinations of treatments per replication and a total of 40 plots per field condition.

2.3. Agronomic Practices

The seedbeds preparations included the use of a plough and harrowing disc. The application of fertilizer was split into two dosages; the first was banded at planting and the second was side-dressed when the plants were at knee height and nitrogen fertilizer sources were applied at the recommended rate of 120 kg/ha. A single super phosphate was applied as basal at 60 kg/ha at planting based on the soil analysis results. The pre-soil sampling analysis during the 2018/19 and 2019/20 planting seasons are indicated in Table 2.

Table-2. The results of the soil chemical (mg/kg^{-1}) and physical properties of samples collected before planting at two depths (0-15 and 15-30 cm) for two field conditions during the 2018/19 and 2019/20 seasons

Field condition	Chemical/physical properties	2018/19		2019/20	
		0-15	15-30	0-15	15-30
Irrigation	$N\text{-}NO_3$	2.72	1.81	0.60	0,01
	$N\text{-}NH_4$	0.70	1.05	1.45	1.00
	P(Bray-1)	58	55	13	10
	K	208	225	228	190
	%Sand	85	84	84	83
	%Silt	3	3	3	4
	%Clay	12	13	13	13
	pH (H_2O)	6.86	6.87	6.59	6.13
Dryland	$N\text{-}NO_3$	1.05	0.85	0.74	0.36
	$N\text{-}NH_4$	2.20	2.30	1.80	2.00
	P(Bray-1)	12	12	10	8
	K	130	140	145	155
	%Sand	87	86	84	84
	%Silt	1	1	4	1
	%Clay	12	13	12	15
	pH (H_2O)	6.95	6.98	3.96	5.63

K=Potassium, $N\text{-}NO_3^-$ = Nitrate, $N\text{-}NH_4^+$ = Ammonium, P=Phosphorus

Three weeks after emergence, thinning was done and one plant was left per stand. Weeding was done 3 weeks after planting and successively throughout the plant's growth cycle. Bulldock granules were applied to control the sorghum stalk borer at the vegetative stage, before the appearance of the flag leaf. Bulldock Beta liquid solution was also applied to control the stalk borer at the grain-filling stage. Sorghum panicles were covered with monofilament bags to protect them from birds. Irrigation was applied twice a week and was not applied during the days when it was raining. Supplementary irrigation was applied using a sprinkler system under irrigated field conditions. The volume of water used for supplementary purposes was 17mm per day, depending on the strength of the wind and the availability of water. A rain gauge was used to measure the amount of water after a four-hour period of irrigation.

2.4. Data Collection

The sorghum panicles were harvested from the harvesting area (9.92 m^2) within each plot. They were threshed, cleaned and grain samples of approximately 250 grams were measured in small bags per plot and sent to Dohne Analytical Services in Eastern Cape Province for analysis. A total of 120 samples for both field conditions and seasons were then analysed for ash, fibre, fat, protein and starch contents in percentages by using a Near infrared spectroscopy (NIR) machine.

2.5. Data Analysis

The data collected were subjected to analysis of variance (ANOVA) to compare the means of treatment using the Gen discovery 4th Edition (2012). Treatment means were separated using LSD at 5% level of probability and high factor relations were taken into account for the measured parameters.

3. Results

3.1. Grain Ash Content

As indicated in Fig 1, nitrogen fertilizer source had no significant effect (P>0.05) on sorghum grain ash content during the 2018/19 and 2019/20 planting seasons. Nevertheless, sorghum treated with ammonium sulphate had a higher grain ash content of 7.05% during the 2019/20 planting season. Cultivar had no significant effect (P>0.05) on sorghum grain ash content during the 2018/19 planting season (Fig 2) but a significant effect (P<0.001) during the 2019/20 planting season. Sorghum cultivar Titan had a higher grain ash content of 7.12% compared to sorghum cultivar Avenger.

Field condition had no significant effect (P>0.05) on sorghum grain ash content during the 2018/19 planting season (Fig 3) but a significant effect (P<0.001) during the 2019/20 planting season. Sorghum planted under dryland field conditions had a significantly higher grain ash content of 7.13% compared to sorghum planted under irrigation field conditions.

The interaction of treatment factors had no significant effect (P>0.05) on sorghum grain ash content during the 2018/19 planting season. However, during the 2019/20 planting season, cultivar x field condition had a significant effect (P=0.003) on sorghum grain ash content.

