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Research Article
Maize Grain Quality in Response to the Timing of Nitrogen Fertilizer Application and Environmental Variation

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Abstract

Background and Objective: Maize is recognized as one of the locally produced field crops and a staple food for the bulk of the population in South Africa. The timing of nitrogen application is an essential management decision for maize production. The research study was carried out to determine the effect of nitrogen fertilizer timing, cultivar and location on the grain quality of maize. **Materials and Methods:** The study was carried out at Mafikeng and Taung in the North West Province during the 2019/20 and 2020/21 planting seasons. A randomized complete block design and four replications were used for the experimental design. Nitrogen application stages were zero nitrogen, during planting and emergence and during the five and ten leaf stages with two cultivars PAN 4A 111 and PAN 413. **Results:** The study showed a significant effect of nitrogen fertilizer application on protein content in both planting seasons. The PAN 4A 111 and PAN 413 produced higher starch and protein content, respectively. Location also had a significant effect on protein content. Nitrogen application during emergence, five and ten leaf stages produced higher maize protein, fat, crude fiber and ash content. **Conclusion:** Maize grain responded positively to the application of nitrogen fertilizer during planting, emergence and five-leaf stage and resulted in a high-quality grain.

Key words: Timing of nitrogen application, maize, cultivar, growth stages, grain quality, planting season

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The quality of maize grain is heavily impacted by environmental conditions[1]. Drought and heat stress, commonly known as abiotic stressors, are two prevalent conditions associated with environmental conditions that regularly impact the quality of maize grain[2]. Grain quality is affected by heat stress, which affects the physiological and biological properties of maize[3,4]. Grain filling is one of the most essential and critical stages in determining the quality of the grain. Thus, the high temperature associated with heat stress during this period could have a significant impact on maize grain quality[5]. Drastic increases in temperature reduce the starch content of the grain[6,7]. High-temperature stress during the early stages of maize plant development, especially after anthesis, results in limited starch production[8]. Heat stress before pollination has an even greater impact on grain production and quality than heat stress at later stages in the development of the maize plant[9]. Drought periods tend to severely reduce starch content and granular size and to proportionately increase protein content[10].

During the grain-filling period, the maize protein components are extremely susceptible to drought stress[11]. Prolonged drought stress periods reduce the quality of the grain[12]. Under normal climatic conditions, maize relatively contains a high property of starch in the grains. Water shortages tend to reduce grain yields, resulting in a reduction in the quality of the grain[13]. The soil's physico-chemical properties can influence the starch content of the grain[14]. Soils with reduced bulk density and increased total porosity enhance maize plant development in that they promote an adequate uptake of nutrients, thus leading to an increase in the components of the grain that affect its quality[15]. Maize is highly sensitive to soils with high salinity levels. Such soils lead to a reduction in biosynthetic activities that normally promote the protein and starch content levels of the maize grain[16].

Nitrogen is regarded as a significant component of protein which affects the quality of the maize grain to a large extent. As such, a correct balance of nitrogen fertilizer results in an increase in the quality components of maize such as its protein content[17,18]. According to Subedi and Ma[19], the application timing of nitrogen fertilizer at later stages (V8) upward reduces yields and thus the protein content of the grain. However, early and appropriate applications of nitrogen result in increased protein content and lead to a reduction in the starch and fat content[20]. The timing of nitrogen application at planting produces higher grain yields, thus resulting in a high-quality maize grain[21]. On the other hand, the inappropriate timing of nitrogen fertilizer applications may greatly reduce the quality of the maize grain[22].

According to Binder *et al.*[23], a delay in applying nitrogen fertilizer up to the V6 stage leads to a reduction in yields, thus causing a significant reduction in the quality of the grain. The nitrogen timing application on maize at the early growth stages leads to a significant accumulation of protein and therefore a high protein content[24,25].

Late application of nitrogen fertilizer normally results in poor grain quality[26]. Heavily textured soils restrict the uptake of water and nutrients in maize plants, thus delaying the grain-filling process and resulting in low grain quality. The objective of the study was to evaluate the effect of nitrogen fertilizer timing and environmental variation on the grain quality of two maize cultivars.

MATERIALS AND METHODS

Description of the study area: The field experiment was carried out at two different locations in the North West Province in South Africa during the 2019/2020 and 2020/2021 planting seasons. The sites were the Department of Agriculture station situated in Taung and the North West University research farm situated in Mafikeng. The NWU (North West University) research farm is at 25°48'S and 45°38'E. The area receives a mean annual rainfall of 571 mm during the summer season[27]. The mean maximum temperature is 34°C while the mean minimum temperature varies between 7-11°C. The soil in the location is classified as sandy loam red soils under the South African Soil Classification and belongs to the Hutton series. The North-West University Research Farm soil is categorized as Ferric luvisol[28]. Taung's Department of Agriculture Experimental Station is located at 27°30'S and 24°30'E. Taung receives an annual rainfall average of 1061 mm, which commences in October. The mean maximum temperature is 37°C while the mean minimum temperature ranges between 2-20°C. According to South Africa's soil classification, the soil at the Taung location belongs to the Hutton series and consists of deep, finely-textured red sandy soils[27]. The climatic data at two locations during the course of the study were different as indicated in Table 1.

Experimental design: The experiment was laid out in a 5×2×2 arrangement fitted into a Randomized Complete Block Design (RCBD) with four replications. Each replication of 10 combined treatments. Each location had 40 plots. The five nitrogen application timing stages were zero nitrogen application, during planting, during emergence, during five-leaf stages and during the ten-leaf stage. The two cultivars planted were early maturing (PAN 4A 111) and late maturing (PAN 413). The research experiment study was carried out at two locations, namely Mafikeng and Taung.

