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GROWTH, PHYSIOLOGICAL AND YIELD RESPONSE OF PROVITAMIN A BIOFORTIFIED MAIZE CULTIVARS TO DIFFERENT NATURAL ENVIRONMENTS

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ABSTRACT

Malnutrition remains a main problem in sub-Saharan Africa regardless of the applied interventions to combat food and nutrition insecurity. Biofortication of staple crops has been regarded as the latest intervention strategy to combat micronutrient diseases such as vitamin A deficiency in developing countries in southern Africa. The aim of the study was to determine the response of provitamin A biofortified maize cultivars under different environmental conditions. A randomized complete block design with five cultivars, two provitamin A varieties and three common maize varieties were planted in two on farm trails located under different agro-ecological zones (Bulwer and KwaDlangezwa) of KwaZulu-Natal in a two-season period (2015/16 and 2016/17). The five cultivars namely Border king (BK), provitamin A biofortified maize (PVABM), local landrace (LL), SC 506 and SC510 recorded a highly significant ($P<0.001$) plant growth (height and leaf number) in both experimental sites across two seasons (2015/16 and 2016/17). Chlorophyll content showed no significant differences for both trial sites in both 2015/16 and 2016/17 seasons. For the first season, no significant differences ($P< 0.05$) were observed for biomass among the maize varieties in both trial sites. However, it was observed that SC510 had higher biomass (2.33 t/ha), while BK recorded lowest biomass (0.66 t/ha) in Bulwer. In KwaDlangezwa, the biomass ranged from 0.713 t/ha (PVA) to 1.66 t/ha (SC510). For the second season (2016/17), Biomass in Bulwer ranged from 0.86 t/ha (LL) to 1.52 t/ha (SC510) and 0.94 t/ha (BK) to 1.44 (SC510) in KwaDlangezwa. The performance of the provitamin A biofortified varieties (SC510 and PVABM) showed that they can adapt and produce similarly to common varieties. It is noted that there is potential for these varieties to adapt under different environmental conditions of KwaZulu-Natal, South Africa. The provitamin A biofortified varieties can be produced for human consumption at common smallholder farming systems.

Key words: SC510, chlorophyll content, KwaDlangezwa, Bulwer, yield, vitamin A deficiency, planting, smallholder, biofortification

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INTRODUCTION

Maize (*Zea mays*) also known as corn, belongs to the family of grasses Poceace [1]. Maize is a cross pollinating plant with female and male (tassel) flowers located on the plant and is the main staple crop in sub–Saharan Africa (SSA). In South Africa it is the most consumed food item in both urban and rural communities [2]. Furthermore, it is an important carbohydrate, iron, vitamin B, minerals and protein source [3]. It can also be used for dual purposes, human consumption and as an animal feed. However, the challenge with maize consumption is its unbalanced nutrient composition especially the low vitamin A levels caused by lack of provitamin A carotenoids [4]. This could justify the existence of micronutrient deficiency in rural communities where maize is considered as a staple crop [5].

In smallholder systems where maize is a subsistence crop, there is high vitamin A deficiency (VAD) with the most vulnerable group being children under the age of five years [6]. Different strategies have been deployed as means of reducing VAD in rural communities; these strategies are fortification of foods, supplementation with vitamin A and biofortification of staple crops such as sweet potato and maize [7]. HarvestPlus program aims at developing biofortified varieties (maize, millet, rice, sweet potatoes and beans) [8]. This program targets improving micronutrients (iron, zinc and vitamin A) levels in staple crops for rural communities. Vitamin A deficiency is targeted by provitamin A biofortification maize [9].

Provitamin A biofortified maize (PVABM) has the potential to reduce hidden hunger and VAD in low-income households. The potential of PVABM is justified by maize being a staple crop in rural communities. Provitamin A biofortified maize has improved carotenoids with enhanced vitamin A unlike the normal white and yellow maize [10]. This variety has the potential to reduce vitamin A deficiency. Moreover, as a product of biofortification, PVABM is a drought and disease tolerant hybrid making it perfect for smallholder farmers with drought and diseases challenges in their maize production systems. Studies [2, 6, 7, 10] show that PVABM can be incorporated into smallholder farming systems and there is consumer willingness to include the products into the diets. However, there is scant information on the agronomic potential of PVABM and response of these under dryland conditions. Therefore, the aim of the study was to determine the response of provitamin A biofortified maize cultivars (commercial and non- commercial) under different environmental conditions.

MATERIALS AND METHODS

Site description

The study was carried out in two small-scale farms located in two different locations (Bulwer and KwaDlangezwa) of KwaZulu-Natal, South Africa. These two locations were representatives of distinct agro-ecologies (Table 1). Planting dates were in November for summer season of 2015/16 and 2016/17. The geographical characteristics of the two locations are in Table 1 below.

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Planting material

Five maize varieties were planted, two provitamin A biofortified (SC 510 and PVABM), one local landrace (LL), commercial variety (Border King [BK]) and common yellow maize [SC506]). Provitamin A biofortified maize (PVABM) seeds were donated by Seedco Zimbabwe. Light Orange provitamin A biofortified maize (SC 510) seeds were received from the plant breeding department in the University of KwaZulu-Natal, Pietermaritzburg while local landraces were collected from local farmers in Nkwezela area in Bulwer, KwaZulu-Natal, South Africa. Border king (BK) seeds were sourced from McDonalds (Pietermaritzburg, RSA) was and were selected due to their popularity amongst farmers.