Figure-1. The effect of nitrogen fertilizer source on sorghum ash content during the 2018/19 and 2019/20 planting seasons

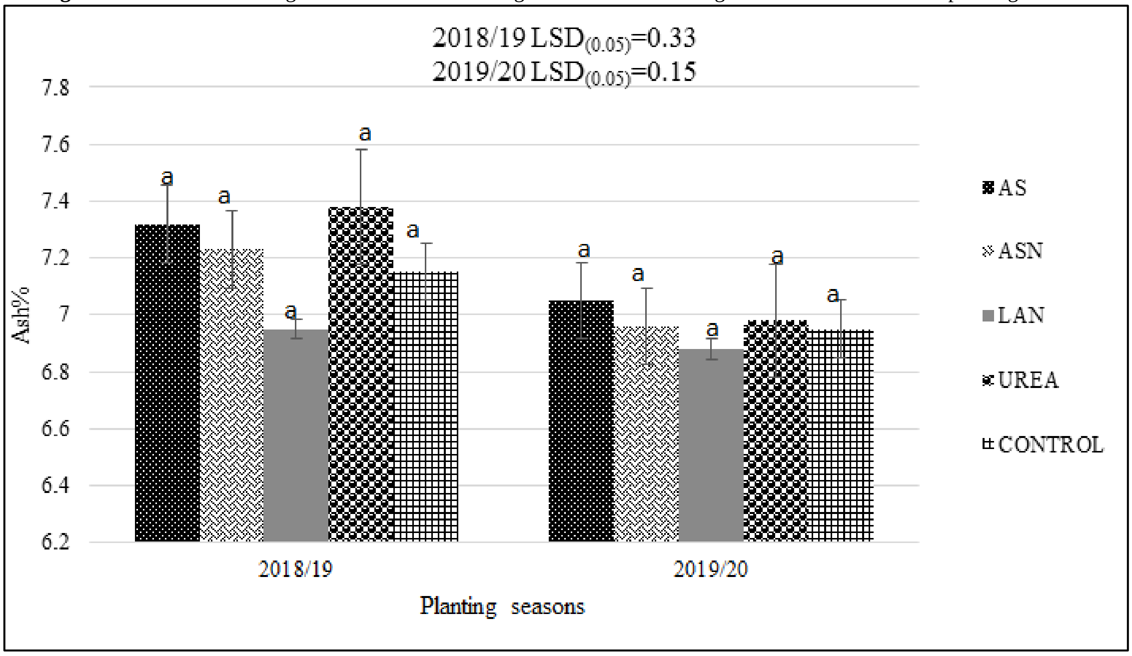


Figure-2. The effect of cultivar on sorghum ash content during the 2018/19 and 2019/20 planting seasons

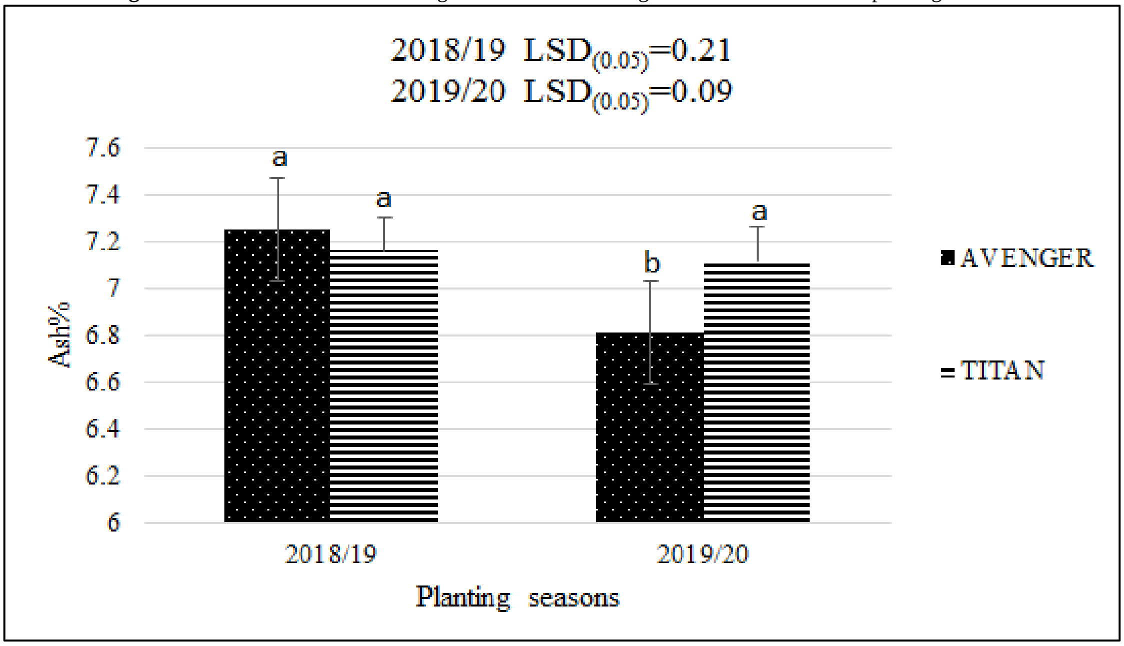
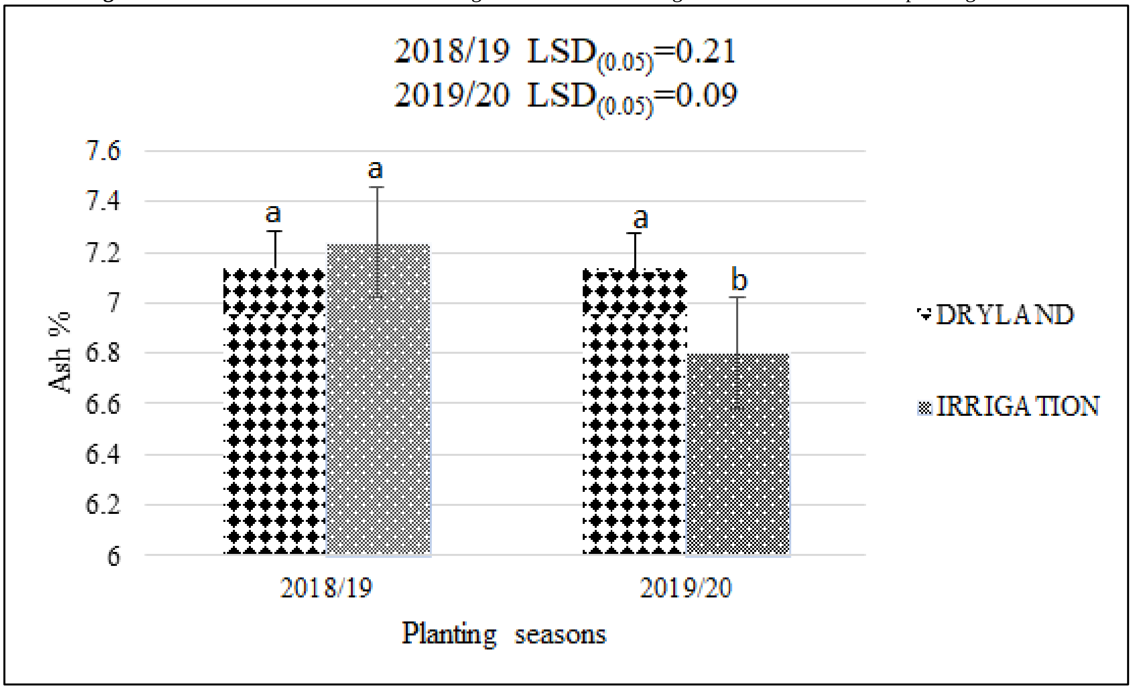


