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On-farm agronomic performance and farmer preference of quality protein maize grown under conservation agriculture in Southern Africa: a case for Zimbabwe

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Abstract

Maize is the most important staple food crop in southern Africa with human consumption averaging 91 kg/capita/year. Most smallholder farmers and weaning children depend on maize for much of the daily food requirements and it is the largest contributor of dietary proteins. Despite the development of quality protein maize (QPM) with high tryptophan and lysine content, stunting and kwashiorkor remain high in southern Africa partly due to low adoption of QPM varieties. The objective of this study was to compare the agronomic performance and farmer preferences of new generation of QPM with non-QPM varieties under conservation agriculture on-farm conditions. Eight QPM and four non-QPM varieties were tested on on-farm trials in Zimbabwe during the 2014/15 and 2015/16 cropping seasons at five different locations. Significant differences were detected among the genotypes for the measured traits in the two seasons. Similarly, genotype plus genotype × environment interactions were significant for both seasons for grain yield. Three QPM varieties, SC527, SC535 and SC643, recorded the highest and stable yield. Four QPM varieties, SC643, SC535, SC527 and MQ623, and a non-QPM variety, PAN413, were ranked high among farmers for overall ear characteristics as their most preferred varieties. The high-yielding and stable QPM varieties are likely to be adopted by farmers in southern Africa.

Introduction

In sub-Saharan Africa (SSA), maize (*Zea mays* L.) contributes over 55% of the daily calorie intake, with an average consumption of 85–140 kg/year/person (Bhatnagar *et al.*, 2003). Despite this high consumption, protein energy deficiency has remained high, resulting in retarded growth and productivity as well as high infant mortality rates among pregnant and lactating women, and children below the age of five (De Groote *et al.*, 2014). The maize varieties grown by farmers have an endosperm that is deficient in the two essential amino acids called lysine and tryptophan (Krivanek *et al.*, 2007; Machida *et al.*, 2014). However, quality protein maize (QPM) was developed through conventional breeding from a mutant maize with an *opaque-2* gene which elevates the levels of lysine and tryptophan (Vasal, 2000). These two essential amino acids allow the body to synthesize proteins that reduce the incidence of pellagra through its conversion to niacin in the body. Therefore, QPM varieties are considered to have a superior nutritive value compared to non-QPM varieties, both as food for humans and feed for monogastric livestock (Vivek *et al.*, 2008; Mpofu *et al.*, 2012).

Adoption of QPM varieties in SSA varies from country to country (De Groote *et al.*, 2010). This suggests that despite the importance and availability of QPM varieties, most farmers are not aware of QPM products and their benefits (Machida *et al.*, 2014). Understanding the factors that influence farmers' choice of varieties to grow is a key factor that guides the development, promotion and adoption of varieties that are widely grown in southern Africa region. Several studies have shown that farmers mainly select varieties based on high grain yield and other visible and desirable plant morphological traits (Bello *et al.*, 2014; Machida *et al.*, 2014) and some of these choices become traditional (Prasanna *et al.*, 2001). However, in order to determine yield and agronomic performance of new varieties, they have to be evaluated under a multi-location model, by assessing genotype main effects (G) plus genotype by environment (GE) interaction (Yan *et al.*, 2000, 2007). Multi-location trials assist in determining the yield performance and stability of individual varieties through biplot comparisons (G + GE biplot analyses) as described by Yan and Kang (2002). A high-yielding and stable variety is identifiable if it has a high average yield coupled with a low degree of changeability in yielding ability when grown in varied environments (Arshad *et al.*, 2003). Identification of stable and high-yielding varieties is vital since it determines successful adoption of such particular new varieties in different environments (Mebratu *et al.*, 2019). A similar research involving new experimental QPM varieties was conducted by Mebratu *et al.* (2019) and assisted in the identification of potentially high-yielding and stable QPM varieties in southern Africa.

According to Dugje *et al.* (2014), farmers' participatory data collection helps researchers to select and recommend new varieties based on farmers' preference. Using this approach, QPM hybrids with relatively high-yielding advantage to non-QPM varieties have been developed by CIMMYT (Secretariat, 2001). Farmers' participatory variety selection (PVS) is an efficient way of effecting rapid awareness and adoption of newly improved varieties by farmers (Etwire *et al.*, 2013). This is achieved through farmers' variety preference and acceptability assessed using variety ear characteristics and sensory evaluations (De Groote *et al.*, 2010). In the past, more attention has been paid to the agronomic performance of new varieties, while palatability attributes of consumers have been ignored (Kiria *et al.*, 2010). Anecdotal evidence suggests that the palatability of maize is greatly influenced by its oil and amino acid composition among other factors, hence the need to ascertain farmers' perceptions regarding QPM palatability as well as the yield and agronomic performance of new varieties (De Groote *et al.*, 2010; Ouma *et al.*, 2012) for them to adopt it based on their own preferences.

Moreover, with marginal rainfall which has been received of late, farmers are employing conservation agriculture (CA) as a mitigatory strategy against drought. CA is a resource-saving technology aimed at conserving soil and soil moisture through the use of three main principles of minimum soil disturbance, permanent ground cover and diverse crop rotations (Derpsch *et al.*, 2010). Thierfelder and Wall (2010) and Masvaya *et al.* (2017) reported CA as a promising climate change adaptation relative to conventional tillage as it is less sensitive to the effects of drought. Unlike conventional tillage, CA has higher infiltration rates hence high effective rainfall (Derpsch *et al.*, 2010). In contrast to conventional tillage, CA has the advantages of reversing organic matter loss, improving soil–microbial interactions as well as maintaining soil porosity and prolong plant-available water, hence resultant high grain yield (Twomlow *et al.*, 2008; Derpsch *et al.*, 2010). According to Rockström *et al.* (2009) and Ngoma *et al.* (2015), yield increases ranging from 20 to 120% have been recorded on CA over conventional tillage systems around the world. The objective of this study was to compare multi-location agronomic performance of new generation of QPM with non-QPM varieties under the basin planting method of CA and to ascertain farmers' perceptions of QPM palatability.

Materials and methods

Study site and germplasm

The experiment was carried out on-farm in Gokwe South District, Midlands province in agro-ecological region III of Zimbabwe during the 2014/15 and 2015/16 summer growing seasons. The description of the trial sites is presented in Table 1. Twelve locally procured maize varieties were used for this study (Table 2).