Experimental design

Two on farm trails were established in Nkwezela Area (Bulwer) and KwaDlangezwa (UMhlathuze) under dry land conditions. Soil properties and climatic conditions of these areas were distinct (Table 1). The experimental design was randomized complete block design (RCBD) replicated four times in each ecological condition (on farm trial). The individual plot was $16m^2$ (4m x 4m) while the main plot was $576m^2$ per experimental site under rainfed conditions.

Agronomic practices

Prior to planting, soil samples were taken for fertility tests. Fertilizer applications were based on the soil fertility recommendation. Land preparation was initially done using tractor mounted moldboard plough and hand. Weeding was done manually using a hand hoe.

Data collection

Plant height was measured from the soil surface to the base of the tassel and the number of leaves was also counted. Chlorophyll content index was measured using the CCM 200 and yield component were measured at harvest. Data collection at harvest included total biomass, yield, cob length, cob mass per plant, kernel row, kernel per row, no of cobs per plant, 100 seed mass, and harvest index following modified recommendations by Mazvimbakupa *et al*. [1]. Cob length was measured using a ruler and the mean of five cobs was calculated. The 100 seed weight was calculated using 100 seeds per cob and the mean of five replicates was calculated. The harvest index (HI) was calculated using the formula:

$$HI = \text{seed yield}/\text{biological yield} \times 100$$

Statistical analyses

Data was captured in Microsoft excel and checked for outliers. Data were subjected to statistical analyses of variance (ANOVA) using GenStat® version 17 (VSN International, Hermel Hempstead, UK 2011). Fischer's unprotected test was used to separate means at the 5 % level of significance. This test was used for pairwise comparisons of different treatment group. Means that shared a common letter(s) were not significantly different from each other, while means not sharing a similar letter(s) were considered statistically different.

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RESULTS AND DISCUSSION

Plant height

Maize growth during the first season (2015/16) was highly and significantly different (P< 0.001) among varieties between Bulwer and KwaDlangezwa (Figure 1a) during the planting period. In both sites a growing trend with time was observed for plant height from 4 weeks after planting (WAP) to 16 weeks after planting (WAP). After 16 weeks the plant height ranged between 142.27 (LL) to 169.93 cm (SC510) in Bulwer, while in KwaDlangezwa, 96.47 (SC506) to 117 cm (SC510). Overall, plant height was higher in Bulwer than KwaDlangezwa with SC510 recording tallest height in both sites. In the second season (2016/17), plant height showed highly significant differences (P< 0.001) among varieties between Bulwer and KwaDlangezwa during the planting period. A growing trend with time was observed in both trial sites from 4 WAP to 16 WAP (Figure 1b). After 16 WAP, the height ranged from 145.87(LL) to 172.93 cm (SC510) in Bulwer while in KwaDlangezwa it ranged from 99.47 (SC506) - 124.33 cm (BK).

Leaf number

With respect to first season (2015/16), leaf number of the varieties increased with time in both study sites (Figure 2a). Highly significant differences (P< 0.001) in leaf number were observed between maize varieties across the two sites (Bulwer and KwaDlangezwa). On 16 WAP, leaf number ranged between 14 (SC506) and 16 (SC510) in Bulwer and 12 (BK) -14 (SC510) in KwaDlangezwa. Like plant height, the leaf number for SC510 was higher in both sites during the study. With respect to second season (2016/17), there were significant differences (P< 0.001) observed among the maize varieties in both trial sites (Figure 2b). A growing trend with time was observed for number of leaves during the study period. At 16 WAP, the leaf number ranged from 14 (SC506) to 16 (PVABM) in Bulwer while in KwaDlangezwa it ranged from 13 (BK) to 14 (SC506).

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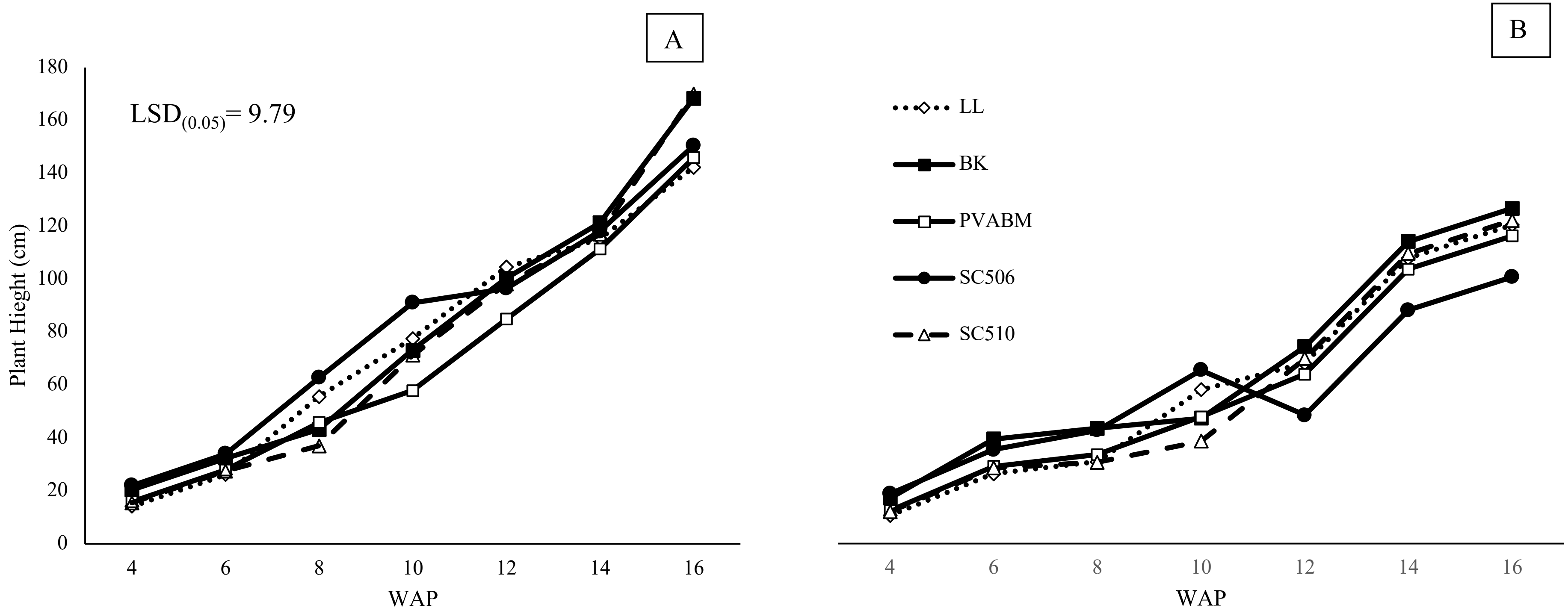

