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Maize Seed Quality in Response to Different Management Practices and Sites

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Abstract

Maize seed quality during storage can decline to a level that may make the seed unacceptable for planting purpose. A factorial experiment randomized in complete block design with three replications was conducted during 2011/12 and 2012/13 planting seasons. The experiment comprised of three cropping systems (cowpea-maize rotation, monocropping maize and intercropped maize), three sites (Potchefstroom, Taung and Rustenburg) and two rates of nitrogen fertilizers applied in kg ha^{-1} at each site (0 and 95 at Potchefstroom, 0 and 92 at Rustenburg, 0 and 113.5 at Taung). The experiment was conducted to investigate the effect of cropping system, site and nitrogen fertilization on maize seed quality. Maize seeds harvested from Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher oil content of 4.4% than maize seeds harvested from Taung. Maize plots applied with nitrogen fertilizer had significantly ($P < 0.05$) higher seeds protein content of 8.7% than maize plots without nitrogen fertilizer application. Maize seeds harvested from Potchefstroom had significantly ($P < 0.05$) higher starch content of 71.8% than maize seeds harvested from Rustenburg and Taung. Cowpea-maize rotation and intercropped maize had significantly ($P < 0.05$) higher seed phosphorus content of 0.50 and 0.52%, respectively than monocropped maize. In this study, site as factor played a vital role on quality of maize seeds. Maize seed quality was improved significantly by the interaction effect of site x season.

Keyword: oil, phosphorus, protein, site, starch

1. Introduction

High seed quality is necessary to establish crops, therefore cultivated seed should have vigour and related physiological characters (Farshadfar et al., 2012). Maximum seed vigour is attained at harvest maturity and not at physiological maturity (Wambagu et al., 2012). Fertilizer applications led to a significant increase in seed vigour and viability. Protein quality is a relevant factor for producers and consumers, especially when grain quality determines the final price of the commodity (Da Silva et al., 2005). Quality characteristics in maize such as protein contents in seed is improved with optimum N level (Amanullah et al., 2009). Low and high nitrogen dose have adverse effect on quality of maize (Stone et al., 1998). Application of various N levels significantly influences seed protein content (Hammad et al., 2011). Without application of nitrogen, seed quality will extremely be decreased.

Nitrogen application at silking increases kernel crude protein content, up to the application of 100 kg ha^{-1} nitrogen (Da Silva et al., 2005). This response showed that N applied during flowering is taken by the plant and accumulated in the grains. The advantage of increasing grain protein content with late N-side dressing is reducing kernel susceptibility to breakage at harvesting, a feature that allows greater aggregation of commercial value to the product (Tsai et al., 1992). The quality of maize was improved by intercropping due to more nitrogen availability for maize in intercropping (Eskandari & Ghanbari, 2009).

High oil maize contains higher energy content and more essential amino acids than conventional maize, which increases its value as animal feed (Lambert, 2001). The higher oil content of pollinator seed may influence seed germination and vigour. Seeds with high oil levels have often been associated with shorter longevity and greater deterioration than seeds with high starch content (Copeland & Mc Donald, 2001). The inability of oily seed to imbibe moisture and hold it tightly causes additional water to become excessive quickly and may contribute to more rapid deterioration of oily seed compared to starchy seed at comparable moisture levels (Thomison et al., 2002). The major chemical component of the maize kernel is starch, which provide up to 72 to 73 percent of the kernel weight (Boyer & Shannon, 1987). The composition of maize starch is genetically controlled. There is significant negative relationship between starch content and crude protein (Idikut et al., 2009). The crude protein decreases with increasing starch content of maize grain. Maize grown without fertilizer N promotes the greatest concentration of kernel starch, which has on average greater than kernels grown with the maximum N supply (Seebauer et al., 2010). Concentration of phosphorus in corn plants plays a critical role in intake of these nutrients by animal. Several studies have been done looking for the concentration of P in corn seed (Baker et al., 1970). The P concentration in corn hybrids depends on its genetics and environments where it is grown (Gautam et al., 2011). Nitrogen fertilizer application reduces phosphorus content of maize and increases crude protein content significantly (Khogali et al., 2011).

Maize seed quality during previous studies was not extensively compared among intercropping and rotation in relation to nitrogen fertilization. These cropping systems were studied separately during previous studies. The hypothesis of the study was that, intercropping, cowpea-maize rotation and nitrogen fertilization will have no significant effect on maize seed quality. The interaction effect of site, cropping system, nitrogen and season on maize seed quality was evaluated in this study. The objective of this study was to determine the effect of cropping system, site, nitrogen fertilization and season on maize seed quality.