Table 1: Mean rainfall and temperature at Mafikeng and Taung 2019/2020 and 2020/2021 planting seasons

Location	Season	Climate data	September	October	November	December	January	February	March	April	May
Mafikeng	2019/20	Rainfall (mm)	0.6	0.6	54.6	160.4	106.4	52.2	88.0	46.8	0.0
		Max temperature (°C)	29.3	33.6	33.3	30.2	30.7	31.1	28.4	25.8	24.7
		Min temperature (°C)	9.5	15.6	17.5	18.1	17.4	17.8	14.8	11.6	5.7
Mafikeng	2020/21	Rainfall (mm)	0.0	17.2	132.2	17.4	0.0	0.0	0.0	0.0	4.0
		Max temperature (°C)	28.3	31.5	30.2	30.5	29.7	28.5	29.1	28.6	24.1
		Min temperature (°C)	9.8	15.3	15.2	17.1	18.1	16.6	13.5	10.3	5.8
Taung	2019/20	Rainfall (mm)	0.0	0.0	9.4	76.6	57.6	128	106	65.8	0.0
		Max temperature (°C)	30.4	34.2	36.8	33.4	34.2	31.7	30.3	26.6	25.8
		Min temperature (°C)	8.6	13.2	16.5	18.5	18.9	18.6	15.6	11.3	4.1
Taung	2020/21	Rainfall (mm)	13.3	31.6	94.6	114.4	216	140.8	62.2	0.0	1.0
		Max temperature (°C)	29.4	33.3	32.3	33.4	30.9	31.4	30.9	30.5	25.4
		Min temperature (°C)	8.2	13.8	15.2	17.4	18.6	17.4	13.8	10.2	4.2

Table 2: Soil texture, physical and chemical properties from Mafikeng and Taung during 2019/2020 and 2020/2021 planting seasons

		2019/20		2020/21	
Location	Chemical/physical properties	0-15	15-30	0-15	15-30
Mafikeng	$N\text{-}NO_3$	1.85	0.01	9.40	17.50
	$N\text{-}NO_4$	2.45	0.90	1.60	2.50
	P (Bray-1)	16	11	40	26
	K	140	123	245	218
	Sand (%)	86	86	80	80
	Silt (%)	1	1	4	5
	Clay (%)	13	13	16	15
	pH (H_2O)	7.08	5.76	6.66	6.68
Taung	$N\text{-}NO_3$	5.20	4.00	5.10	5.85
	$N\text{-}NO_4$	1.10	0.50	0.75	1.00
	P (Bray-1)	7	8	2	5
	K	160	143	158	195
	Sand (%)	90	90	84	84
	Silt (%)	1	1	3	4
	Clay (%)	9	9	13	12
	pH (H_2O)	6.81	6.54	6.80	6.69

P: Phosphorus, K: Potassium, $N\text{-}NO_3$: Nitrate and $N\text{-}NO_4$: Ammonium

Agronomic practices: The experimental sites were ploughed and harrowed to pulverize the soil and the seedbeds were prepared before planting. A mouldboard and disc plough were used as primary tillage in order to loosen the soil structure (to break up any compacted soil), bury the plant and soil waste and control and remove the weeds. A disc harrow was used to break up the soil clods, harrow the soil and plant waste from the field and level the soil surface. Urea was used as a nitrogen fertilizer source and applied at 120 kg ha^{-1}. The nitrogen fertilizer was applied during planting, during emergence, during the five-leaf stages and the ten-leaf stage. Based on the soil analysis, phosphorus was applied as the basal fertilizer. The maize cultivars used, namely PAN 4A 111 (early maturing) and PAN 413 (late maturing), were purchased from PANNAR (SA seed company). After emergence, thinning was carried out in order to remain with one plant per stand. Weeding was done manually and irrigation was done using sprinklers. The chemicals applied to control pests such as aphids, flies and armyworms were Avi-sipermetrin-EC and Bulldock Sc 125. The pre-soil sampling analysis during the planting seasons of the study was indicated in Table 2.

Data collection: Dried maize ears were hand-harvested from a harvesting area of 12.6 m^2. The maize ears harvested from the harvesting area were shelled. The Spectra Star XL Infrared Analyser (NIR) machine was then used to analyse a total of 30 samples per location for starch, fat, protein crude fiber and ash content, the analysed results of which were expressed in percentages.

Statistical analysis: The collected data were combined, analysed using the Analysis of Variance (ANOVA) and performed the analysis of variance using Genstat 11th edition. The least significant difference (LSD) at a (5%) level of probability was subjected to separate means. The correlation coefficient method SPSS (version 16) was used to assess the relationship between the grain quality variables.

RESULTS

Maize grain protein content: The timing of nitrogen fertilizer application significantly had an effect ($p \leq 0.05$) on maize protein content during the 2019/20 and 2020/21 planting seasons (Fig. 1). During the 2019/20 planting season, nitrogen fertilizer applied during planting, five-leaf and ten leaf stage produced a significantly higher protein content of 10.59, 11.25 and 10.66%, respectively. During the 2020/21 planting season, nitrogen fertilizer applied during the five-leaf and ten-leaf stages produced a significantly higher protein content of 11.95 and 12.19%, respectively. Cultivar had a significant effect ($p \leq 0.05$) on maize protein content during the 2020/21 planting season (Fig. 2). Maize cultivar PAN 413 produced a significantly higher protein content of 11.91%. During the 2019/20 planting season, cultivars significantly showed no effect on maize protein content. Location significantly had an effect ($p<0.001$) on maize protein content during the 2019/20 and 2020/21 planting seasons (Fig. 3). Maize planted at Taung produced a significantly higher protein content of 11.68 and 12.55% during the 2019/20 and 2020/21 planting seasons, respectively. The interaction for cultivar×location significantly had an effect ($p \leq 0.05$) on maize protein content during the 2019/20 and 2020/21 planting seasons. During the 2020/21 planting season, interaction for cultivar×location×timing nitrogen application significantly had an effect ($p \leq 0.05$) on maize protein content.