Agronomic evaluation

Experimental design and crop management

Twelve maize varieties were planted under dry-land conditions at five different sites (Table 1) in Gokwe South District of Zimbabwe for two cropping seasons (2014/15 and 2015/16). Planting basins (dug holes in which crops are planted) of 15 cm length × 15 cm

Table 1. Description of trial sites used in the evaluation of the maize varieties

Location	Altitude (m)	Latitude	Longitude	Rainfall 2014/15	Rainfall 2015/16	Long-term average temperature for each location (°C)	Soil type	pH	%N	P (mg/kg)	K^+ (mg/kg)	Na^+ (mg/kg)	Ca^{2+} (mg/kg)	Mg^{2+} (mg/kg)	%OC
Chisina 2	929	−18.2544	29.2611	427.2	594.3	36	Sandy-loam	5.32	0.000145	15	31.47	23.97	1468.5	127	1.153
Njelele 2	1226	−18.3217	29.1091	246	291.5	31	Heavy red clay	5.39	0.000733	4.5	27.03	22.31	10 754	1917.5	1.388
Nemangwe 3	144	−17.9314	28.7047	339	435.8	36	Sandy loam	6.97	5.88×10^{-5}	19.25	31.56	30.42	2618	119.5	1.473
Nemangwe 5	743	−17.7945	28.5543	455	105	36	Sandy- loam	6.11	0.000188	7.5	33.06	18.04	1493.5	139.5	0.811
Ngomeni	1112.2	−18.3928	28.5604	269	380.5	31	Sandy- loam	3.32	5.29×10^{-5}	2.25	15.69	22.12	1888	316.5	1.11

pH, concentration of hydrogen ions; %N, percentage nitrogen; P, phosphorus; K^+, potassium ion; Na^+, sodium ion; Ca^{2+}, calcium ion; Mg^{2+}, magnesium ion; %OC, percentage organic carbon.

Table 2. Maize varieties used in the study

Entry code	Entry name	Source	Protein quality status	Attributes
1	MQ623	Mukushi Seeds Pvt Ltd	QPM	Medium maturity, drought-tolerant hybrid
2	MH1416	Mukushi Seeds Pvt Ltd	QPM	Medium maturity, yellow kernel, drought-tolerant hybrid
3	MH1429	Mukushi Seeds Pvt Ltd	QPM	Medium maturity hybrid
4	MH1410	Mukushi Seeds Pvt Ltd	QPM	Medium maturity hybrid
5	OPV5195	Mukushi Seeds Pvt Ltd	QPM	Early maturity open pollinated variety
6	SC643	Seed Co. Pvt Ltd	QPM	Medium maturity hybrid
7	SC527	Seed Co. Pvt Ltd	QPM	Medium maturity hybrid
8	SC535	Seed Co. Pvt Ltd	QPM	Early maturity hybrid
9	PHB3253	Du Pont Pioneer-Pannar Zimbabwe Pvt Ltd	Non-QPM	Medium maturity hybrid
10	SC513	Seed Co. Pvt Ltd	Non-QPM	Medium maturity hybrid
11	PAN413	Du Pont Pioneer-Pannar Zimbabwe Pvt Ltd	Non-QPM	Medium maturity, drought-tolerant hybrid
12	SC403	Seed Co. Pvt Ltd	Non-QPM	Early maturity, drought-tolerant hybrid

QPM, quality protein maize.

width × 15 cm depth were established at each site (Twomlow *et al*., 2008). The 12 maize varieties were planted in a 4 × 3 α-lattice design with four incomplete blocks and three varieties per incomplete block replicated three times across the five sites for the two seasons. A spacing of 90 cm inter-row and 60 cm in-row was used, as recommended for CA in farming region III where the study sites were located (Twomlow *et al*., 2008; Harford *et al*., 2009). Three maize seeds were planted at each planting station using the triangle planting pattern recommended for CA (Harford *et al*., 2009) and later thinned to two plants per station 2 weeks after crop emergence (WACE). Compound D (7% N, 14% P_2O_5, 7% K_2O) basal fertilizer was applied at the rate of 11.2 kg N/ha, 9.8 kg P/ha and 9.3 kg K/ha, followed by split application of ammonium nitrate (34.5% N) at the rate of 27.6 kg N/ha at four and six WACE to mimic farmer practice (Harford *et al*., 2009; Chitagu *et al*., 2014). Weeds were controlled using glyphosate (N-(phosphonomethyl) glycine); atrazine (6-chloro-N-ethyl-N9-(1-methylethyl)-1,3,5-triazine-2,4-diamine); stella® star (3,6-Dichloro-2-methoxybenzoic acid + [3-(4,5-Dihydro-3-isoxazolyl)-2-methyl-4-(methylsulfonyl)phenyl] (5-hydroxy-1-methyl-1H-pyrazol-4-yl) methanone); and alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)acetamide). The glyphosate, atrazine and alachlor were tank mixed and sprayed before emergence of the maize, while the stellar star was applied post emergence mainly to control *Cynodon dactylon*. Harvesting was done manually on a plot of 15.12 m^2 net size at all sites. The trial at Nemangwe 5 failed in the 2015/16 farming season due to the effects of the El Nino-induced drought. This site was not included in the single site analysis for the 2015/16 farming season and was excluded from the combined analysis across sites and years.

Data collection

Rainfall data were recorded at all the sites (Table 1). Observations on the agronomic traits were recorded based on the descriptions by Magorokosho *et al*. (2009). Grain weight per plot was adjusted to 12.5% moisture content and used to calculate grain yield per hectare.

Data analyses

The quantitative data collected were analysed using the unbalanced analyses of variance (ANOVA) option of GenStat statistical package version 14 (GenStat, 2011). For across years the model was;

$$Y_{ijklm} = \mu + b_{ijkm} + r_{jkm} + g_l + s_k + y_m + (gs)_{lk} + (gy)_{lm} + (sy)_{km} + (gsy)_{klm} + e_{ijklm} \quad (1)$$

where Y_{ijklm} is the response of the lth genotype evaluated in the ith incomplete block nested within the jth replication also nested within the kth site by the mth year, μ is the grand mean, b_{ijkm} is the effect of the ith incomplete block nested within the jth replication also nested within the kth site by the mth year, r_{jkm} is the effect of the jth replication nested within the kth site by the mth year, g_l is the effect of the lth genotype, s_k is the effect of the kth site, y_m is the effect of the mth year, $(gs)_{lk}$ is the interaction effect between the lth genotype by the kth site, $(gy)_{lm}$ is the interaction effect of the lth genotype by the mth year, $(sy)_{km}$ is the interaction effect of the kth site by the mth year, $(gsy)_{klm}$ is the interaction effect of the lth genotype by kth site by the mth year, and e_{ijklm} is the pooled error term, and $i = 1, 2, 3 \ldots 12$, $j = 1, 2, 3, 4$ and 5, $k = l = 1, 2$ and 3, and $m = 1$ and 2. Means were generated using the restricted maximum likelihood estimation option of GenStat version 14. The genotype plus genotype × environment interaction (GGE) analysis was done on the adjusted means from the across site × variety analysis of variance using GenStat version 14 software (GenStat, 2011). The GGE biplot model was described by Yan *et al*. (2000) and Yan and Kang (2002) as:

$$Y_{ij} - \mu - \beta_j = + \sum_{l=1}^{k} \lambda_l \, \xi_{ij} \, \eta_{jl} + \varepsilon_{ij} \quad (2)$$

where Y_{ij} is the mean yield of the ith genotype in the jth environment; μ is the grand mean; β_j is the main effect of the environment j; λ_l is the singular value of the lth principal component and $k = 2$ in this case; ξ_{il} is the eigenvector of the genotype i for PC l; η_{jl} is the eigenvector of environment j for PC l; and ε_{ij} is the residual associated with genotype i in the environment j. Based on this model the biplot is environment-centred using GenStat software version 14 (GenStat, 2011). Visualization of the mean yield and stability of genotypes using a genotype comparison biplot was achieved by representing an average environment by an arrow. A line that passed through the biplot origin to the average environment was drawn followed by a perpendicular line that passed through the biplot origin.