Figure-3. The effect of field condition on sorghum ash content during the 2018/19 and 2019/20 planting seasons



3.2. Grain Crude Fibre

Nitrogen fertilizer source had no significant effect (P>0.05) on sorghum grain crude fibre content during the 2018/19 and 2019/20 planting seasons (Fig 4). Even though the nitrogen fertilizer source had no significant impact, sorghum treated with urea had a higher grain crude fibre content of 7.45% during the 2018/19 planting season. Cultivar had no significant effect (P>0.05) on sorghum grain crude fibre content during the 2018/19 and 2019/20 planting seasons.

Field condition had no significant effect (P>0.05) on sorghum grain crude fibre content during the 2018/19 planting season (Fig 5). However, during the 2019/20 planting season, it had a significant effect (P<0.009) on the grain crude fibre content. Sorghum planted under dryland field conditions had a higher grain crude fibre content of 7.73% compared to sorghum planted under irrigation field conditions.

The interaction of treatment factors had no significant effect (P>0.05) on sorghum crude fibre content during the 2018/19 planting season. However, during the 2019/20 planting season, field condition x nitrogen source had a significant effect (P=0.027) on the crude fibre content of sorghum.

Figure-4. The effect of nitrogen fertilizer source on sorghum crude fibre content during the 2018/19 and 2019/20 planting seasons