Maize grain starch content: The timing of nitrogen fertilizer application significantly had an effect ($p>0.05$) on maize starch content during the 2019/20 and 2020/21 planting seasons (Fig. 4). During 2019/20 planting season, even though there was significantly no difference on nitrogen fertilizer application, nitrogen fertilizer applied during planting produced a significantly higher starch content of 63.63%. Cultivar had a significant effect ($p \leq 0.05$) on maize starch

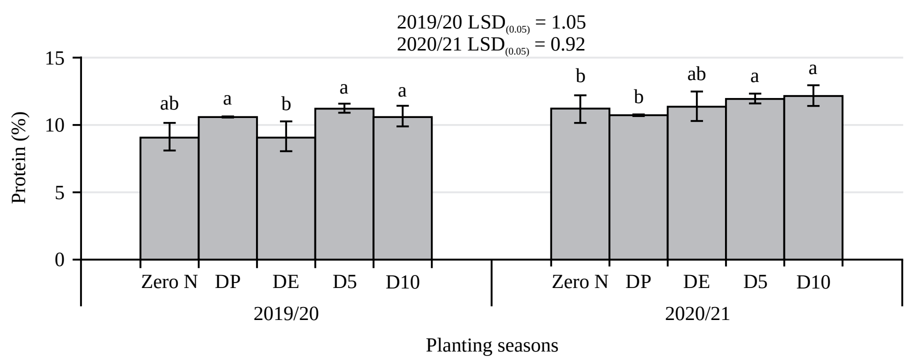

Fig. 1: Effect of timing of nitrogen fertilizer application on maize protein content during the 2019/20 and 2020/21 planting seasons

Zero N: Zero nitrogen, DP: During planting, DE: During emergence, D5: During five leaf stage, D10: During ten leaf stage and different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

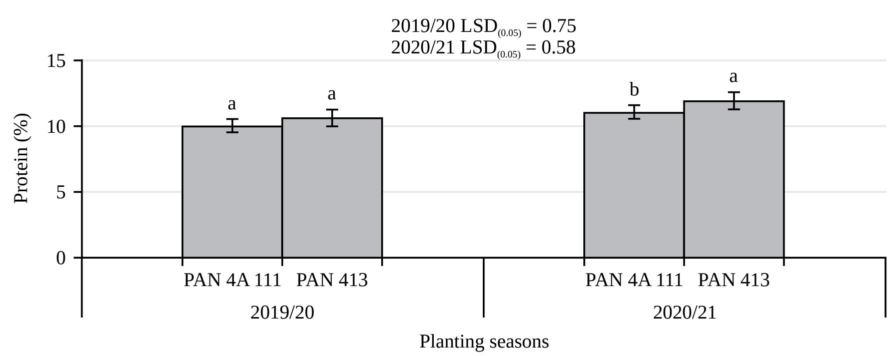

Fig. 2: Effect of cultivar on maize protein content during the 2019/20 and 2020/21 planting seasons

Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

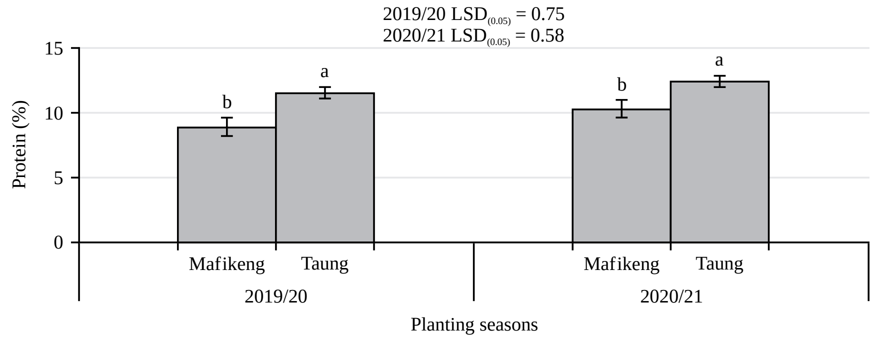

Fig. 3: Effect of location on maize protein content during the 2019/20 and 2020/21 planting seasons

Different letters indicate significant differences while the same letters indicate no significant differences according to the Tukey's test

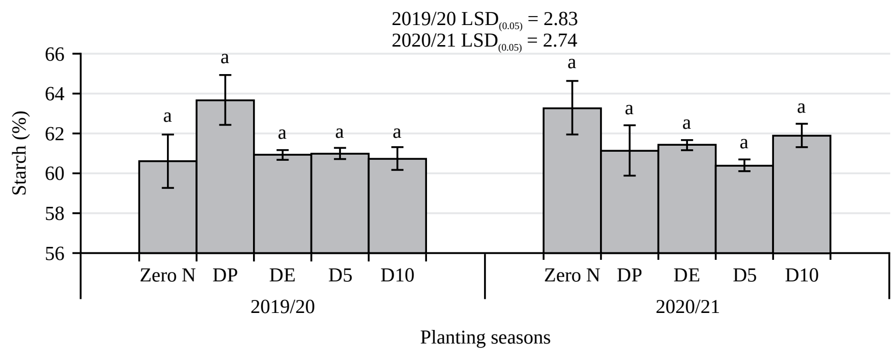

Fig. 4: Effect of timing of nitrogen fertilizer application on maize starch content during 2019/20 and 2020/21 planting seasons