Farmer participatory variety selection

Experimental design and procedure

In addition to the data on agronomic traits, variety preference by farmers was assessed at harvesting. The total numbers of farmers for 2014/2015 cropping season were: 141, 54, 27, 30 and 45 at Chisina 2, Njelele 2, Nemangwe 3, Nemangwe 5 and Ngomeni respectively. However, for 2015/2016 cropping season, the total numbers of farmers were as follows: 39, 18, 21 and 30 at Chisina 2, Njelele 2, Nemangwe 3 and Ngomeni, respectively, were provided with scoring sheets, which they used for scoring overall variety ear characteristics (such as number of kernel rows per ear, number of kernels per row and cob and kernel size) based on a 1–5 hedonic scale where 1 = liked very much, and 5 = disliked very much. Ear texture score was recorded using a scale of 1–5 where 1 = flint and 5 = dent.

After the harvesting of 12 maize varieties during the 2014/15 cropping season, the varieties were separately ground into maize flour. Sensory evaluations, specifically organoleptic tests, were done to assess the taste of sadza (thick porridge), a common local maize product made from maize flour in Zimbabwe. A panel of 30, 41, 37, 28 and 36 farmers at Chisina 2, Njelele 2, Nemangwe 3, Nemangwe 5 and Ngomeni respectively was selected as judges to perform the tests on the samples. The central location test (CLT) method was used as the suitable method for the palatability evaluations. The CLT involves a gathering of potential consumers of a product in one central point, at a central homestead of a village in this study (Kiria *et al*., 2010). The samples were evaluated using a 1–5 hedonic scale similar to the one described by Ahenkora *et al*. (1999) where 1 = delicious and 5 = distasteful.

Triangulation tests were also carried out using the top two selected varieties (one QPM and one non-QPM) and MQ623 variety which is currently the major QPM variety on the market (Kiria *et al*., 2010). A panel of ten farmers was randomly selected and each given a plate with three portions of sadza labelled with codes (two portions of sadza from the same mealie-meal and one made from the other variety); they were asked to perform sensory evaluations in which they were tasked to identify the odd one out. The process was repeated three times with a panel of ten farmers each time.

Data analyses

Ordinal data from farmers' ear rankings were analysed using the non-parametric, Friedman's test using GenStat statistical package version 14 (GenStat, 2011). The lower the mean rankings, the best that variety was ranked by farmers.

Sensory scores were analysed using non-parametric Friedman's test using GenStat statistical package version 14 (GenStat, 2011). For triangulation tests, the number of people who were able to distinguish between the two varieties was recorded, and the data subjected to χ^2 test of independence using GenStat software version 14 (GenStat, 2011).

Results

Agronomic performance

Highly significant differences ($P < 0.001$) in terms of grain yield and other traits were recorded among the 12 varieties across all the five sites over the 2014/15 and 2015/16 cropping seasons (Tables 3 and 4) as well as across the two cropping seasons (Table 5). The QPM varieties SC527, SC535 and SC643 were the top three yielding varieties during the first season (Table 6). The QPM variety SC527 recorded the highest grain yield across all the sites with a mean yield of 4.2 t/ha (Table 6). This variety yielded a ton more than the highest yielding local non-QPM variety, PAN413, which recorded 3.2 t/ha even though it recorded more days to 50% anthesis than SC527 (Table 6). In general, all non-QPM varieties had moderate yield (3.0–3.2 t/ha), but comparable to that of the widely-grown QPM variety, MQ623 (Table 6). Three of the QPM varieties (SC527, SC535 and SC643) were high-yielding and stable across the five sites relative to non-QPM local checks (Fig. 1). One non-QPM local check (PAN413) and one QPM variety (SC643), which were in the same maturity category with regard to days to 50% anthesis, recorded the highest yield at 2.8 t/ha (Table 7). However, in all cases, the open pollinated variety (OPV5195) had the lowest yield compared to the hybrids described in Tables 6–8. The GGE biplot revealed some QPM hybrids (SC643 and MQ623) which were comparable in stability to widely grown non-QPM hybrids such as SC403 and PAN413 (Fig. 2). Similarly, across seasons, analysis revealed that the non-QPM variety PAN413 was the highest yielder, but comparable to QPM varieties such as SC643, SC527 and SC535 which recorded relatively earlier days to 50% anthesis in comparison to PAN413 (Table 8). The non-QPM variety PHB3253 recorded significantly ($P < 0.001$) less yield than the QPM varieties (SC535 and MQ623) in the same maturity category (Tables 5 and 8). Across seasons, GGE biplot showed that QPM hybrids (SC643 and SC535) and non-QPM (PAN413) were more stable than the rest of the varieties (Fig. 3).

There were also significant variations ($P < 0.001$) among the 12 varieties in terms of ear texture in both seasons. Interestingly, in terms of ear texture some QPM hybrids (MQ623, SC527, SC553 and SC643) and some non-QPM local checks (PAN413, PHB3253 and SC513) were recorded to be dent. However, there were also some QPM hybrids that were flint as well as one non-QPM local check, SC403 (Tables 6 and 7). QPM varieties SC527 and SC643 recorded significantly ($P < 0.05$) greater hundred kernel weights, which were comparable to that of the non-QPM variety (SC403) during the first farming season. During the second season, one non-QPM variety, PHB3253, had the greatest kernel weight, which was comparable to that of SC527, a QPM variety (Table 7). Overall, the QPM varieties SC527 and SC643 recorded the greatest hundred kernel weights across the two cropping seasons (Table 8).

Combined ANOVA also revealed significant variations ($P < 0.001$) in terms of ear placement (ear height) during the 2014/15 farming season. QPM varieties such as MQ623 and SC535 had similar ear heights as the non-QPM local checks including SC403 (Table 6). Similar results were recorded for both seasons

Table 3. ANOVA table showing error mean squares recorded during the 2014/2015 cropping season for maize yield and agronomic traits in Zimbabwe

Source	DF	GY	100 KW	PH	EH	DTA	DTS	DPM	NKR	NKRE	ET	PV
Site	4	6.70***	377.50***	11893.50***	65304.93***	594.06***	504.63***	1854.80***	124.42***	5.38***	0.63ns	3.77***
Entry	11	2.97***	192.13***	465.65***	66.79***	72.71***	55.20***	47.77***	44.02***	11.69***	11.11***	1.11***
Entry × site	44	0.28ns	11.03*	72.94**	37.80***	4.91***	6.60***	19.26ns[a]	6.07ns	0.79ns	0.35ns	0.56***
Site.Rep	10	0.43ns	5.37ns	211.12***	33.40ns	7.75**	8.71***	58.99**	8.09ns	0.64ns	0.76ns	0.40ns
Site.Rep.Block	45	0.25ns	11.77*	104.47**	23.07ns	4.13*	5.33***	12.32ns	5.49ns	0.63ns	0.44ns	0.46*
Residual	65	0.22	6.64	48.26	17.40	2.46	2.22	18.15	5.11	0.52	0.39	0.27
Total	179	0.63	31.19	378.62	1494.88	22.79	20.32	64.53	11.71	1.63	1.40	0.57

DF, degrees of freedom; GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

[a] Trait recorded in two of the four sites.