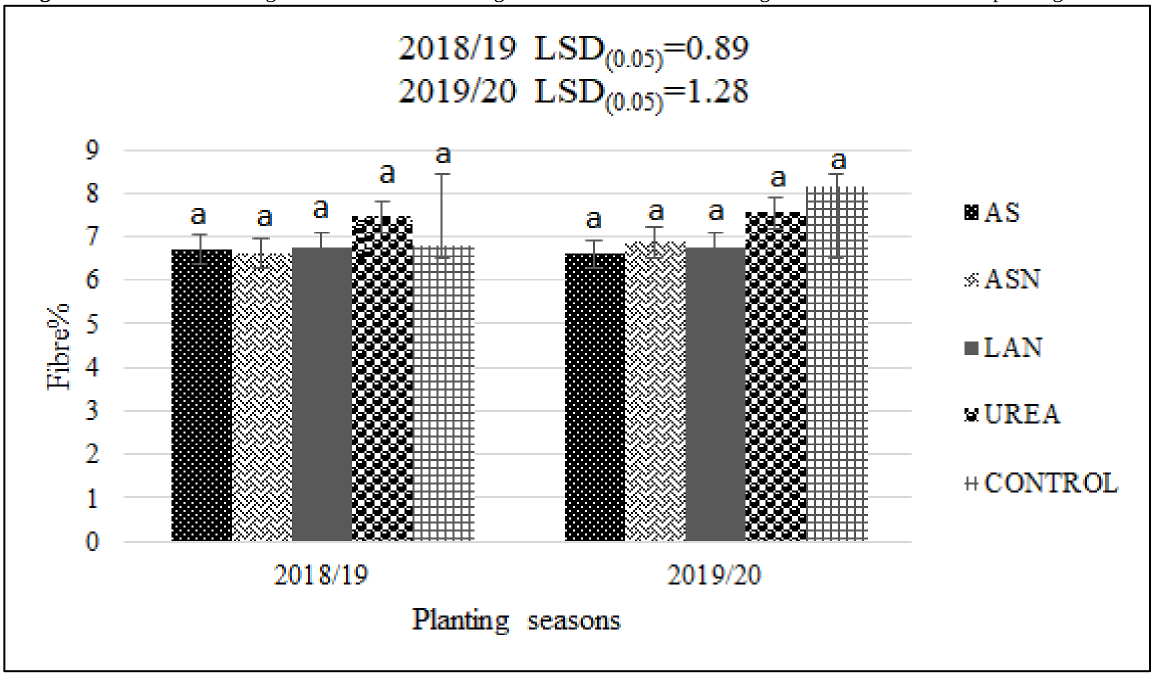
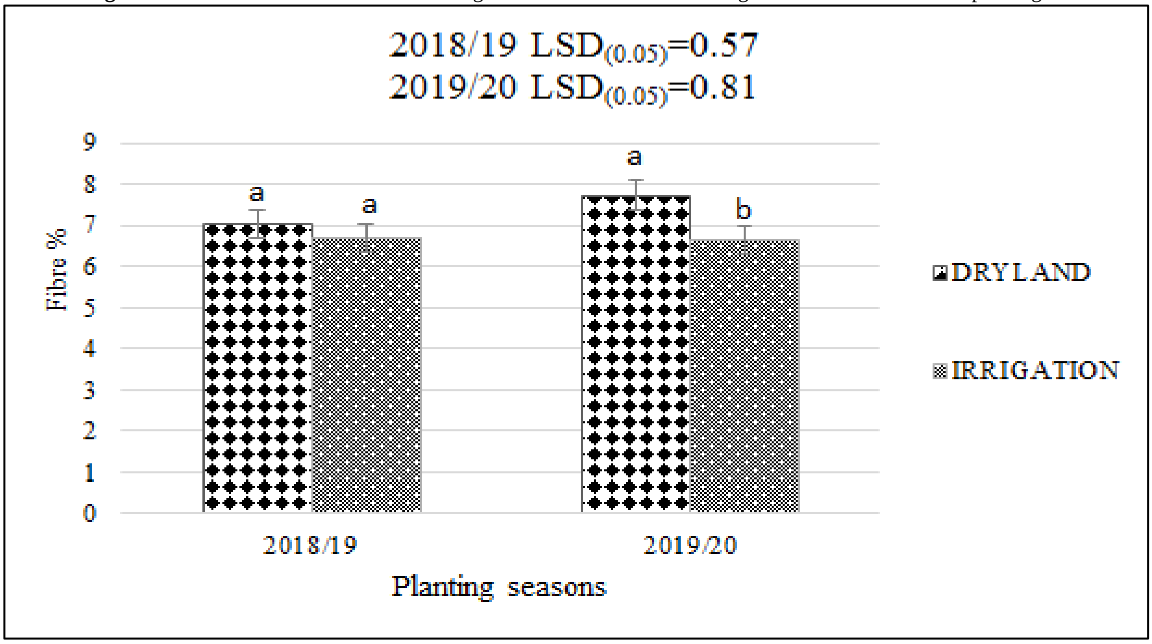


Figure-5. The effect of field condition on sorghum crude fibre content during the 2018/19 and 2019/20 planting seasons



3.3. Grain Fat Content

Nitrogen fertilizer source had no significant effect (P>0.05) on sorghum fat content during the 2018/19 and 2019/20 planting seasons (Fig 6). Though no significant difference was observed statistically, sorghum treated with ammonium sulphate nitrate had a higher fat content of 14.38% during the 2018/19 planting season.

Cultivar had significant effect (P<0.001) on sorghum grain fat content during the 2018/19 and 2019/20 planting seasons (Fig 7). During the 2018/19 planting season, sorghum cultivar Avenger had a higher grain fat content of 15.15% than sorghum cultivar Titan. On the other hand, sorghum cultivar Titan had a higher grain fat content of 15.49% than sorghum cultivar Avenger during the 2019/20 planting season.

Field condition had no significant effect (P>0.05) on sorghum grain fat content during the 2018/19 and 2019/20 planting seasons. The interaction of treatment factors also had no significant effect (P>0.05) on sorghum grain fat content during the 2018/19 and 2019/20 planting season.

Figure-6. The effect of nitrogen fertilizer source on sorghum crude fat content during the 2018/19 and 2019/20 planting seasons