Figure 1a: **Plant height for maize varieties (LL, BK, PVABM, SC506 and SC510) in Bulwer (A) and KwaDlangezwa (B) during 2015/16 season**

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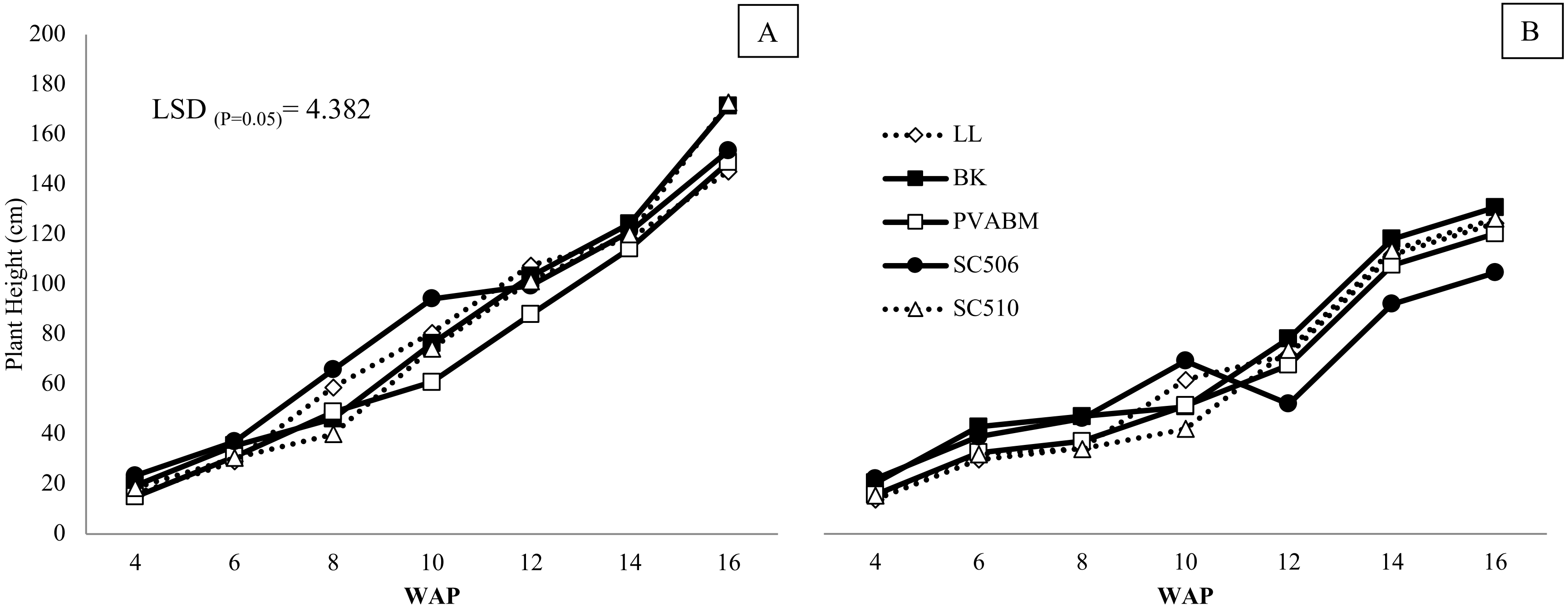

Figure 1b: **Plant height for maize varieties (LL, BK, PVABM, SC506 and SC510) in Bulwer (A) and KwaDlangezwa (B) in 2016/17 season**