2. Materials and Methods

2.1 Experimental Sites

The study was conducted at three dryland sites in South Africa, namely the department of Agriculture experimental station in Taung situated at 27°30′S and 24°30′E, Agriculture Research Council-Grain Crops Institute (ARC-GCI) experimental station in Potchefstroom situated at 27°26′S and 27°26′E and the Agricultural Research Council-Institute for Industrial Crops (ARC-IIC) experimental station in Rustenburg 25°43′S and 27°18′E. The ARC-GCI experimental station has clay percentage of 34 and receives annual mean rainfall of 622.2 mm, with daily temperature range of 9.1 to 25.2 °C during planting (Macvicar et al., 1977). The ARC-IIC experimental station has clay percentage of 49.5 and receives an annual mean rainfall of 661 mm. Taung experimental site is situated in grassland savannah with annual mean rainfall of 1061 mm that begins in October. Potchefstroom (ARC-GCI) has plinthic catena soil, eutrophic, red soil widespread (Pule-Meulenberg et al., 2010). The soil at Taung is described as Hutton, deep, fine sandy dominated red freely drained, eutrophic with parent material that originated from Aeolian deposits (Staff, 1999). The soil at Rustenburg (ARC-IIC) has dark, olive grey and clay soil, bristle consistency, medium granular structure (Botha et al., 1968). The climatic data at three different sites during the course of the study were different as indicated on Table 1.

Table 1. The mean temperature and rainfall data for Potchefstroom, Taung and Rustenburg for the duration of experimental period

Site	Season	Climate data	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Potch	2011/12	Rainfall (mm)	35.58	66.29	75.95	19.05	33.78	66.29	4.32	0
		Max T (^oC)	28.64	29.45	28.57	30.42	29.11	28.72	25.00	25.00
		Min T (^oC)	11.19	13.78	15.81	16.22	16.30	13.59	8.05	5.17
	2012/13	Rainfall (mm)	21.84	13.46	42.42	45.72	28.7	43.94	47.5	8.14
		Max T (^oC)	29.01	30.21	27.99	30.11	31.03	28.43	24.32	22.61
		Min T (^oC)	12.43	14.62	15.41	16.81	15.5	14.58	9.12	3.86
Taung	2011/12	Rainfall (mm)	3.05	36.07	71.37	7.87	40.89	12.45	5.08	0.51
		Max T (^oC)	31.05	33.28	32.8	36.12	32.87	32.96	28.02	27.65
		Min T (^oC)	9.25	10.6	14.79	16.19	17.01	13.75	8.24	4.48
	2012/13	Rainfall (mm)	0.25	8.89	14.99	40.89	32.00	14.2	9.2	8.4
		Max T (^oC)	32.5	34.98	32.86	36.29	31.5	31.8	27.3	26.8
		Min T (^oC)	10.74	14.27	15.71	17.83	17.7	15	9.4	6.2
Rust	2011/12	Rainfall (mm)	23.37	49.79	47.24	19.3	6.35	27.94	6.6	0.25
		Max T (^oC)	28.68	30.18	28.28	30.20	30.95	29.00	25.04	25.13
		Min T (^oC)	11.71	14.91	17.00	15.34	17.21	14.37	9.34	6.58
	2012/13	Rainfall (mm)	21.08	25.91	48.01	37.34	20.58	10.92	46.48	0
		Max T (^oC)	28.28	29.95	28.13	29.9	31.05	29.05	25.48	23.23
		Min T (^oC)	12.82	14.76	16.14	17.38	16.28	14.67	10.17	4.68

Potch = Potchefstroom, Rust = Rustenburg, Max T (^oC) = Maximum temperature in decrees Celsius, Min T (^oC) = Minimum temperature in decrees Celsius, mm = millimetres.

2.2 Experimental Design

The experiment was established in 2010/11 planting season and data considered for experiment was collected during 2011/12 and 2012/13 planting seasons. The experimental design was factorial experiment laid out in Random Complete Block Design (RCBD) with three replicates. The experiment consisted of three cropping systems (monocropping, rotational and intercropping), three locations Potchefstroom, Taung and Rustenburg and two levels of nitrogen fertilizer at each site, which were the amount of 0 and 95; 0 and 92; 0 and 113.5 kg N ha^{-1} applied on maize plots at Potchefstroom, Rustenburg and Taung respectively. Maize cultivar (PAN 6479) and cowpea (Bechuana white) were used as test crop.