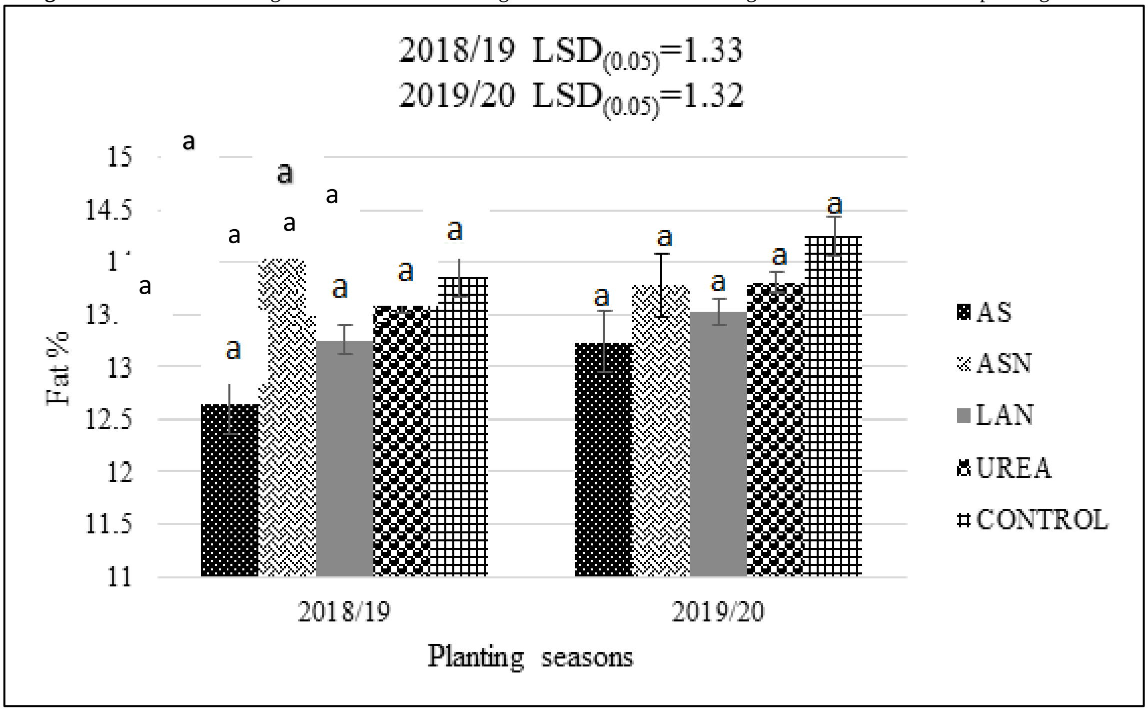
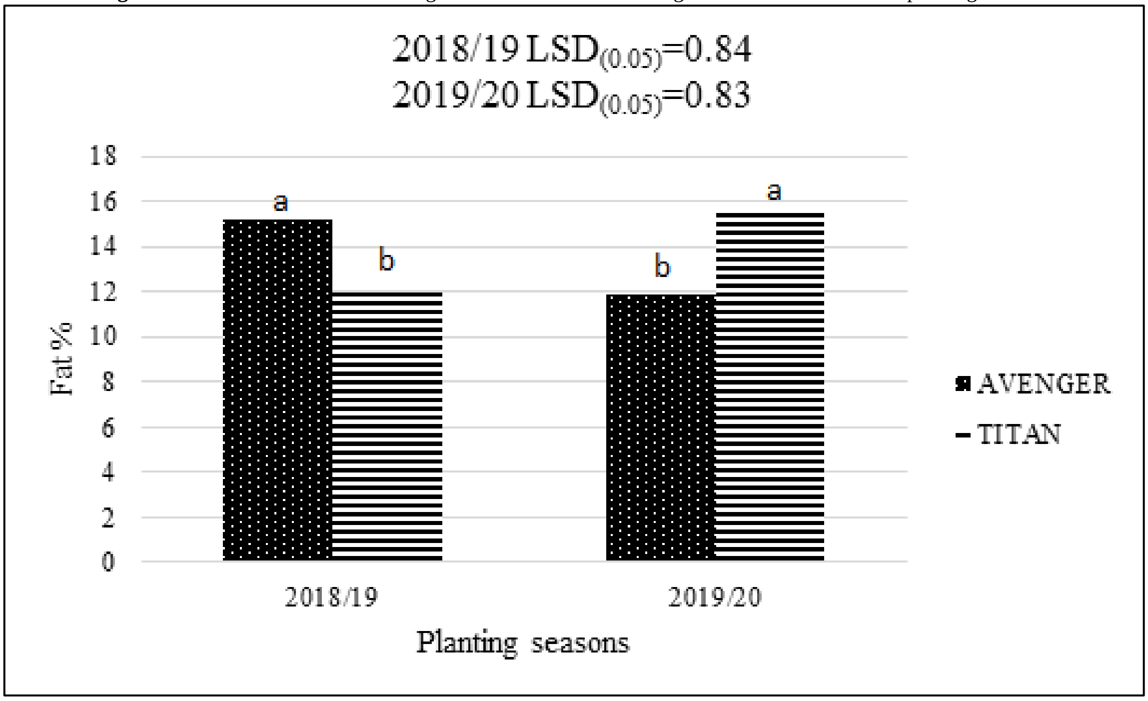


Figure-7. The effect of cultivar on sorghum crude fat content during the 2018/19 and 2019/20 planting seasons



3.4. Grain Crude Protein

Nitrogen fertilizer source had no significant effect (P>0.05) on sorghum grain crude protein during the 2019/20 planting season (Fig 8), but had a significant effect (P=0.032) during the 2018/19 planting season. Sorghum treated with limestone ammonium nitrate had a higher grain crude protein content of 28.95% compared to sorghum treated with other sources of nitrogen fertilizer.