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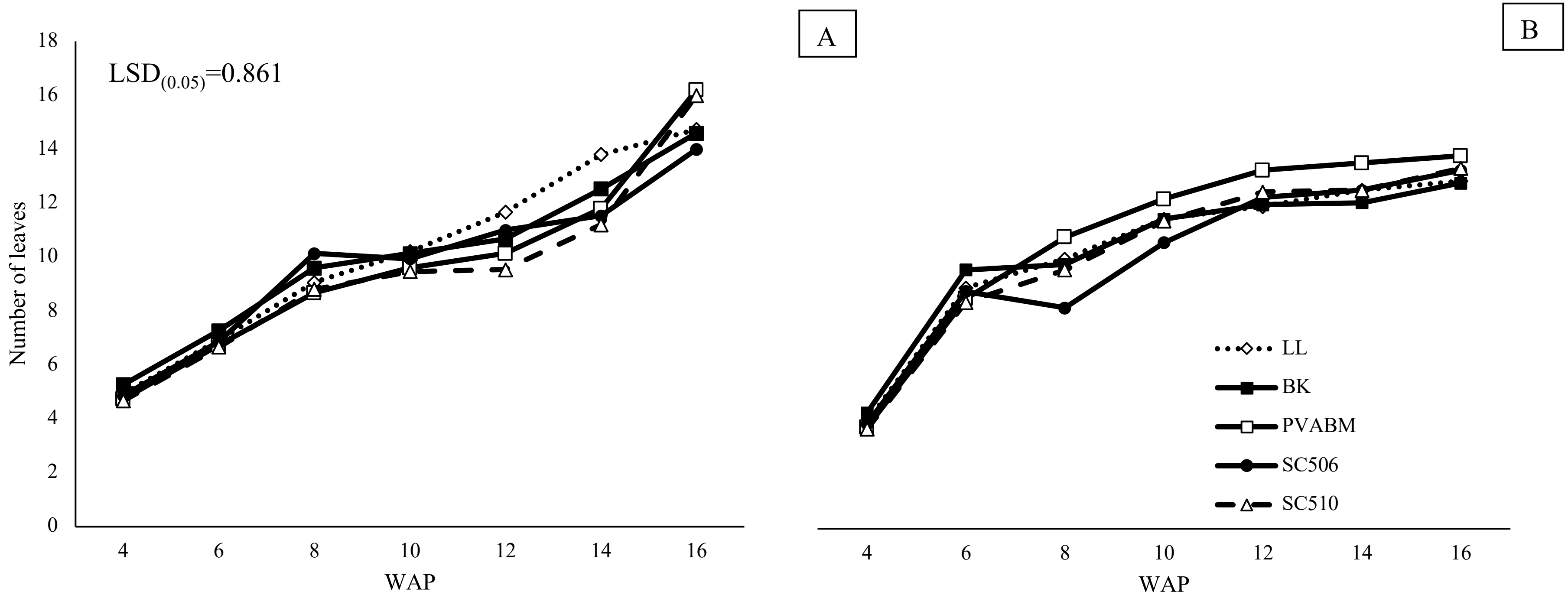

Figure 2a: **Number of leaves for maize varieties (LL, BK, PVABM, SC506 and SC510) in Bulwer (A) and KwaDlangezwa (B) during 2015/16 season**

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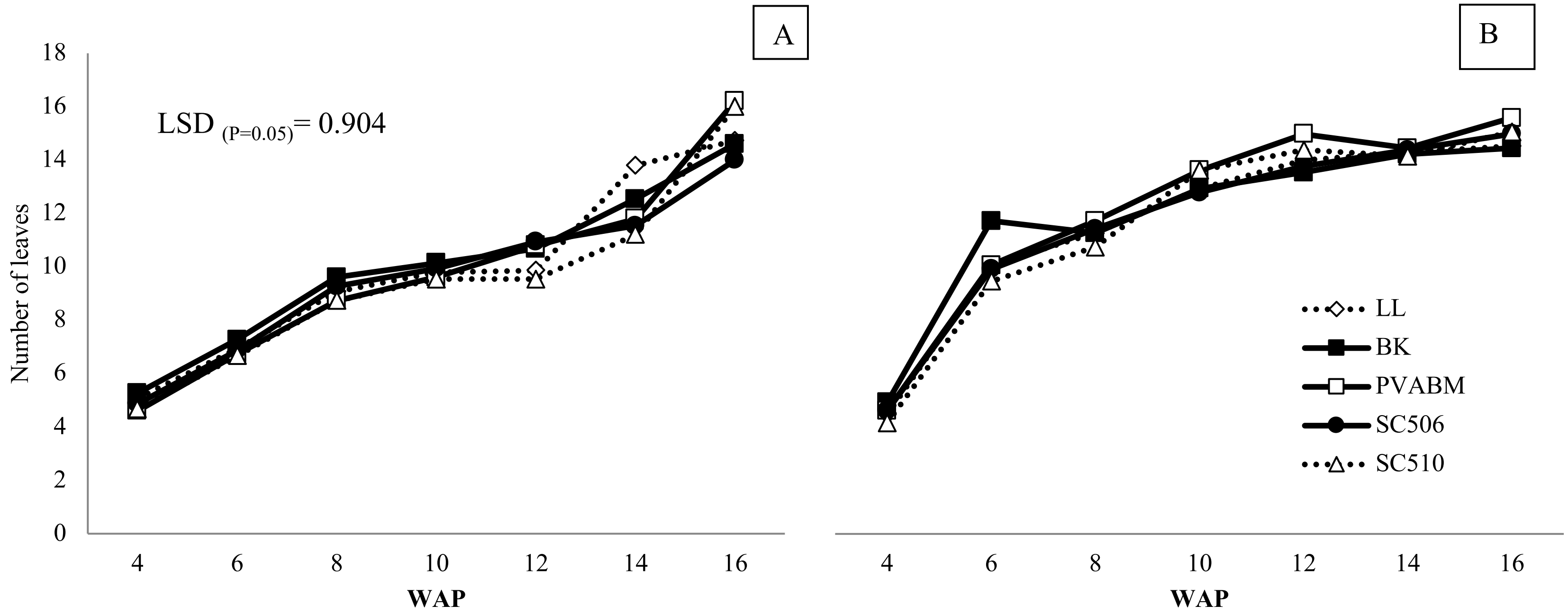

Figure 2b: **Number of leaves for maize varieties (LL, BK, PVABM, SC506 and SC510) in Bulwer (A) and KwaDlangezwa (B) in 2016/17 season**

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Chlorophyll content index

In the 2015/16 season, there were no significant differences (P> 0.05) observed for chlorophyll content on maize varieties across the two study sites. In Bulwer, the chlorophyll content for all varieties increased with time and a similar trend was observed in KwaDlangezwa during the study period (Figure 3a). The Chlorophyll content index for Bulwer ranged from 30.47 (LL) to 35.02 (SC506) compared to 29.12 (PVABM) to 31.62 (SC506) of KwaDlangezwa during the first season (Figure 3a).