*, ** and ***Significant at the 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

Table 4. ANOVA table showing error mean squares recorded during the 2015/2016 cropping season for maize yield and agronomic traits in Zimbabwe

Source	DF	GY	100 KW	PH	EH[a]	DTA	DTS	DPM	NKR	NKRE	ET	PV[b]
Site	3	28.07***	22.74	10360.1***	812.05***	473.58***	608.10***	1665.91***	508.45***	7.19***	1.28ns[c]	8.47***
Entry	11	1.65***	94.14***	328.9ns	133.38ns	37.22***	42.13***	178.60***	38.22***	9.74***	4.33***	1.28*
Entry × site	33	0.33ns	9.98ns	193.1ns	59.07ns	5.96**	9.87ns	34.77ns	12.74*	0.50ns	0.87ns	0.71ns
Site.Rep	8	0.74*	3.27	418.1*	60.06	7.10*	33.15***	35.89	12.17	0.74*	1.61*	2.73***
Site.Rep.Block	36	0.75***	15.26*	261.3ns	144.72*	10.48***	13.67**	57.86**	30.30***	1.24***	0.98*	1.07**
Residual	51	0.27	8.88	197.4	63.60	2.89	6.38	25.20	6.74	0.34	0.59	0.52
Total	142	1.13	17.33	448.2	104.62	18.26	25.89	82.85	27.45	1.50	1.11	1.05

DF, degrees of freedom; GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

[a] Trait recorded in two of the four sites.

[b] Degrees of freedom for residual for plant vigour, plant height, days to 50% tasselling and 50% silking were 52 while it was 26 for ear height.

*, ** and *** significant at the 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

Table 5. ANOVA table showing error mean squares recorded across 2014/2015 and 2015/2016 cropping seasons for maize yield and agronomic traits in Zimbabwe

Source	DF[a]	GY	100 KW	PH	EH[b]	DTA	DTS	DPM	NKR	NKRE	ET	PV
Site	3	13.16***	262.98***	6257.30***	3833.90***	723.07***	943.13***	2155.38***	95.26***	4.51***	0.32ns	1.56*
Year	1	64.58***	5.10ns	160248.80***	1208.68***	0.01ns	249.39***	3627.47***	830.75***	21.27***	0.93ns	0.45ns
Site × year	3	23.33***	139.39***	17826.40***	–	327.89***	103.79***	984.87***	566.63***	8.93***	1.74*	11.45***
Replication	16	0.62**	4.15ns	336.00**	57.42ns	7.59***	21.45***	54.03**	9.66ns	0.73ns	1.15**	1.61***
Block	72	0.65***	19.03***	210.60**	113.47***	11.00***	12.71***	41.57**	20.19***	1.26***	1.33***	0.87***
Genotype	11	3.26***	225.86***	520.90***	141.60**	91.34***	85.32***	188.30***	40.41***	17.69***	11.09***	1.45***
Genotype × site	33	0.30ns	9.60ns	107.30ns	65.94ns	6.77***	9.17**	32.20ns	8.93ns	0.63ns	0.65ns	0.63*
Genotype × year	11	0.84***	28.59***	241.00*	71.01ns	8.50***	3.45ns	35.80ns	28.08***	1.84***	2.19***	0.84*
Genotype × site × year	33	0.32ns	12.79*	158.40ns	–	4.67*	8.80**	25.85ns	10.03*	0.81*	0.56ns	0.81**
Residual	103	0.23	8.12	126.20	42.84	2.67	4.35	23.65	6.00	0.46	0.49	0.39
Total	286	1.12	24.56	987.10	143.52	20.28	23.24	82.94	22.45	1.66	1.25	0.84

DF, degrees of freedom; GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

[a] Degrees of freedom of residual for DTA, DTS, PH and PV were 104 while degrees of freedom for EH were 10, 45 and 65 for replications, blocks and residual respectively.

[b] EH was recorded in two out of four sites during 2015/2016 cropping season.

*, ** and *** significant at the 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

in terms of number of kernel rows per ear. The QPM varieties SC535 in the first season and SC535 and SC643 in the second season recorded the highest number of kernels rows per ear relative to all non-QPM local checks. The high-yielding QPM varieties also had moderate kernel numbers per row, which were similar to those recorded for some non-QPM local checks such as PHB3253 (Tables 6–8).

During the 2014/15 farming season, an independent two-sample *t* test revealed that there were no significant differences ($P > 0.05$) between QPM and non-QPM varieties for grain yield and all the secondary traits (Table 9). However, results for the 2015/16 farming season indicated significant differences ($P < 0.05$) between QPM and non-QPM varieties only in terms of number of kernel rows per ear, ear height and hundred kernel weight (Table 10).

Yield was observed to be positively correlated with hundred kernel weight ($P < 0.05$; $r = 0.67$), ear texture ($P < 0.001$; $r = 0.71$) and plant vigour ($P < 0.05$; $r = 0.66$). Correlations for the 2015/16 farming season revealed that days to physiological maturity were positively correlated to days to 50% silking ($P < 0.05$; $r = 0.68$).

Farmer participatory variety selection

Famers' overall variety ear characteristics ranking

The non-parametric Friedman's test showed that there were significant differences ($P < 0.001$) among the famers' overall variety ear characteristics mean rankings across all the five sites for the 2014/15 cropping season (Table 11). For the 2015/16 cropping season, Friedman's test revealed significant differences ($P < 0.05$) among the varieties in terms of overall variety ear characteristic rating across all the five sites as well (Table 12).

Palatability tests (sensory evaluation)

There were significant differences ($P < 0.001$) in terms of palatability mean ranks between QPM and non-QPM varieties across the sites (Table 13) but post hoc analysis showed that there were no differences among varieties. The χ^2 contingency table for triangulation results revealed that there were no significant differences ($P > 0.05$) among the varieties in terms of taste at Chisina 2 ($\chi^2 = 4.8$), Njelele 2 ($\chi^2 = 0$), Nemangwe 3 ($\chi^2 = 3.7$) and Nemangwe 5 ($\chi^2 = 1.9$) (Table 14).