Zero N: Zero nitrogen, DP: During planting, DE: During emergence, D5: During five leaf stage, D10: During ten leaf stage and different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

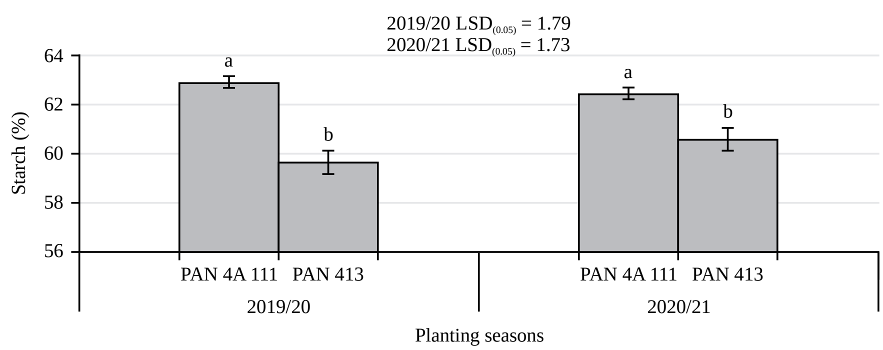

Fig. 5: Effect of cultivar on maize starch content during the 2019/20 and 2020/21 planting seasons

Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

content during the 2019/20 and 2020/21 planting seasons (Fig. 5). Maize cultivar PAN 4A 111 significantly produced higher starch content of 63.01 and 62.54% during the 2019/20 and 2020/21 planting seasons, respectively. Location significantly had no effect ($p>0.05$) on maize starch content during the 2019/20 and 2020/21 planting seasons (Fig. 6). The interaction for cultivar×location was significant ($p\leq 0.05$) on maize starch content during the 2019/20 and 2020/21 planting seasons. During the 2019/20 planting season, the interaction of location×timing nitrogen application significantly had an effect ($p\leq 0.05$) on maize starch content.

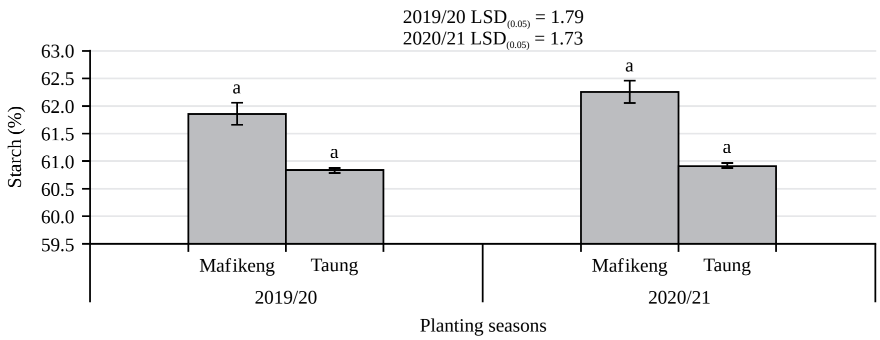

Fig. 6: Effect of location on maize starch content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

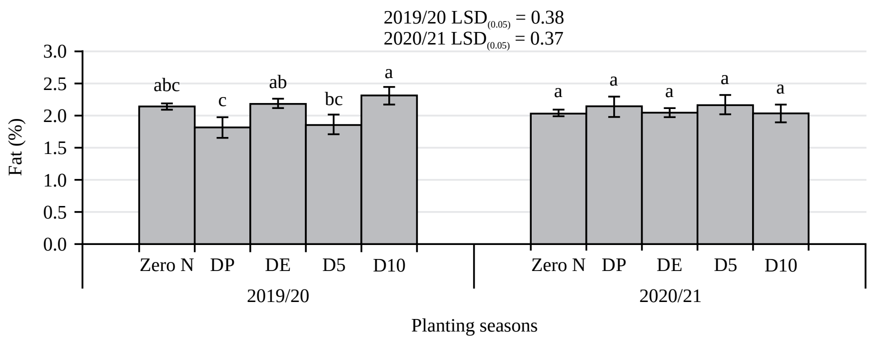

Fig. 7: Effect of timing of nitrogen fertilizer application on maize fat content during the 2019/20 and 2020/21 planting seasons
Zero N: Zero nitrogen, DP: During planting, DE: During emergence, D5: During five leaf stage, D10: During 10 leaf stage and different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

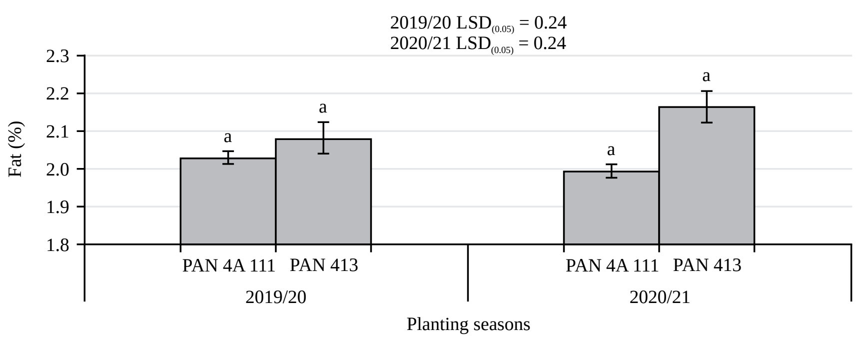

Fig. 8: Effect of cultivar on maize fat content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

Maize grain fat content: The timing of nitrogen fertilizer application significantly had effect ($p \leq 0.05$) on maize fat content during the 2019/20 planting season (Fig. 7). Nitrogen fertilizer applied during ten leaf stage produced a significantly higher fat content of 2.301%. During the 2020/21 planting season, the timing of nitrogen fertilizer application showed no significant effect on maize fat content. Cultivar significantly had no effect ($p > 0.05$) on maize fat content during the 2019/20 and 2020/21 planting seasons (Fig. 8). Location significantly had effect ($p < 0.001$) on maize fat content during the 2020/20 planting season (Fig. 9). Maize planted at Mafikeng significantly produced higher fat content of 2.278%. During the 2019/20 planting season, location significantly showed no effect on maize fat content Fig. 10. The interaction for cultivar×location significantly had effect ($p \leq 0.05$) on maize fat content during 2019/20 planting season.