During the second season (2016/17), maize varieties showed no significant differences (P> 0.05) in the chlorophyll content during the study period. However, there was a growing trend in chlorophyll content with time in both trial sites (Bulwer and KwaDlangezwa). At 15 WAP, the chlorophyll content ranged from 27.90 (SC510) to 46.5 (PVABM) in Bulwer and in KwaDlangezwa the range was 29.95 (BK) to 48.15 (SC506), (Figure 3b).

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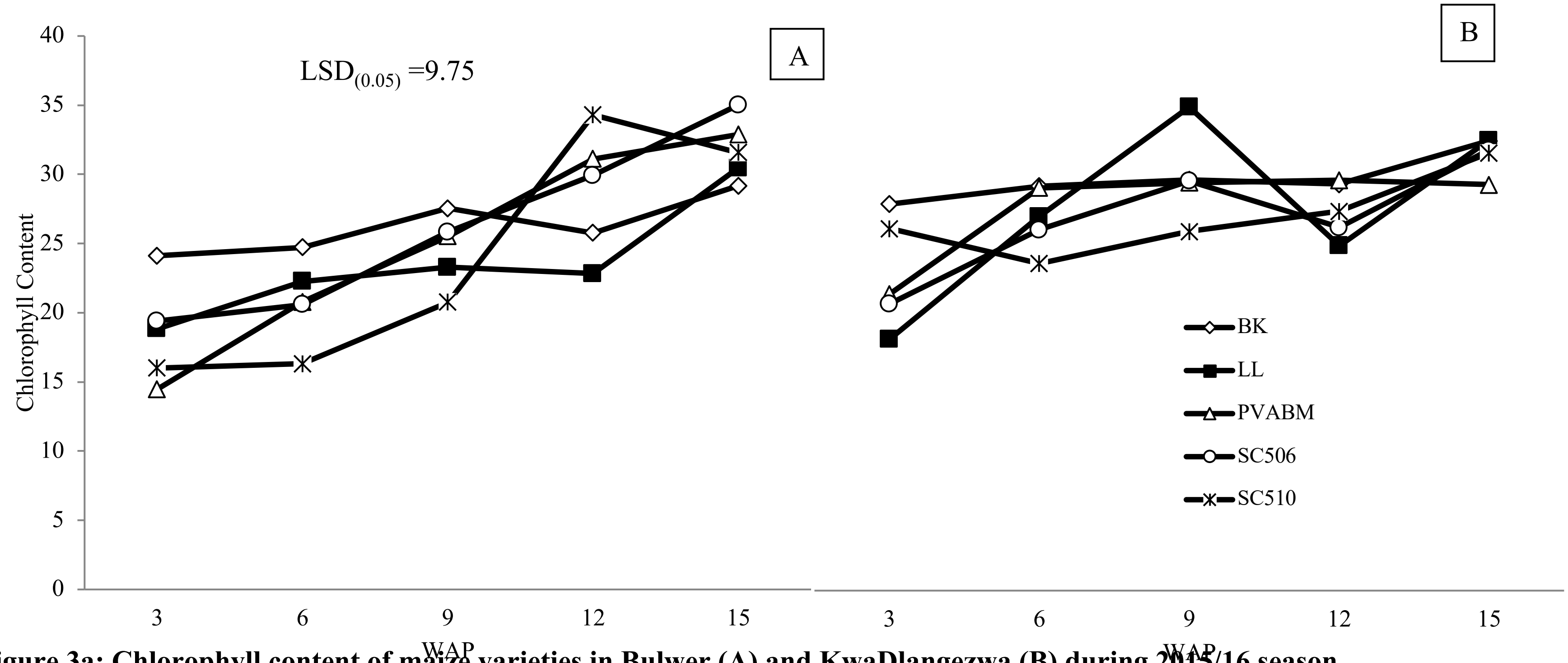

Figure 3a: Chlorophyll content of maize varieties in Bulwer (A) and KwaDlangezwa (B) during 2015/16 season