2.3 Chemical and Data Analysis

The seeds of maize were collected during harvest maturity and were analysed using Near Infrared Reflectance Grain Analyser (NIR) at ARC-GCI food quality laboratory. The seeds were analysed for starch, protein and oil content. The seeds were sent to ARC-IIC for analysis of phosphorus content. The method used to analyse phosphorus content at ARC-IIC laboratory was micro-kjeldahl digestion process. Analysis of variance was performed using GenStat 14th edition (2012). Least significant difference (LSD) was used to separate means. A probability level of less than 0.05 was considered as significant statistically (Gomez & Gomez, 1984).

3. Results

3.1 Maize Seed Oil Content

Maize seed oil content was significantly affected ($P < 0.001$) by the effect of site (Table 2). Maize seeds harvested at Potchefstroom and Rustenburg had significantly ($P < 0.05$) higher oil content of 4.4% than maize seeds harvested from Taung. Maize seed oil content was significantly ($P < 0.001$) affected by the interaction of site x season and the interaction of site x nitrogen x season. Maize seed oil content was also significantly ($P < 0.001$) affected by the interaction of cropping system x site x nitrogen x season.

Table 2. The interaction effects of cropping system, nitrogen fertilizer, site and season on maize seed oil content in percentages

Cropping system	Site	N-fertilization		Zero-N	
		2011/12	2012/13	2011/12	2012/13
Intercropping	Potch	4.4	4.4	4.2	4.5
	Rust	4.3	4.5	4.4	4.2
	Taung	4.4	4.0	4.3	3.9
Monocropping	Potch	4.2	4.5	4.5	4.3
	Rust	4.4	4.6	4.3	4.5
	Taung	4.3	3.8	4.1	4.2
Rotation	Potch	4.2	4.6	4.4	4.3
	Rust	4.3	4.5	4.4	4.6
	Taung	4.4	3.7	4.3	4.1
SEM	0.09				
LSD (0.05)	0.24				

N-fert = Nitrogen fertilization, Zero-N = Zero nitrogen fertilizer, Potch = Potchefstroom, Rust = Rustenburg, SEM = standard error of means, LSD = least significant difference.

3.2 Maize Seed Protein Content

Maize seed protein content was significantly affected ($P < 0.001$) by the effect of site (Table 3). Maize seeds harvested from Taung had significantly ($P < 0.05$) higher protein content of 8.8% than maize seeds harvested from Potchefstroom and Rustenburg. Application of nitrogen fertilizer had significant effect ($P < 0.001$) on maize seed protein content. Maize plots applied with nitrogen fertilizer had significantly ($P < 0.05$) higher seeds protein content of 8.7% than maize plots without nitrogen fertilizer application. Maize seed protein was also significantly ($P < 0.001$) affected by seasonal effect. Maize seeds harvested during 2012/13 planting season had significantly ($P < 0.05$) higher seed protein content of 8.7% than maize seeds harvested during 2011/12 planting season. Maize seed protein content was significantly affected ($P < 0.001$) by the interaction of site x nitrogen ($P = 0.013$) and the interaction of site x season.

Table 3. The interaction effects of cropping system, nitrogen fertilizer, site and season on maize seed protein content in percentages

Cropping system	Site	N-fertilization		Zero-N	
		2011/12	2012/13	2011/12	2012/13
Intercropping	Potch	7.4	9.6	6.5	8.8
	Rust	8.5	8.6	8.0	9.6
	Taung	8.5	9.5	7.7	8.8
Monocropping	Potch	7.3	9.6	6.0	7.4
	Rust	8.5	7.2	7.8	6.9
	Taung	8.7	8.9	8.4	9.6
Rotation	Potch	8.3	10.5	5.9	8.2
	Rust	9.0	7.8	7.7	6.7
	Taung	9.1	9.1	7.7	9.9
SEM	0.59				
LSD (0.05)	1.67				

N-fert = Nitrogen fertilization, Zero-N = Zero nitrogen fertilizer, Potch = Potchefstroom, Rust = Rustenburg, SEM = standard error of means, LSD = least significant difference.

3.3 Maize Seed Starch Content

Maize seed starch content was significantly affected ($P < 0.001$) by site effect (Table 4). Maize seeds harvested from Potchefstroom had significantly ($P < 0.05$) higher starch content of 71.8% than maize seeds harvested from Rustenburg and Taung. Maize seed starch content was significantly affected ($P < 0.001$) seasonal effect. Maize seeds harvested during 2011/12 planting season had significantly ($P < 0.05$) higher starch content of 72.0% than maize seeds harvested during 2012/13 planting season. Maize seeds starch content was significantly affected ($P = 0.037$) by the interaction of nitrogen x season.