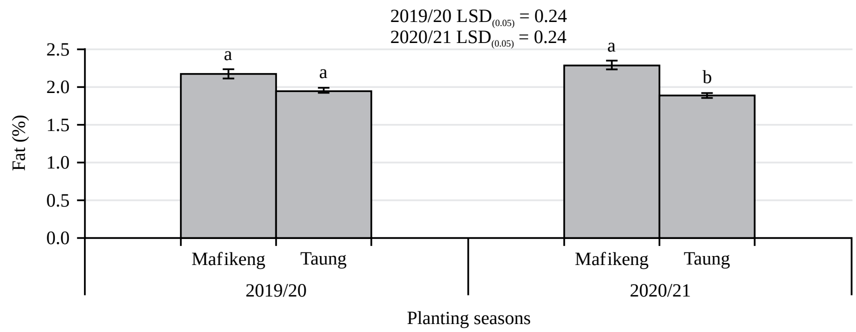

Fig. 9: Effect of location on maize fat content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

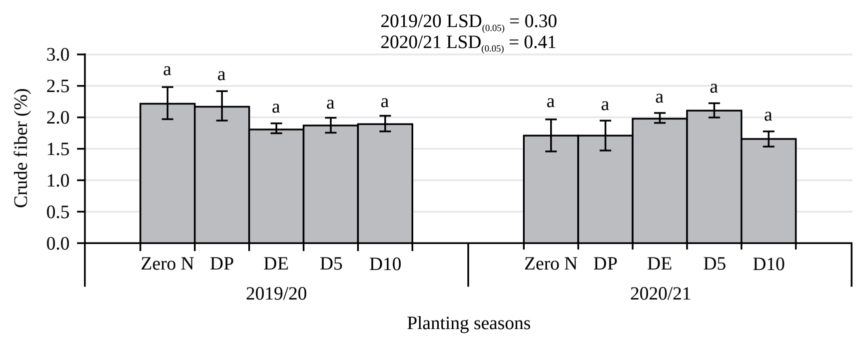

Fig. 10: Effect of timing of nitrogen fertilizer application on maize crude fiber content during the 2019/20 and 2020/21 planting seasons
Zero N: Zero nitrogen, DP: During planting, DE: During emergence, D5: During five leaf stage, D10: During ten leaf stage and different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

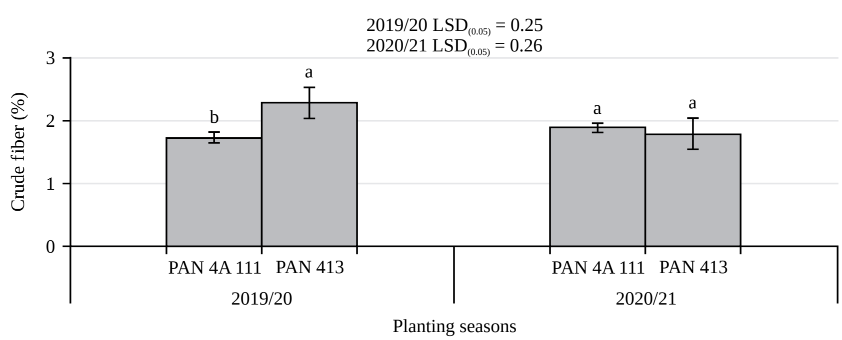

Fig. 11: Effect of cultivar on maize crude fiber content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

Maize grain crude fibre content: The timing of nitrogen fertilizer application significantly had no effect (P>0.05) on maize crude fibre content during the 2019/20 and 2020/21 planting (Fig. 10). During the 2020/21 planting season, even though there was significantly no difference on nitrogen fertilizer application, nitrogen fertilizer applied during five leaf stage produced a significantly higher crude fibre content of 2.11%. Cultivar had a significant effect (P=0.05) on maize crude fibre content during the 2019/20 planting season (Fig. 11). Maize cultivar PAN 413 produced a significantly higher crude fibre content of 2.28%. During the 2020/21 planting season, maize cultivar significantly showed no effect on maize on the crude fibre content. Location significantly had effect (P<0.001) on maize crude fibre content during the 2019/20 and 2020/21 planting seasons (Fig. 12). Maize planted at Taung significantly produced higher crude fibre content of 2.20% and 2.515 during the 2019/20 and 2020/21 planting seasons respectively. The interaction of cultivar × timing

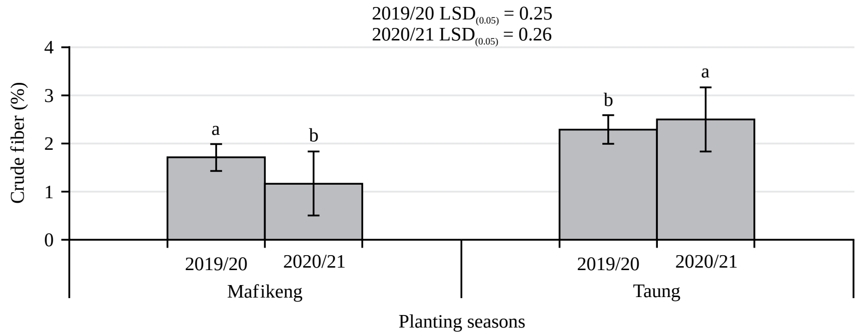

Fig. 12: Effect of location on maize crude fiber content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