Sorghum cultivars did not differ in grain crude protein during the 2018/19 planting season (Fig 9), but had a significant effect (P<0.001) during the 2019/20 planting season. Sorghum cultivar Avenger had a higher grain protein content of 28.86% compared to cultivar Titan.

Field condition had no significant effect (P>0.05) on sorghum grain crude protein content during the 2018/19 planting season (Fig 10), but had a significant effect (P=0.006) during the 2019/20 planting season. Sorghum planted under irrigation field conditions had a higher grain protein content of 28.63% than sorghum planted under dryland field conditions. The interaction of treatment factors had no significant effect (P>0.05) on sorghum grain protein content during the 2018/19 planting season but during the 2019/20 planting season, cultivar x nitrogen source had a significant effect (P=0.043) on sorghum grain crude protein content.

Figure-8. The effect of nitrogen fertilizer source on sorghum crude protein content during the 2018/19 and 2019/20 planting seasons

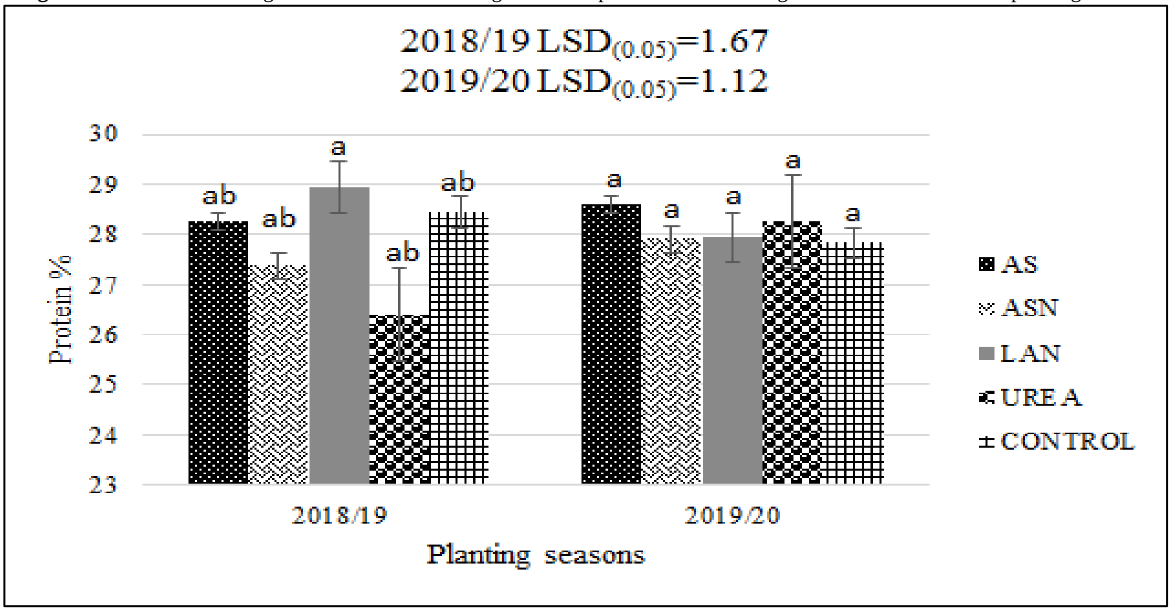


Figure-9. The effect of cultivar on sorghum crude protein content during the 2018/19 and 2019/20 planting seasons