Table 4. The interaction effects of cropping system, nitrogen fertilizer, site and season on maize seed starch content in percentages

Cropping system	Site	N-fertilization		Zero-N	
		2011/12	2012/13	2011/12	2012/13
Intercropping	Potch	73.0	71.0	73.2	69.5
	Rust	71.4	68.5	71.4	68.6
	Taung	71.5	69.8	71.9	69.8
Monocropping	Potch	73.0	70.2	73.1	71.4
	Rust	70.9	68.7	71.7	70.0
	Taung	71.3	70.3	71.8	69.0
Rotation	Potch	72.1	71.2	73.3	70.3
	Rust	71.4	69.7	71.9	70.2
	Taung	71.0	70.7	71.9	68.6
SEM	0.59				
LSD (0.05)	0.14				

N-fert = Nitrogen fertilization, Zero-N = Zero nitrogen fertilizer, Potch = Potchefstroom, Rust = Rustenburg, SEM = standard error of means, LSD = least significant difference.

3.4 Maize Seed Phosphorus Content

Cropping system had significant effect ($P = 0.05$) on maize seed phosphorus content (Table 5). Cowpea-maize rotation and intercropped maize had significantly ($P < 0.05$) higher seed phosphorus content of 0.50 and 0.52% respectively than monocropped maize. Application of nitrogen fertilizer had significant effect ($P = 0.001$) on maize seed phosphorus content. Maize plots applied with nitrogen fertilizer had significantly ($P < 0.05$) higher seed phosphorus content of 0.52% than maize plots without nitrogen fertilizer application. Maize seeds phosphorus content was significantly affected ($P < 0.001$) by season effect. Maize seeds harvested during 2012/13 planting season had significantly ($P < 0.05$) higher phosphorus content of 0.58% than maize seeds harvested during 2011/12 planting season. Maize seeds phosphorus content was significantly affected ($P < 0.001$) by the interaction of site x season.

Table 5. The interaction effects of cropping system, nitrogen fertilizer, site and season on maize seed phosphorus content in percentages

Cropping system	Site	N-fertilization		Zero-N	
		2011/12	2012/13	2011/12	2012/13
Intercropping	Potch	0.42	0.68	0.32	0.66
	Rust	0.48	0.61	0.53	0.60
	Taung	0.35	0.66	0.39	0.52
Monocropping	Potch	0.33	0.65	0.28	0.55
	Rust	0.49	0.49j	0.48	0.41
	Taung	0.43	0.64	0.41	0.50
Rotation	Potch	0.40	0.79	0.32	0.58
	Rust	0.50	0.43	0.50	0.52
	Taung	0.40	0.61	0.45	0.51
SEM	0.05				
LSD (0.05)	0.14				

Zero-N = Zero nitrogen fertilizer, Potch = Potchefstroom, Rust = Rustenburg, SEM = standard error of means, LSD = least significant difference.

4. Discussion

4.1 Maize Seed Oil

The higher maize seed oil content at Potchefstroom and Rustenburg might have been attributed to the soil type. Shen et al. (2010) reported that maize seed oil content is determined by the oil concentration in the embryo, embryo size and oil in the endosperm. Maize seeds collected from those two locations had large grain size with large embryos. The differences in oil seeds across the locations corroborates the findings by De Geus et al. (2008) who reported that oil content was affected by location and genotype. Their findings revealed that oil content of seeds produced in a low input system was significantly higher than in conventional systems in both years of production. Maize seed oil content that was affected by the interaction effect of cropping system x site x nitrogen x season contributed towards significant of this study on maize grain quality improvement, since such interaction effect on maize seed was not reported previously. The study conducted by Riedell et al. (2009) indicated that year had no significant effect on kernel oil concentration and there were no significant N input x rotation interactions for kernel oil concentration in their study. The study conducted by Esmailian et al. (2011) also found interaction of irrigation x fertilizer treatments to have no significant influence on maize oil content.