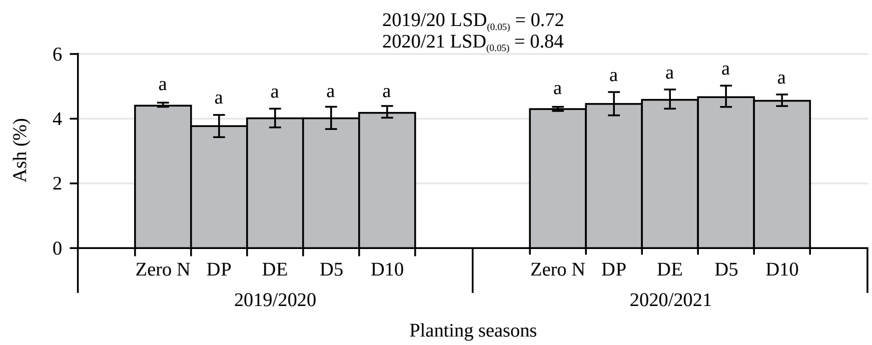

Fig. 13: Effect of timing nitrogen fertilizer application on maize ash content during 2019/20 and 2020/21 planting seasons
Zero N: Zero nitrogen, DP: During planting, DE: During emergence, D5: During five leaf stage, D10: During ten leaf stage and different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

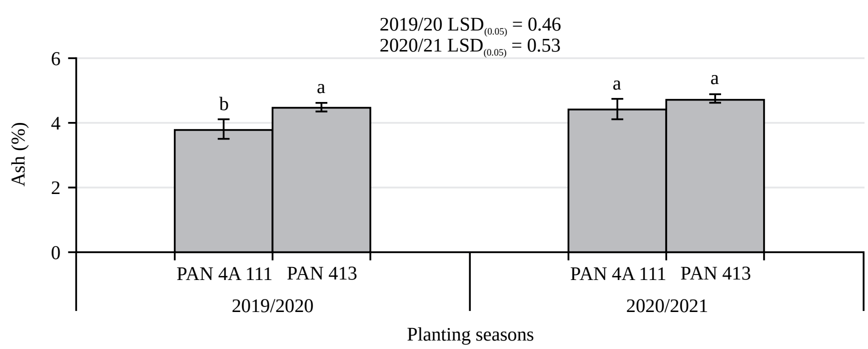

Fig. 14: Effect of cultivar on maize ash content during the 2019/20 and 2020/21 planting seasons
Different letters indicate significant differences while same letters indicate no significant differences according to Tukey's test

nitrogen application was significant (P=0.05) on maize crude fibre content during the 2019/20 planting season. During the 2020/21 planting season, interaction for cultivar × location × timing nitrogen application significantly had effect (P=0.05) on maize crude fibre content.

Maize grain ash content: The timing of nitrogen fertilizer application significantly had no effect (p>0.05) on maize ash content during the 2019/20 and 2020/21 planting seasons (Fig. 13). During 2020/21 planting season, even though there was significantly no difference on nitrogen fertilizer application, nitrogen fertilizer applied during emergence and five leaf stage produced a significantly higher ash content of 4.63 and 4.73%, respectively. Cultivar had a significant effect ($p \leq 0.05$) on maize ash content during the 2019/20 planting season (Fig. 14). Maize cultivar PAN 413

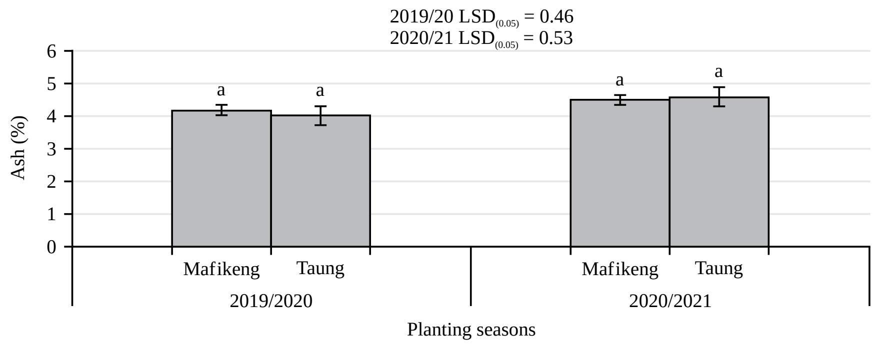

Fig. 15: Effect of location on maize ash content during the 2019/20 and 2020/21 planting season

Different letters indicate significant differences while the same letters indicate no significant differences according to Tukey's test

Table 3: Correlation between maize quality variables during the 2019/20 planting season

Variables	Protein	Fat	Crude fiber	Ash	Starch
Protein	1	-0.172	0.411**	-0.112	-0.163
Fat	-0.172	1	0.151	0.518**	-0.677**
Crude fiber	0.411**	0.151	1	0.471**	-0.332**
Ash	-0.112	0.518**	0.471**	1	-0.341**
Starch	-0.163	-0.677**	-0.332**	-0.341**	1

**Correlation is significant at the 0.01 level (2-tailed)

Table 4: Correlation between maize quality variables during the 2020/21 planting season

Variables	Protein	Fat	Crude fiber	Ash	Starch
Protein	1	-0.124	0.423**	0.334**	-0.391**
Fat	-0.124	1	-0.216	0.519**	-0.549**
Crude fiber	0.423**	-0.216	1	-0.049	-0.407**
Ash	0.334**	0.519**	-0.049	1	-0.512**
Starch	-0.391**	-0.549**	-0.407**	-0.512**	1