Discussion

Significant differences observed among the 12 varieties during both 2014/15 and 2015/16 as well as across the two cropping seasons highlight the genetic variations for the different traits of the varieties (Akande and Lamidi, 2006). Moreover, across sites, variations might be due to different soil properties (Table 1). Sandy-loam soils are normally acidic and characterized by low organic matter content, hence the need for CA to improve percentage carbon of such soils (Haynes and Mokolobate, 2001). Sandy soils are mainly deficient in nitrogen (N), phosphorus (P) and potassium (K) due to heavy leaching and are also associated with higher salt concentrations and little exchangeable calcium (Zingore *et al*., 2008). Under acidic conditions phosphorus is immobile and coupled with low P concentrations as well (Table 1). Thus low yield obtained in some sites such as Ngomeni can be explained by low N and P (Table 1 and Fig. 3). Hence the stability of some of these varieties is due to tolerance to acidic conditions coupled with high nutrient use

Table 6. Means of grain yield and secondary traits of QPM and non-QPM varieties across five sites arranged according to grain yield evaluated in 2014/2015 summer cropping season in Zimbabwe

Entry code	Entry name	GY (t/ha)	100 KW (g)	PH (cm)	EH (cm)	DTA	DTS	DPM	NKR	NKRE	ET	PV
7	SC527	4.2	30.2	185.0	80.3	59.9	66.1	124.6	34.3	13.8	3.3	3.7
8	SC535	3.8	24.0	175.2	74.3	59.8	64.2	122.0	34.2	15.3	3.5	3.7
6	SC643	3.6	29.6	176.8	70.7	63.9	67.8	125.7	32.0	12.8	3.4	2.7
11	PAN413	3.2	22.8	163.6	74.1	62.0	67.0	125.3	35.7	13.2	4.1	3.9
10	SC513	3.1	27.2	182.9	80.5	59.8	64.9	123.6	32.1	14.0	3.6	3.4
9	PHB3253	3.1	24.7	184.0	82.2	61.8	66.3	125.9	33.9	14.3	3.1	3.0
12	SC403	3.0	29.7	183.1	74.0	56.9	63.5	122.2	36.4	12.8	2.1	3.7
4	MH1410	3.0	22.3	172.5	76.4	62.2	65.8	125.2	39.3	11.6	1.1	3.2
1	MQ623	2.8	20.5	178.8	76.9	63.0	68.1	127.8	35.9	12.9	2.8	3.3
2	MH1416	2.8	18.7	178.7	85.7	65.8	70.1	124.9	35.1	14.9	0.9	3.1
3	MH1429	2.6	20.0	173.3	74.7	64.7	69.6	127.5	34.0	13.2	1.5	3.0
5	OPV5195	2.5	22.1	175.2	73.7	60.0	63.7	120.7	34.7	13.4	3.2	3.5
Mean		3.2	24.3	177.4	77.6	61.6	66.4	124.6	34.8	13.5	2.7	3.3
$LSD_{(0.05)}$		0.22	1.19	1.64	1.93	0.73	0.69	1.97	1.04	0.33	0.29	0.24
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)		14.59	10.60	3.92	5.38	2.55	2.24	3.42	6.50	5.36	23.00	15.85

GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

Table 7. Means of grain yield and secondary traits of QPM and non-QPM varieties across four sites arranged according to grain yield evaluated in 2015/2016 summer cropping season in Zimbabwe

Entry code	Entry name	GY (t/ha)	100 KW (g)	PH (cm)	EH[a]	DTA	DTS	DPM	NKR	NKRE	ET	PV
11	PAN413	2.8	24.2	122.8	67.6	62.9	69.7	126.7	36.1	12.5	4.2	4.2
6	SC643	2.8	25.8	132.3	71.4	63.0	70.2	122.7	31.5	13.9	2.4	3.3
1	MQ623	2.4	22.3	125.8	58.9	62.3	70.2	124.7	31.6	11.7	3.3	3.5
8	SC535	2.3	25.8	127.9	59.9	62.6	68.8	115.6	30.0	14.2	2.8	3.4
12	SC403	2.3	26.9	138.7	59.6	60.1	65.5	112.8	30.2	12.1	2.4	2.9
10	SC513	2.2	28.1	132.2	65.9	60.7	68.0	118.4	30.1	13.3	2.9	2.8
9	PHB3253	2.1	29.4	120.3	64.7	63.3	69.2	117.2	31.2	13.1	2.6	3.1
7	SC527	2.1	28.6	125.5	50.3	61.4	68.1	123.3	27.9	14.1	3.5	3.3
2	MH1416	2.0	20.0	134.0	63.9	66.1	72.3	121.5	32.5	13.7	1.8	3.0
4	MH1410	1.7	22.8	125.3	69.3	61.4	68.3	113.0	31.3	10.9	1.3	3.2
5	OPV5195	1.5	21.4	117.7	55.3	60.9	67.4	112.9	27.6	12.3	1.7	2.9
3	MH1429	1.4	21.8	124.7	54.2	66.7	73.4	124.9	33.2	12.3	1.9	2.9
Mean		2.1	24.8	127.3	61.7	62.6	69.3	119.5	31.1	12.9	2.6	3.2
$LSD_{(0.05)}$		0.24	1.34	6.49	3.68	0.79	1.17	2.32	1.20	0.27	0.35	0.33
P value		<0.001	<0.001	0.038	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.014
CV (%)		24.73	12.01	11.04	12.93	2.71	4.20	3.64	8.35	4.54	29.50	22.50

GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

[a] EH was recorded in two out of the four sites.