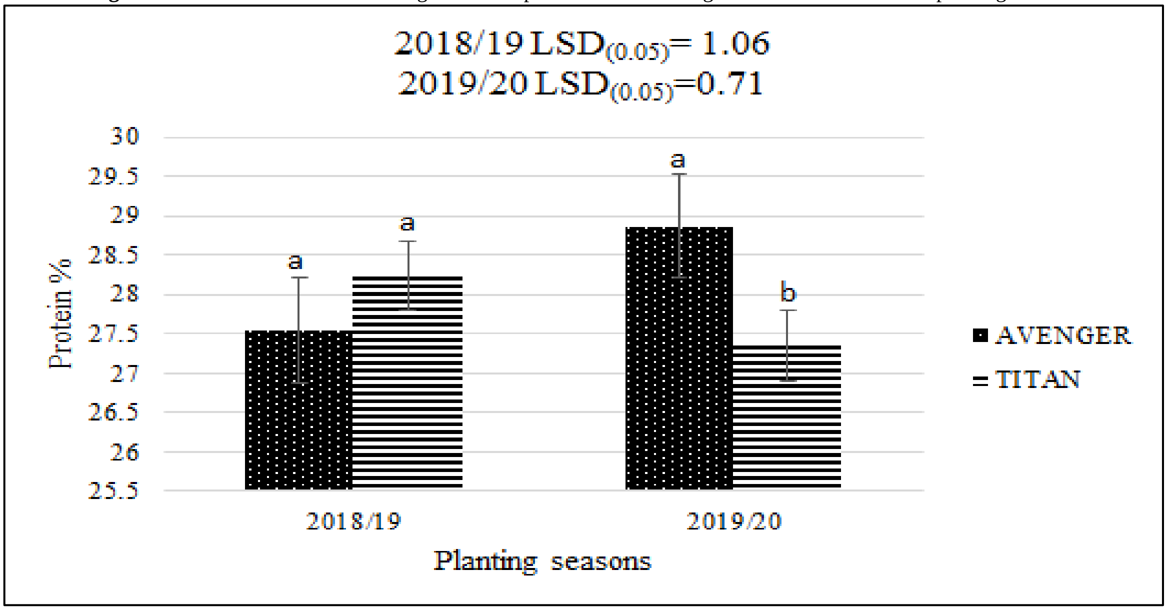
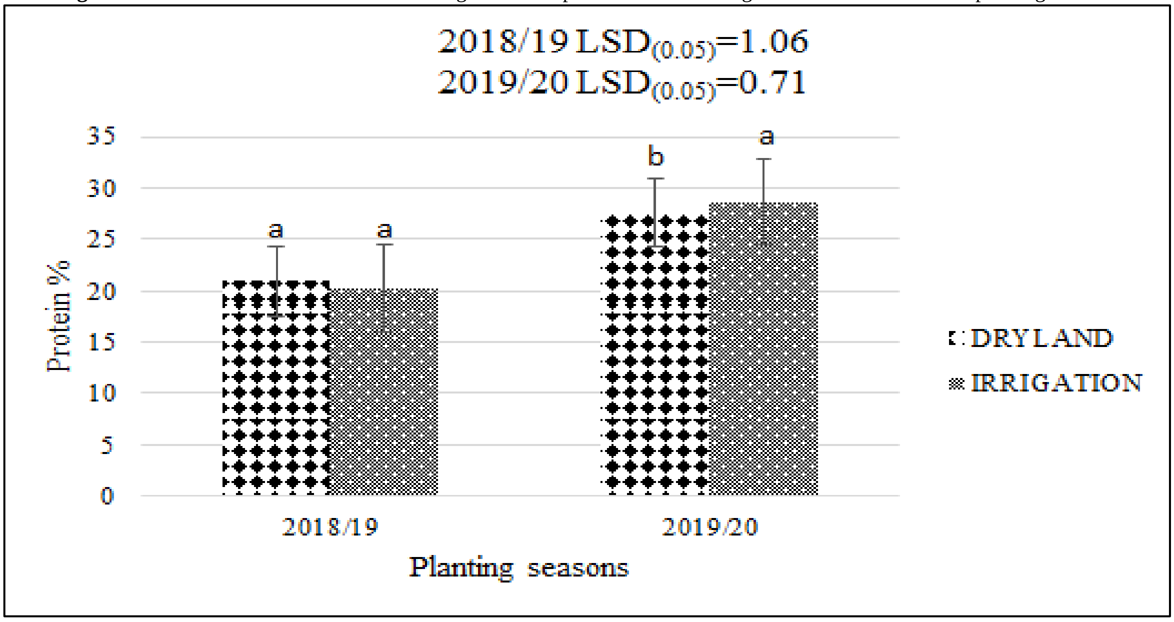


Figure-10. The effect of field condition on sorghum crude protein content during the 2018/19 and 2019/20 planting seasons

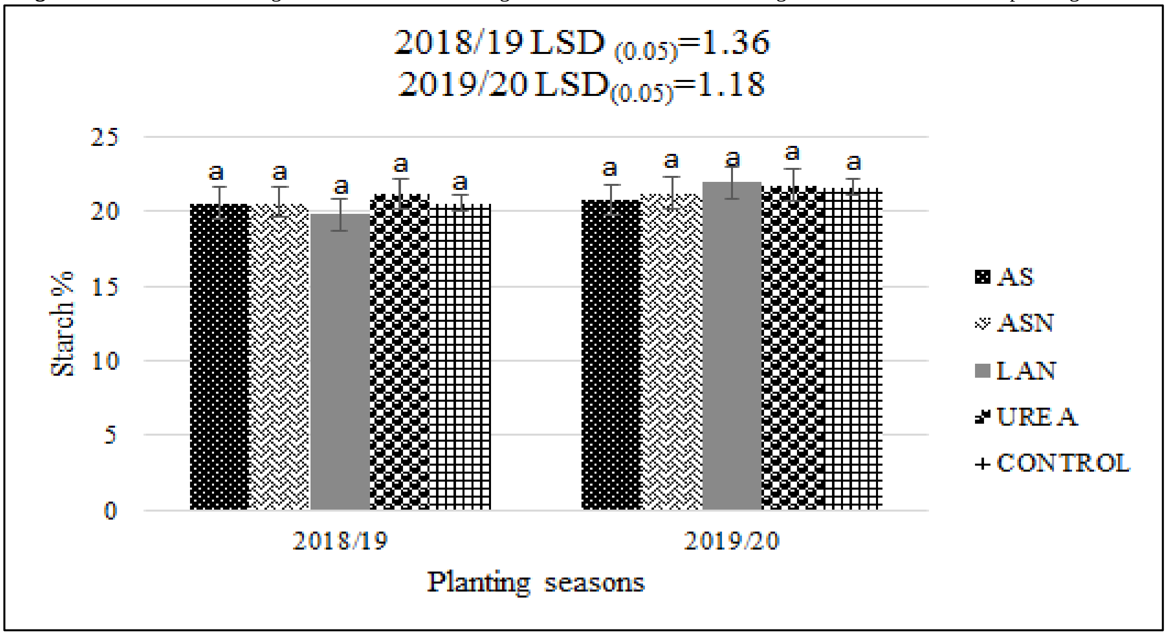


3.5. Grain Starch Content

Nitrogen fertilizer source and cultivar had no significant effect (P>0.05) on sorghum grain starch content during the 2018/19 and 2019/20 planting seasons (Fig 11). Though no significant difference was observed, sorghum treated with urea and limestone ammonium nitrate had a higher grain starch content of 21.20% and 21.96% respectively during the 2018/19 and 2019/20 planting seasons.