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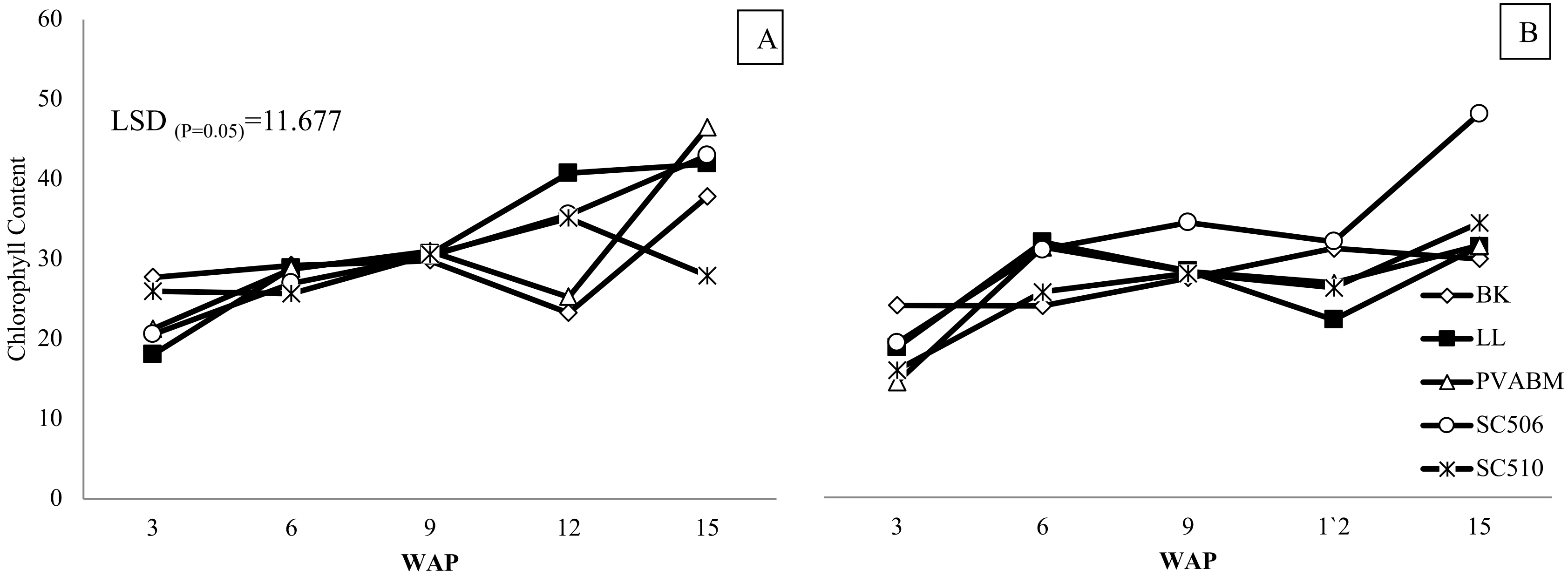

Figure 3b: Chlorophyll content for maize varieties (LL, BK, PVABM, SC506 and SC510) in Bulwer (A) and KwaDlangezwa (B) in 2016/17 season

Yield and yield components

There was no significant difference (P>0.05) in cob length for the maize varieties in both sites during the first season (2015/16), (Table 2). However, in Bulwer the LL had higher cob length (15.67 cm) than other varieties. In KwaDlangezwa, the PVABM variety had higher cob length (14.39 cm) while SC510 recorded lowest cob length (12.20 cm). No significant difference (P> 0.05) was observed for cob mass. In Bulwer, it was observed the cob mass per plant ranged from 270.7 g (SC510) to 309g (SC506), while in KwaDlangezwa the cob mass ranged from 243.8 g (SC510) to 283.3 g (SC506). The varieties in both sites showed no significant difference with respect to number of cobs per plant. Results showed the number of cobs per plant ranged from 1.2 (PVABM) to 2 (SC510) in Bulwer while in KwaDlangezwa they ranged from 1.2 (PVABM) to 1.93 (SC506).

With respect to kernel rows, there was no significant difference (P> 0.05) observed in both experimental sites. However, in Bulwer the SC506 had higher kernels row (12.5) while BK had lowest (8), and a similar observation was recorded in KwaDlangezwa. There were no significant differences (P> 0.05) observed for number of kernels per row for all the maize varieties in both sites (Table 2). Biomass showed no significant differences (P> 0.05) for location and variety combination (Table 2). However, with respect to varieties there were significant differences (P< 0.05). The SC510 variety had higher biomass (2.33 t/ha), while BK recorded lowest biomass (0.66g) in Bulwer. In KwaDlangezwa, the biomass ranged from 0.713 t/ha (PVABM) to 1.66 t/ha (SC510).

The 100 seed weight showed no significant differences (P>0.05). In Bulwer the mass ranged from 20.9 g (SC510) to 30.89 g (LL), while in KwaDlangezwa 24.82 g (PVABM) -30.89 g (LL). Yield obtained during the experiment showed no significant difference (P> 0.05) amongst varieties in both study sites. However, SC510 yielded higher in Bulwer (3.53 t/ha) compared to other varieties. A similar trend was observed in KwaDlangezwa where SC510 yielded (2.64 t/ha) and BK produced lower yield (1.47 t/ha). No significant difference (P> 0.05) observed for harvest index for all the maize varieties in both sites during the study.

During the second season (2016/17), yield components such as cob length recorded highly significant differences (P>0.001) among maize varieties across the two sites (Table 3). Cob length in Bulwer ranged from 13.81 (SC510) to15.67 (LL), while in KwaDlangezwa the range was 12.2 (SC510) to 14.93 (PVABM). No significant difference (P>0.05) was observed for cob mass per plant. Kernel rows were significantly different (P<0.05) among maize varieties during the second season (2016/17) for both sites. The rows ranged from 9.6 (BK) to 12.27 (SC510) in Bulwer and 9.47 (BK) to11.93 (PVABM) in KwaDlangezwa (Table 3).