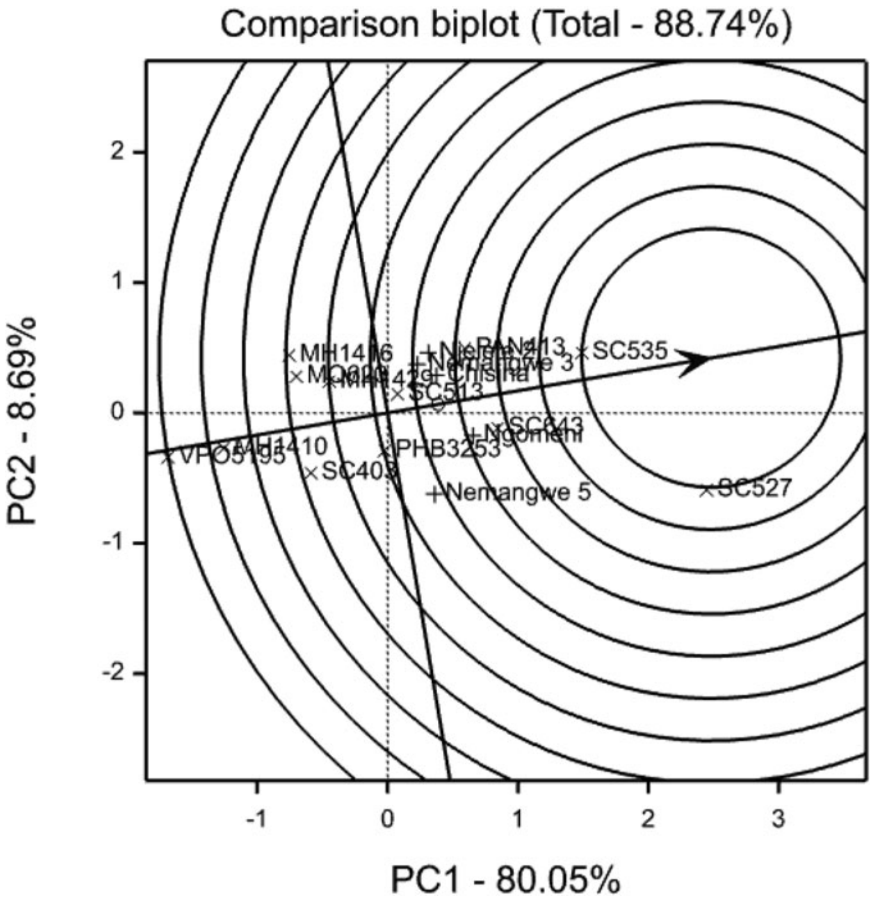

Fig. 1. The comparison biplot showing the best yielding and stable maize varieties evaluated across five sites during the 2014/2015 cropping season in Zimbabwe. The biplot was produced based on genotype SVP, no transformation, no scaling and the data were environment centred.

efficiency particularly for NPK. However, in general higher yields were obtained across sites than expected, probably due to CA which was used as the farming method, which is in line with 20–120% yield difference of CA against conventional tillage as reported by Rockström *et al.* (2009) and Ngoma *et al.* (2015). In CA, residual moisture and fertility as well as organic nutrients released from other decomposing crop residues all contribute to a nourished crop stand leading to an increased final yield (Hobbs *et al.*, 2008; Derpsch *et al.*, 2010). Moreover, CA can also increase yield through suppression of weeds, diseases, pests and may favour beneficial soil-microorganisms' activity (Derpsch *et al.*, 2010). Despite the generally high yield obtained, variations existed among the varieties in terms of yield under CA. These significant differences in traits offer an opportunity to select varieties with desirable traits. The three QPM varieties SC527, SC535 and SC643 performed very well in terms of final grain yield as they out-yielded all the local non-QPM checks. The same trend was also observed across seasons with the only exception that PAN413 (non-QPM) recorded the highest yield which was comparable to the top three yielding QPM varieties, although these QPM varieties recorded earlier days to 50% anthesis than PAN413. Practically, days to 50% anthesis are positively correlated to days to physiological maturity (Trachsel *et al.*, 2017). Most importantly, late maturity varieties normally have higher grain yield than early maturity varieties, but it was not the case with QPM varieties as alluded earlier (Gasura *et al.*, 2013). Yield was related with hundred kernel weight, ear texture and plant vigour. This is mainly because greater individual kernel weight directly increases final yield (Milošević *et al.*, 2010; Gasura *et al.*, 2013). Flint varieties have kernels that are denser than dent kernels (since starch in the endosperm is closely packed), resulting in greater kernel weight in flint varieties which are commonly found among the QPM varieties (Prasanna *et al.*, 2001; Olakojo *et al.*, 2007). Moreover, ear texture is an important quality trait in maize; it is important in that it determines the processing properties, flour-cooking properties and susceptibility to insect pests (Abadassi, 2015). Hence in relation to this information, some QPM and non-QPM varieties were observed to be flint (Tables 6–8). These results are consistent with those reported by Bello *et al.* (2014) in that quality similarities existed between QPM and non-QPM varieties. Hence farmers who consider ear texture when choosing maize varieties can have QPM with a range of ear textures to choose from.

The non-QPM varieties PAN413 and SC403 and the QPM variety SC527 had the best plant vigour. Good vigour gives the plant a competitive advantage over weeds in terms of growth performance, and the vigourous canopy cover also deprives weeds of much-needed sunlight (Milošević *et al.*, 2010). According to Milošević *et al.* (2010), good plant vigour indicates that the plant tolerates different stresses, including adverse environmental factors. As a preference trait, some QPM and non-QPM local checks exhibited good plant vigour across sites, thereby confirming their wide environmental adaptation. Consequently, QPM varieties have the same chances as non-QPM varieties of being selected for planting by farmers as they possess similar plant vigour.

Although QPM varieties had similar trait performance as non-QPM varieties, they also differed in traits such as ear

Table 8. Means of grain yield and secondary traits of QPM and non-QPM varieties across four sites arranged according to grain yield evaluated across 2014/2015 and 2015/2016 summer cropping seasons in Zimbabwe

Entry	Entry name	GY	100 KW	PH	EH	DTA	DTS	DPM	NKR	NKRE	ET	PV
1	MQ623	2.7	22.2	153.6	72.2	62.7	68.9	126.3	33.1	12.3	2.8	3.5
2	MH1416	2.6	20.7	156.7	77.4	66.1	71.2	124.8	34.0	14.2	1.4	3.2
3	MH1429	2.0	20.9	146.4	68.9	66.5	71.9	127.2	34.1	12.9	1.6	3.0
4	MH1410	2.6	22.2	145.9	73.6	62.1	67.4	121.1	35.9	11.2	1.4	3.2
5	OPV5195	1.8	21.5	145.2	65.9	60.8	66.5	117.4	30.5	12.8	2.6	3.0
6	SC643	3.0	28.1	152.0	74.8	64.3	70.0	126.4	31.4	13.3	2.9	2.9
7	SC527	3.1	30.1	153.6	69.1	60.7	67.4	123.8	31.4	14.0	3.5	3.3
8	SC535	3.1	25.2	148.7	69.7	61.5	66.9	120.4	31.9	14.8	3.1	3.5
9	PHB3253	2.5	26.8	151.4	78.1	63.2	68.7	123.6	32.6	13.6	2.8	3.1
10	SC513	2.6	28.0	155.9	74.8	61.1	67.3	122.0	30.6	13.6	3.2	3.0
11	PAN413	3.2	24.9	141.3	70.0	63.2	69.1	126.5	35.6	12.7	4.0	4.0
12	SC403	2.6	28.3	159.7	68.9	59.0	64.9	118.2	34.0	12.4	2.4	3.3
Grand mean		2.6	24.9	150.9	72.0	62.6	68.3	123.1	32.9	13.2	2.6	3.3
LSD(0.05)		0.3	1.6	6.4	5.1	0.9	1.2	2.8	1.4	0.4	0.4	0.4
P value		<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)		18.12	11.44	7.45	9.18	2.61	3.05	3.95	7.44	5.16	26.43	19.19

GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

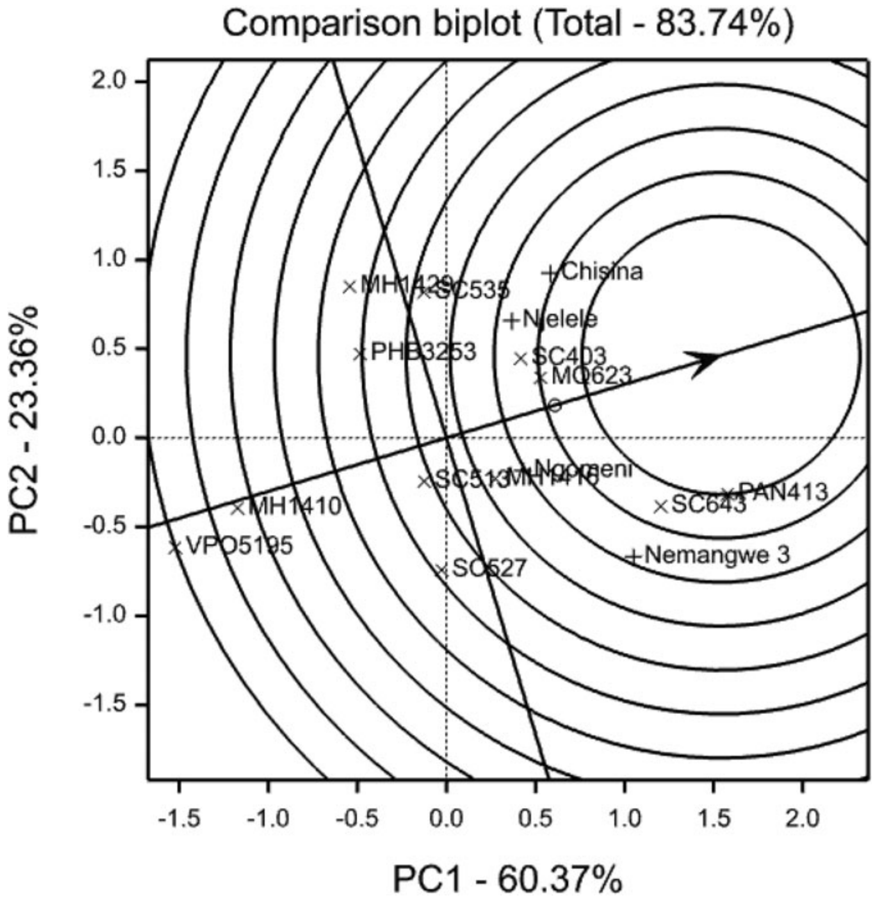

Fig. 2. The comparison biplot showing the best yielding and stable maize varieties evaluated across four sites during the 2015/2016 cropping season in Zimbabwe. The biplot was produced based on genotype SVP, no transformation, no scaling and the data were environment centred.

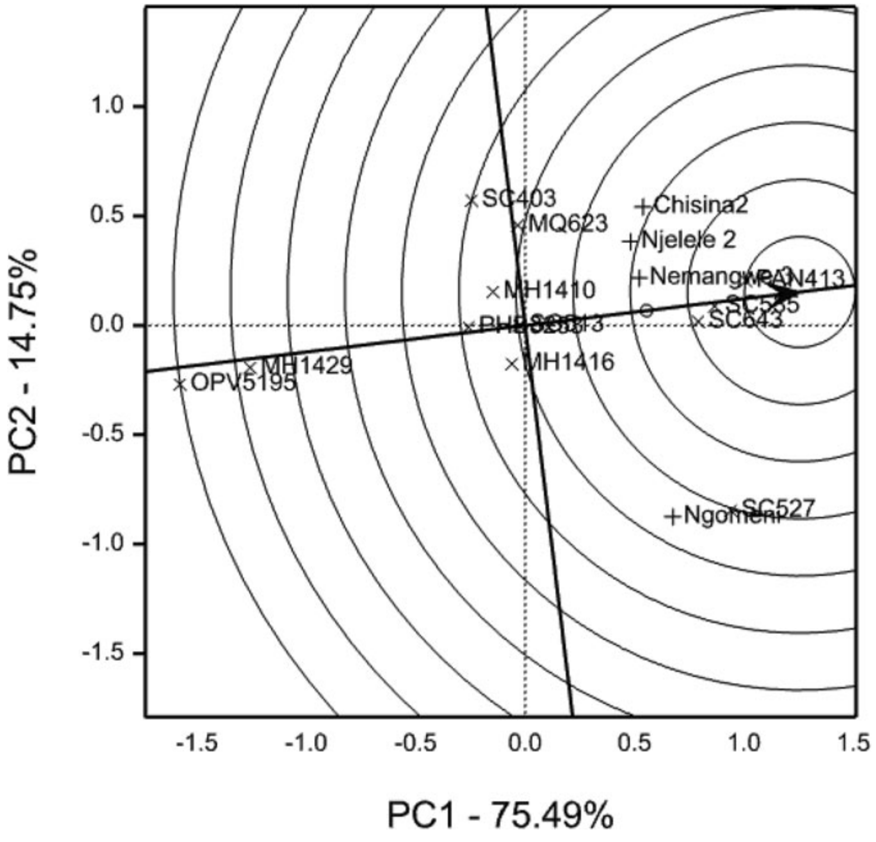

Fig. 3. The comparison biplot showing the best yielding and stable maize varieties evaluated across 2014/15 and 2015/2016 cropping seasons in Zimbabwe. The biplot was produced based on genotype SVP, no transformation, no scaling and the data were environment centred.

Table 9. Independent two-sample *t* test for QPM and non-QPM varieties secondary traits during the 2014/2015 cropping season in Zimbabwe

Entry	Class	GY	100 KW	PH	EH	DTA	DTS	DPM	NKR	NKRE	ET	PV
1	QPM	2.836	20.47	178.8	46.11	62.97	68.11	127.8	35.94	12.85	2.8	3.278
2	QPM	2.772	18.68	178.7	51.4	65.82	70.06	124.9	35.09	14.87	0.9	3.07
3	QPM	2.626	20	173.3	44.35	64.65	69.61	127.5	34.02	13.19	1.5	3.046
4	QPM	2.988	22.29	172.5	45.93	62.23	65.82	125.2	39.34	11.55	1.1	3.174
5	QPM	2.543	22.13	175.2	44.24	60.01	63.7	120.7	34.72	13.37	3.2	3.51
6	QPM	3.61	29.55	176.8	47.45	63.92	67.76	125.7	32	12.76	3.4	2.699
7	QPM	4.163	30.21	185	48.04	59.89	66.09	124.6	34.26	13.81	3.3	3.692
8	QPM	3.837	23.97	175.2	44.89	59.79	64.21	122	34.23	15.32	3.5	3.666
Mean		3.171875	23.4125	176.9375	46.55125	62.41	66.92	124.8	34.95	13.465	2.4625	3.266875
Variance		0.373808	18.54151	15.79411	5.723184	5.4638	5.546971	5.994286	4.412371	1.4516	1.219821	0.116846
9	Non-QPM	3.099	24.73	184	50.67	61.83	66.29	125.9	33.85	14.26	3.1	3.008
10	Non-QPM	3.126	27.23	182.9	48.56	59.75	64.87	123.6	32.06	13.97	3.6	3.387
11	Non-QPM	3.217	22.8	163.6	44.13	62.01	67.02	125.3	35.72	13.19	4.1	3.857
12	Non-QPM	3.032	29.74	183.1	43.02	56.87	63.53	122.2	36.37	12.79	2.1	3.685
Mean		3.119	26.13	178.4	46.595	60.12	65.43	124.25	34.5	13.55	3.23	3.48
Variance		0.006	9.097	97.580	13.108	5.732	2.397	2.817	3.787	0.463	0.729	0.139
Standard error of differences		0.220	2.143	5.135	1.998	1.455	1.137	1.206	1.224	0.545	0.579	0.222
Mean difference		0.053	−2.713	−1.463	−0.044	2.295	1.493	0.55	0.45	−0.088	−0.763	−0.217
Degrees of freedom		10	10	10	10	10	10	10	10	10	10	10
t-calculated		0.243	−1.266	−0.285	−0.022	1.578	1.313	0.456	0.368	−0.161	−1.318	−0.980
t-probability		0.813 ns	0.234 ns	0.782 ns	0.983 ns	0.146 ns	0.219 ns	0.658 ns	0.721 ns	0.876 ns	0.217 ns	0.350 ns

GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour; ns, non-significant.