**Correlation is significant at the 0.01 level (2-tailed)

Table 5: Summary of cluster analysis of measured maize grain quality parameters

Cluster number	Clusters combined	Co-efficient	Included quality parameter
1	2 and 4	1.445	Fat and ash
2	1 and 3	4.160	Protein and crude fiber
3	2 and 5	7.090	Fat and starch
4	1 and 2	10.625	Protein and fat

produced a significantly higher ash content of 4.45%. During the 2020/21 planting season, cultivar significantly showed no effect on maize ash content. Location significantly had no effect ($p>0.05$) on maize ash content during the 2019/20 and 2020/21 planting seasons (Fig. 15). The interaction of cultivar×location was significant ($p\leq 0.05$) on maize ash content during the 2020/21 planting season.

Correlation between maize quality variables during the 2019/20 planting season: Protein showed a positive and medium correlation with crude fiber ($r = 0.411$) as indicated in Table 3. Protein also showed a negative and weak correlation with fat ($r = -0.172$), ash ($r = -0.112$) and starch ($r = -0.163$). Fat showed a negative and strong correlation with starch ($r = -0.677$). Fat also showed a positive and medium correlation with ash ($r = 0.518$). Crude fiber showed a positive and medium correlation with protein ($r = 0.411$) and ash ($r = 0.471$). Furthermore, crude fiber had a negative and weak correlation with starch ($r = -0.332$). Ash indicated a positive and medium correlation with fat ($r = 0.518$) and crude fiber ($r = 0.471$). Ash showed a negative and significant correlation with starch. Starch showed a negative correlation with fat ($r = -0.677$). Starch showed a negative and significant correlation with crude fiber and ash.

Correlation between maize quality variables during the 2020/21 planting season: Protein showed a positive and medium correlation with crude fiber ($r = 0.423$) as indicated in

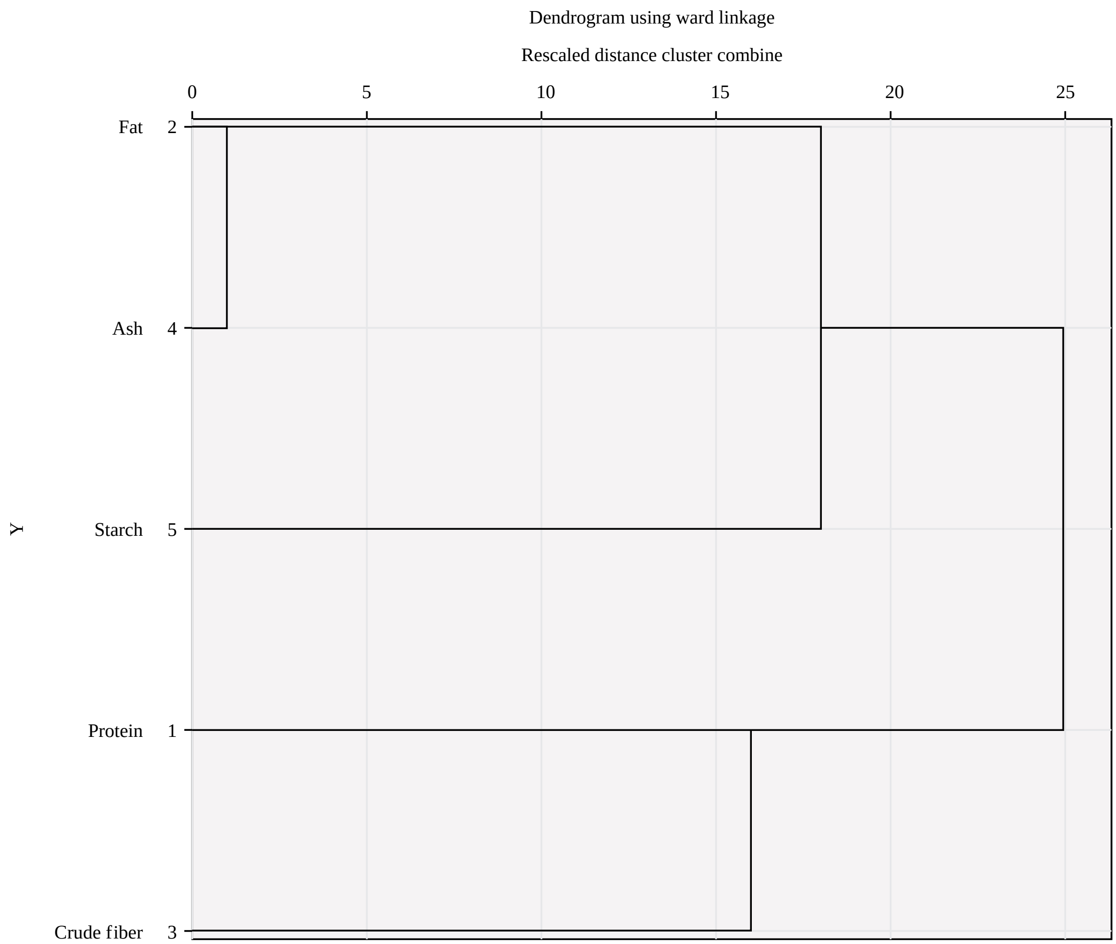

Fig. 16: Dendrogram showing the distance among measured maize grain quality parameters

Table 4. Protein also showed a positive and weak correlation with ash (r = 0.334). Furthermore, protein showed a negative and significant correlation with starch (r = -0.391). Fat showed a positive and medium correlation with ash (r = 0.519). Fat also showed a negative and medium correlation with starch (r = -0.549). Crude fiber indicated a positive and medium correlation with protein (r = 0.423). Crude fiber also showed a negative correlation with starch (r = -0.407). Ash showed a positive and medium correlation with fat (r = 0.519). Ash also showed a positive and weak correlation with protein (r = 0.334). Furthermore, ash showed a negative and significant correlation with starch (r = -0.512). Starch showed a negative correlation with fat (r = -0.549), crude fiber (r = -0.407) and ash (r = -0.512), respectively. Starch showed a negative correlation with protein (r = -0.391).