The 100 seed mass recorded no significant differences (P>0.05), BK variety recorded highest seed mass (36.1 g) while SC510 the lowest (25.5 g) in Bulwer. However, contrary findings were recorded in KwaDlangezwa where SC510 recorded highest (32.4 g) compared to LL (24.6 g). Both yield and biomass during the second season (2016/17) showed no significant differences (P> 0.05) among the maize varieties across the two study sites (Table 3). Biomass in Bulwer ranged from 0.86 t/ha (LL) to 1.52

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t/ha (SC510) and 0.94 t/ha (BK) to 1.44 (SC510) in KwaDlangezwa (Table 3). Yield in Bulwer ranged from 1.73 t/ha (LL) to 2.69 t/ha (SC510) in Bulwer while in KwaDlangezwa it ranged from 1.60 t/ha (BK) to 2.51 t/ha (SC510). Harvest index recorded no significant differences (P> 0.05) for the maize varieties in both trail sites (Table 3).

Discussion

The biofortification of maize is considered as key to the reduction of VAD in Africa [11]. The success of adoption of provitamin A biofortified maize lies on the interaction of the varieties with different natural environments and different soil types [12]. This study investigated the agronomic potential of provitamin A biofortified maize varieties compared with common maize varieties in different environments.

The current results showed that maize varieties growth parameters increased with time during the study. The varieties' growth differed between the two sites and there were significant differences observed amongst varieties in both study sites. As previously reported by Mazvimbakupa *et al*. [1] and Mazvimbakupa *et al*. [13] most maize hybrids have the potential to adapt to KwaZulu-Natal due to the soil types and climatic conditions of the areas. The bio-resource groups were different but there was successful productivity of all the maize varieties planted for the study. During the two-season (2015/16 and 2016/17), all maize varieties showed the ability to grow under different soil and climatic conditions, especially the provitamin A biofortified maize varieties which showed the potential to adapt to local climatic conditions like local common maize hybrids. This shows the growing conditions were optimum for all maize varieties. As suggested by Kalaitzandonakes *et al.* [14], temperature and rainfall are key factors that promote maize growth.

Chlorophyll content was inconsistent for the maize varieties across the two seasons. In KwaDlangezwa it was low compared to Bulwer. These findings support Motsa *et al.* [15] suggestion that the low chlorophyll content in the similar bioresource group (Moist coast forest, thorn and palm veld) was due to energy limits and substrates. The author further suggests that the soil profile has an impact on the chlorophyll content and growth parameters. As observed during the two-season study, growth parameters and chlorophyll in KwaDlangezwa was reduced compared to Bulwer, this could suggest the impact of soil type, climatic condition and plant adaptation.

The planting in two different natural environments had the influence on plant growth (height and leaf number) during the study period. The maize varieties, common, local and provitamin A biofortified recorded a growth with time in both sites. The differences observed during the two-study site on plant growth parameters (plant height and leaf number) could be promoted by different soil types because Bulwer has Clovelly soils that have Orthic A horizons (ordinary topsoil with no special features) while KwaDlangezwa has Dundee soils which have different layers that have different characteristics in water and nutrient retention. The provitamin A biofortified maize varieties produced inconsistent results on growth across two seasons, however it was noted that they have the potential to grow like other varieties under different natural environmental conditions. Motsa *et al*. [16] suggested that the inability of sandy soils in the moist coast forest, thorn & palm veld to hold water and nutrients compared to moist transitional tall grassveld regions has a negative impact on plant growth.

Successful germination and emergence lead to good growth and yield [17]. Current study findings showed that growth had less impact on yield. Significant differences observed on plant growth were not transferred to plant yield during the two-season study. However, positive observations were noted on some yield components among the maize varieties on both seasons. Repetitive breeding and studies can have major impact on significances of the result in PVABM growth and yield response to different agricultural practices [18].

Yield components such as cob mass, 100 seed mass, biomass, yield and harvest index showed no significant differences per growing seasons. However, changes were observed in maize varieties response to different growing seasons and environments. These changes may be caused by soil fertility and climatic changes per growing season and study site. Karimmojeni *et al*. [19] suggested that change in fertility, rainfall, temperature, soil moisture may lead to change in yield. Other yield components, cob length, number of cobs per plant, kernel row and kernel per row produced distinct statistically?? findings. In 2015/16 these components were not significant while in 2016/17 they recorded different significant levels among them. Similar findings were observed by Manjeru *et al.* [20].

Yield recorded no significant difference in the two seasons. However, it was noted from the current findings that provitamin A biofortified maize (SC510) has the potential to produce better yield compared to PVABM. The current findings were similar to those of HarvestPlus [8] which demonstrated no significant differences in yield between provitamin A varieties and normal maize varieties in Zambia. The current findings are not in agreement with the recommendation by HarvestPlus [21] that provitamin A varieties can produce superior yields due to their ability to adapt in drought conditions and resist pests. However, there is scanty information to compare the performance of provitamin A biofortified maize varieties in a natural environment. Previous studies have shown that South African environmental conditions are better suited for newly introduced maize varieties [22]. Obeng- Bio *et al*. [23] also suggested the improvement in breeding systems for PVABM to obtain significant differences. These authors reported that provitamin A biofortified maize has the potential to perform under drought and low fertile soils. Obeng- Bio *et al*. [23] further suggested that certain genes need to be bred for improved yields in PVABM in order to supplement the quality standards of these varieties given that they have better carotenoids and have potential to adapt to drought conditions.

A study with Genetic Modified Bt maize showed significant higher yields in Bt than common hybrids in commercial and smallholder farming systems [24]. Similar findings were observed with Quality Protein Maize (QPM) hybrids [25]. Contrary to current findings, Mabhaudhi and Modi [13] observed that maize hybrids had superior yields to local landraces. Maize hybrids are expected to perform better under different environmental conditions because of their breeding abilities [26] and provitamin A maize varieties as drought resistant crop were expected to yield better. However,

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factors like climate, management and plant dates can impact on the performance of maize varieties [27]. Halilu *et al*. [28] also suggested that there is room for improvement of provitamin A biofortified maize in maintaining consistent carotenoids and grain yields.