Cultivar and field condition had no significant effect (P>0.05) on sorghum grain starch content during the 2018/19 and 2019/20 planting seasons. The interaction of treatment factors had no significant effect (P>0.05) on sorghum grain starch content during the 2018/19 and 2019/20 planting seasons.

Figure-11. The effect of nitrogen fertilizer source on sorghum crude starch content during the 2018/19 and 2019/20 planting seasons



4. Discussion

The study revealed that ash content was higher under sorghum treated with ammonium sulphate, and this dominance may be attributed to the presence of sulphur which enhances the absorption of minerals in the soil in order to increase the ash content of the grains. This concurs with the findings of Ozturk and Aydin [20], who reported an increase in the ash content of wheat under ammonium sulphate applications.

The accumulation of ash content of sorghum under cultivar Titan may be attributed to the genetic variation and long grain-filling period of the cultivar, which gives the plants ample time to accumulate photosynthate needed for ash content. Qadir, *et al.* [21] observed a significant effect of ash content which was attributed to the genetic and environmental conditions and its interaction with the cultivar.

The higher ash content under dryland field conditions may be attributed to rainfall which improved the capacity of plants to translocate nutrients from other plant parts such as the leaves during the grain-filling stage, resulting in a higher ash content in the grains. This result agrees with the findings of Cabrera-Bosquet, *et al.* [22], who discovered that the kernel ash content increases during severe water stress conditions and can be attributed to mineral accumulation in the grain from photosynthetic tissues during plant senescence.

The higher fibre content of sorghum treated with urea could be attributed to the influence of nitrate in the grains which improves the production of amino acid which in their turn stimulate the formation of crude fibre in the grains. This agrees with the findings of Eltelib [23], who recorded an increase in crude fibre under sorghum treated with urea. Sebetha, *et al.* [24] also reported a significant influence of urea on the seed quality of maize.

Crude fibre content of sorghum planted under dryland field conditions attributed to the large accumulation of nutrients in the grains due to diminished translocation caused by low water levels. Queiroz, *et al.* [25] reported a higher fibre content in sorghum under water stress which could be attributed to the concentration of nutrients in the plant tissue as a result of the limited availability of water.

This study revealed that application of ammonium sulphate nitrate increased the fat content, which could be attributed to the sulphur that influences the changes in the chemical composition of the seed and increases the concentration of fatty acids, resulting in a high fat content. This corroborates with the findings of Silva, *et al.* [26], who reported that the fat content of maize increases under applications of ammonium sulphate nitrate. Based on the results, inconsistency in cultivars for both seasons might be due to the environmental changes, that might have influenced the change in adaptation throughout the seasons.

The higher protein content under sorghum treated with limestone ammonium nitrate could be attributed to the easy translocation of limestone ammonium nitrate from the senescing leaves of plants during the grain-filling stage. This translocation process enhances the transportation of amino acids and is responsible for the increased protein content in the grain. The statement above is in accordance with the findings of Ashiono, *et al.* [27], who reported the accumulation of protein in sorghum treated with limestone ammonium nitrate.

The higher protein content under the sorghum Avenger cultivar could be attributed to the short growth cycle of the cultivar, which facilitates the faster accumulation of protein during protein synthesis. This agrees with the findings of Wirnas, *et al.* [28], who reported a significant increase in the protein content of sorghum under different cultivars.

The protein content of sorghum planted under irrigation field conditions was found to be high. This could be due to sufficient moisture that intensifies the translocation of the nutrient and improves protein synthesis. This agrees with the findings of Shrief and El-Mohsen [29], who A high starch content under sorghum treated with urea and limestone ammonium nitrate could be attributed to the availability of nitrate (urea) and ammonium (LAN) in the stem and leaves of the plants. Tranavičiené, *et al.* [30] reported an increase in the starch content of wheat treated with maximum application rates of limestone ammonium nitrate.

5. Conclusions

Application of nitrogen fertilizer source such as limestone ammonium nitrate played a significant role in the quality of the sorghum grain since it affected protein and starch content. Urea was also found to play a significant role in the grain quality as it affected the fibre and starch content of the grain. Dryland field conditions were found to play a significant role in the nutritional content of the grain since it favoured the ash and fibre content of the grain. The study indicates that grain quality is influenced by environmental conditions and cultivar choice.

Titan cultivar, though had less grain yield possesses higher ash content, as a late maturing cultivar. Whilst early maturing cultivar Avenger had higher protein content.

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