Cluster analysis: In this study based on the measured maize grain quality parameters, the distance was achieved as revealed in the dendrogram graph (Fig. 16). The measured maize grain quality parameters were presented in groups based on the results of the cluster analysis to conclude relationships between parameters (Table 5). Cluster 1 contained quality parameters (fat and ash) showing a similar effect among the two parameters. Cluster 2 shows a similar effect between grain protein and crude fiber while cluster 3 shows a similar effect between grain fat and starch. Cluster 4 indicates a similar effect between grain protein and fat.

DISCUSSION

The higher maize protein, fat and ash content observed when nitrogen fertilizer was applied during emergence and at five-leaf and ten-leaf stages might be attributed to the early application of nitrogen that would later be remobilized to reach the maize grains for the grain-filling process. This observation agreed with findings by Amanullah and Shah[29], who reported that there was an increase in maize grain protein with early application of nitrogen. This observation agreed with the findings by Bartzialis *et al.*[30], who reported an increase in protein in sorghum with the application of nitrogen fertilizer two weeks from the sowing of the sorghum. The higher seed protein content obtained at Taung location in this study correlates with findings by Sebetha *et al.*[31], who reported higher maize seed protein harvested from Taung.

The higher maize starch and crude fiber content observed when nitrogen fertilizer was applied during planting and five leaf stage might be attributed to the availability of nutrients for the plant to uptake during the early stages of maize development, which would eventually be translocated for the grain formation and grain filling processes and promote biosynthetic activities in the maize grain. This observation agreed with findings by Bartzialis *et al.*[30], who reported the highest crude fiber levels when nitrogen fertilizer was applied at the sowing of the sorghum. These results also agreed with similar findings by Luo *et al.*[32], who observed that the proper timing in applying nitrogen fertilizer promotes the accumulation of dry matter and increases the starch content.

The higher maize starch content observed under maize cultivar PAN 4A 111 might be attributed to variations in its genetic composition, its rapid adaptability due to favourable climatic factors and its short development period. This observation agreed with the findings by Zhang *et al.*[33], who reported the different starch content among bean varieties.

The higher maize protein, fat, crude fiber and ash content observed in maize cultivar PAN 413 might be attributed to the genetic characteristics of the cultivar and the prolonged period for growth and development, which would tend to increase grain filling. This result corroborated with findings by Ayub *et al.*[34], who observed a distinction in terms of the protein and ash content of maize cultivars. This observation also agreed with the findings by Hunsigi *et al.*[35], who reported variations in the crude fiber content of various sorghum cultivars.

The higher maize protein, crude fiber and ash content observed under maize planted at Taung might be attributed to favorable climatic factors (rainfall and temperature) and a better soil structure. This result corroborated with findings by Queiroz *et al.*[36], who observed a difference in sorghum crude fiber grown under varying temperatures and rainfall conditions. This observation agreed with findings by Uribelarrea *et al.*[37] and Haberle *et al.*[38], who reported that environmental conditions such as temperature influence the protein content of wheat. This observation also agreed with findings by Ihekoronye and Ngoddy[39], Jimoh and Abdullahi[40], who reported that the type of soil and the availability of nutrients in the soil influence the ash content of sorghum.

The higher maize starch and fat content observed in maize planted at Mafikeng might be attributed to preferable prevailing temperatures and rainfall and the sufficiency of nutrients. This result agreed with similar findings by de Geus *et al.*[41], who observed that environmental factors have an impact on fat content. This observation also agreed with the findings by Labuschagne *et al.*[42], who reported that wheat starch is affected by climatic and environmental conditions.

The study will provide farmers with relevant knowledge as to how to reduce the risk of losing nitrogen fertilizer in the soil before the plant can utilize the applied nitrogen to achieve high maize grain quality. Maize cultivars have different climatic conditions and are affected differently. Therefore, the study will educate farmers on which type of environment is suitable or desirable for different types of cultivars. Farmers will learn how to avoid the adverse impacts caused by the application of nitrogen fertilizer to the environment when not applied correctly.

The study recommends that, if grain quality is preferred by maize farmers, applications of nitrogen fertilizer should be during planting, emergence and five leaf stages. However, maize cultivar PAN 4A 111 is recommended for its high starch content. The study recommends climatic and environmental locations similar to the Taung site for higher maize protein content.

CONCLUSION

The timing of nitrogen fertilizer application during planting, five-leaf and ten-leaf stages affected maize grain quality positively. Maize grain responded positively to the application of nitrogen fertilizer during planting, emergence and five-leaf stages and resulting in a high-quality grain. The study concludes that the timing of nitrogen fertilizer application at the correct and early stages of maize growth increases the grain-filling process. The study recommends climatic and environmental locations similar to the Taung site for higher maize protein content.

SIGNIFICANCE STATEMENT

The purpose of the study was to evaluate the timing of nitrogen fertilizer application on the maize grain quality parameters under different environmental conditions. The results of this study indicated that, when nitrogen fertilizer is applied during emergence, five and ten leaf stages, it affects the maize quality parameters such as protein, fat, crude fiber and ash content. The results of this study also indicated that maize quality parameters vary across different locations.

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