CONCLUSION

As new varieties, the provitamin A biofortified maize varieties are known to be drought resistant and high yielding. The current findings showed that the provitamin A biofortified maize varieties (PVABM and SC510) can adapt to different environmental conditions and soils like common and local maize landraces.

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Table 1: Experimental site description for Bulwer and KwaDlangezwa

	Bulwer	KwaDlangezwa
Geographical location	S29.85721 E029.79619	S28.5208 E031.4944
Altitude	964- 1555	< 450
Bioresource Group	Moist Transitional Tall Grassveld	Moist coast forest, thorn & palm veld
Rainfall	848	1230
Frost occurrence	Severe	None
Average temp.	15.9	21.6
Soil type	Clovelly Yellow brown, Orthic A	Dundee
Soil texture	Loam	Sandy

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Table 2: Yield components of different maize varieties under different ecological conditions (Bulwer and KwaDlangezwa) during 2015/16 season

Area	Treatment	Cob length (cm)	Cob mass per plant (g)	Kernel row	Kernel per row	No. of cobs per plant	100 Seed Mass (g)	Biomass (t/ha)	Yield (t/ha)	Harvest Index
Bulwer	**LL**	15.67a	293.1de	10.53bc	28.33c	1.333a	30.89ab	0.92ab	1.56a	0.5915a
	BK	14.46abcd	296de	8a	28.73c	1.4a	25.72ab	0.66a	2.07a	0.4121a
	PVABM	15.16ab	309e	12.4d	27.2c	1.2a	25.4ab	1.10ab	2.38ab	0.4932a
	SC506	14.08bcd	312.1e	12.47d	29.07c	1.6abc	25.92ab	1.41abc	2.4ab	0.6193a
	SC510	13.81bcd	270.7bc	11.6cd	28.07c	2c	20.91a	2.327c	3.53b	0.8095a
		14.64	**296.2**	**11**	**28.28**	**1.507**	**25.8**	**1.29**	**2.39**	**0.585**
KwaDlangezwa	**LL**	14.13abcd	266.7bc	9.07ab	27.27c	1.4a	30.89ab	0.84ab	1.58a	0.5943a
	BK	13.07de	259.7ab	8.4a	20.33a	1.6abc	26.42ab	0.94ab	1.47a	0.6630a
	PVABM	14.93abc	263.8bc	11.27cd	22.87ab	1.2a	24.82ab	0.713a	1.92a	0.5888a
	SC506	13.38cde	283.3cd	11.73cd	24.67bc	1.933bc	31.64b	1.3ab	2.44ab	0.5933a
	SC510	12.2e	243.8a	11.27cd	26.6bc	1.467ab	29.13ab	1.66bc	2.64ab	0.7263a
		13.54	**263.5**	**10.35**	**24.35**	**1.52**	**27.7**	**1.091**	**2.01**	**0.633**
LSD$_{(P=0.05)}$ Treatment*Sites		1.59	10.86	1.48	3.8	0.44	10.24	0.85	1.23	0.5788

Means that shared a common letter(s) were not significantly different from each other, while means not sharing a similar letter(s) were considered statistically different

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Table 3: Yield components of different maize varieties under different ecological conditions (Bulwer and KwaDlangezwa) during 2016/17

Area	Treatment	Cob length (cm)	Cob mass per plant (g)	Kernel row	Kernel per row	No. of cobs per plant	100 Seed Mass (g)	Biomass (t/ha)	Yield (t/ha)	Harvest Index
Bulwer	**LL**	16.8e	309.5f	11bcd	29.27d	1.87bcd	33.9ab	0.86a	1.73abc	0.63a
	BK	15.92de	285.3cdef	9.6ab	29.8d	1.6abc	36.1b	0.90a	2.64c	0.34a
	PVABM	16.16de	287.3def	12.4de	28.47d	1.4a	26.8ab	0.94a	2.21abc	0.43a
	SC506	15.04bcd	301.8ef	12.53e	29.4d	1.6abc	30.3ab	1.48a	2.25abc	0.69a
	SC510	16.65e	245.5ab	12.27de	28.13d	2.27d	25.5ab	1.52a	2.69c	0.72a
		16.11	**285.9**	**11.56**	**29.01**	**1.74**	**30.5**	**1.14**	**2.3**	**0.561**
KwaDlangezwa	**LL**	15.73cde	270.8bcd	10abc	26.6cd	1.46ab	24.6a	1.05a	1.6ab	0.66a
	BK	13.55b	258.1abc	9.47ab	20.27a	1.47ab	30.1ab	0.94a	1.47a	0.66a
	PVABM	15.03bcd	250.1ab	11.93de	23ab	1.27a	25.4ab	1.11a	2.58c	0.42a
	SC506	14.25bc	278.6cde	11.6de	23.87bc	2cd	31ab	1.40a	2.38abc	0.64a
	SC510	11.53a	241.7a	11.13cde	26.87cd	1.46ab	32.4ab	1.44a	2.51bc	0.59a
		14.02	**259.8**	**10.83**	**24.12**	**1.53**	**28.7**	**1.19**	**2.108**	**0.594**
$LSD_{(P=0.05)}$ Treatment*Sites		1.56	28.29	1.53	3.41	0.42	10.84	0.76	0.97	0.46

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