4.2 Maize Seed Protein

The difference in maize seed protein across the sites contradicts the findings by De Geus et al. (2008) who reported that the protein content among genotype significantly differed for both years and in both farming system, but the protein content was not significantly different between locations. The higher seed protein content under nitrogen fertilizer treated plots corroborates the findings by Da Silva et al. (2005), who reported that nitrogen application at silking also increases kernel crude protein content up to the application of 100 kg N ha^{-1}. This response showed that N applied during flowering was taken by the plant and accumulated in grains. They also indicated that possibility of increasing grain protein content with late N site dressing is reducing kernel susceptibility to breakage at harvesting. The difference in maize seed protein across the season corroborate the findings by Szmigiel (1998) who emphasized that protein content in grain is influenced by changes in weather condition during the vegetation period of maize. It was showed that the highest protein content in maize grain is obtained in dry and warm years, while in years of abundant precipitation high yields of grain were obtained at the lower protein content. The higher maize seed protein content at Taung was not expected in this study, due to sandy soil of that location. This finding implies that, it is possible to obtain high maize seed quality from sandy site, if good climatic conditions and supplementary irrigation are available during vegetative and reproductive stage of maize plant. Maize seeds protein content that was affected by the interaction effect of site x nitrogen and site x season was regarded as critical finding of this study, since such interaction effect on maize seed protein were not reported previously. The study by De Geus et al. (2008) revealed that location and location x genotype interactions had no effect on protein content suggesting that selection for high protein can be done in either conventional or low input cropping system.

4.3 Maize Seed Starch

The differences in soil types across the locations contributed to differences in maize seed starch content in this study. This agrees with similar findings by Wilkes et al. (2010) who reported that the soil type had the biggest impact on both protein and starch content, with the grains from grey vertosol soil having higher total insoluble and soluble protein contents and lower starch content. Starch content differed across the locations since quality of grain depend on interplay between the genetic characteristics of the plant and external factors that influence plant growth such as climate, soil and management practices. In this study, the different starch content among sites contradicted the findings by Buresova et al. (2010) who indicated that starch content was significantly affected by cultivar and year. They indicated that starch content was not significantly influenced by growing variant or site. The starch content of maize grains in this study differed across the seasons and this corroborates the findings the findings by Buresova et al. (2010) who reported that starch content was significantly affected by weather during growing season. They indicated that warm weather during the growing season had a significant positive effect on starch content. This explains the reason of high starch at Potchefstroom due to high temperature during planting and vegetative growth of maize. In this study, the interaction of nitrogen x season was found to have significant effect on seed starch content while the findings by Riedel et al. (2009) reported that, no significant N input x rotation interaction for kernel starch.

4.4 Maize Seed Phosphorus

The higher maize seed phosphorus content under rotational and intercropping might have been attributed to improved soil structure by accompanying cowpea. The higher phosphorus content under intercropping system agrees with similar findings by Biareh et al. (2013) who revealed that intercropping culture had significant effect on phosphorus content. They indicated that the system with 100% corn + 15% of bean ratio treatment with mean of 0.55% had the most phosphorus content in grains. The high phosphorus content of maize seed under N-fertilizer treated plots may have been attributed to increased uptake of N by maize. Thiraporn et al. (2008) reported that weight of kernel phosphorus increased slightly with increasing rates of N fertilizer. The influence of nitrogen fertilizer on maize seed phosphorus content was also reported by Tarighaleslami et al. (2013), that different level of nitrogen fertilizer treatments had significant effect on phosphorus of seed and maximum phosphorus of seeds was gained by utilization of 180 kg ha^{-1} of nitrogen fertilizers. Maize seeds phosphorus content that was affected by interaction effect of site x season contributed towards significant of this study on quality improvement of maize. The findings by Tarighaleslami et al. (2013) indicated that phosphorus of seeds was significantly affected by the interaction of irrigation and application of nitrogen fertilizer treatment. Riedel et al. (2009) reported the significant N input x rotation interactions for maize kernel phosphorus.

5. Conclusions

In this study, site as factor played a vital role on quality of maize seeds. Maize seeds collected at site with high clay soil content (Potchefstroom and Rustenburg) had high oil and starch content as compared to site with high sand. It was found that, maize seeds collected at site with high sand had higher protein content. It is then assumed that, soil type might have not been the only factor affected maize seed quality. The difference in seed quality across the site might have been affected by other climatic factors such as rainfall and temperature. The inclusion of legume on cropping system as intercrop or rotated with maize increases maize phosphorus content. The application of nitrogen fertilizer increases maize seed protein and phosphorus content. Maize seed protein, starch and phosphorus content depend on the season. The interaction of site x season played a significant role on this study, since it affected maize seed oil, protein and phosphorus content.

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