Table 10. Independent two-sample *t* test for QPM and non-QPM varieties secondary traits during the 2015/2016 cropping season in Zimbabwe

Entry	Class	GY	100 KW	PH	EH	DTA	DTS	DPM	NKR	NKRE	ET	PV
1	QPM	2.389	22.32	125.8	58.92	62.28	70.39	124.7	31.58	11.74	3.324	3.454
2	QPM	2.006	19.99	134	63.89	66.06	72.27	121.5	32.45	13.73	1.824	3.049
3	QPM	1.439	21.8	124.7	54.19	66.69	73.4	124.9	33.21	12.28	1.856	2.888
4	QPM	1.794	22.78	125.3	69.29	61.44	68.32	113	31.33	10.91	1.351	3.232
5	QPM	1.48	21.44	117.7	55.29	60.85	67.42	112.9	27.57	12.32	1.698	2.932
6	QPM	2.779	25.78	132.3	71.36	63.02	70.17	122.7	31.46	13.92	2.482	3.323
7	QPM	2.116	28.58	125.5	50.32	61.35	68.06	123.3	27.94	14.11	3.496	3.332
8	QPM	2.348	25.75	127.9	59.92	62.56	68.83	115.6	29.99	14.2	2.8	3.367
Mean		2.043875	23.555	126.65	60.3975	63.03125	69.8575	119.825	30.69125	12.90125	2.353875	3.197125
Variance		0.214988	8.201086	25.04	54.29102	4.780413	4.477536	26.43643	4.14707	1.558555	0.63223	0.045412
9	Non-QPM	2.091	29.36	120.3	64.65	63.3	69.19	117.2	31.16	13.14	2.558	3.107
10	Non-QPM	2.175	28.11	132.2	65.9	60.7	68.02	118.4	30.07	13.31	2.891	2.846
11	Non-QPM	2.812	24.29	122.8	67.59	62.9	69.69	126.7	36.08	12.45	4.188	4.187
12	Non-QPM	2.327	26.92	138.7	59.55	60.1	65.49	112.8	30.18	12.12	2.375	2.867
Mean		2.351	27.17	128.5	64.42	61.75	68.10	118.78	31.87	12.76	3.003	3.25175
Variance		0.10	4.68	72.50	12.00	2.52	3.51	33.71	8.11	0.32	0.67	0.40
Standard error of differences		0.23	0.33	0.52	4.61	1.113	1.20	3.43	1.60	0.50	3.13	1.48
Mean difference		−0.31	−3.62	−1.85	−4.03	1.28	1.76	1.05	−1.18	0.15	−0.65	−0.05
Degree of freedom		10	10	10	10	10	10	10	10	10	10	10
t-calculated		−1.18	−2.44	−0.40	−15.42	1.16	1.47	0.31	−4.53	0.28	−1.31	−0.17
t-probability		0.266ns[a]	0.035*	0.697 ns	0***	0.274 ns	0.173 ns	0.765 ns	0.001***	0.786 ns	0.220 ns	0.870 ns

GY, grain yield; 100 KW, hundred kernel weight; PH, plant height; EH, ear height; DTA, days to 50% anthesis; DTS, days to 50% silking; DPM, days to physiological maturity; NKRE, number of kernel rows per ear; NKR, number of kernels per row; ET, ear texture; PV, plant vigour.

[a] Trait recorded in two of the four sites.

*, ** and *** significant at the 5, 1 and 0.1% probability levels, respectively; ns, non-significant.

Table 11. Mean ranks for maize varieties ear characteristics performance across five sites during 2014/2015 cropping season

Entry	Chisina	Njelele	Nemangwe 3	Nemangwe 5	Ngomeni
MQ623	6.16	5.01	9.11	7.97	9.58
MH1416	6.71	5.56	5.63	6.75	6.32
MH1429	7.87	6.30	9.07	6.98	8.18
MH1410	8.80	6.41	6.13	7.47	7.60
OPV5195	7.88	8.75	7.63	8.35	10.38
SC643	5.37	5.07	5.43	4.12	4.01
SC527	4.99	6.08	3.28	3.12	2.90
SC535	5.92	7.03	7.22	6.33	4.81
PHB3253	6.98	6.44	7.04	8.65	5.08
SC513	6.44	7.76	4.43	6.43	5.56
PAN413	4.68	7.23	8.46	6.47	6.48
SC403	6.22	6.33	4.57	5.37	7.11
Sample size (*N*)	141	54	27	30	45
Friedman's statistic	181.35	52.99	82.71	68.93	186.45
Adjusted for ties	207.18	59.58	90.6	76.53	203.75
Degrees of freedom	11	11	11	11	11
P value using χ^2 approximation	<0.001	<0.001	<0.001	<0.001	<0.001

Table 12. Mean ranks for maize varieties ear characteristics performance across four sites during 2015/2016 cropping season

	Chisina	Njelele	Nemangwe 3	Ngomeni
Entry	Mean ranks	Mean ranks	Mean ranks	Mean ranks
MQ623	6.551	5.861	5.31	7.183
MH1416	5.295	7.389	6.024	3.283
MH1429	4.846	8.139	8.405	7.083
MH1410	6.449	6.278	7.976	8.65
OPV5195	10.449	8.389	9.095	9.55
SC643	5.667	4.972	4.333	4.417
SC527	6.538	5.556	5.833	4.067
SC535	6.282	6.917	7.595	6.483
PHB3253	6.038	5.611	8.119	6.1
SC513	6.808	6.139	5.571	7.133
PAN413	6.167	6.333	4.333	6.1
SC403	6.91	6.417	5.405	7.95
Sample size (*N*)	39	18	21	30
Friedman's statistic	63.35	16.42	48.3	88.07
Adjusted for ties	71.74	19.69	54.47	95.25
Degrees of freedom	11	11	11	11
P value using χ^2 approximation	<0.001	0.05	<0.001	<0.001

height, number of kernels per row and hundred kernel weight (Tables 6–8). Significantly high values recorded by non-QPM varieties for number of kernels per row and hundred kernel weight may be attributed to individual varieties such as PAN413 and PHB3253 respectively, which were specifically bred for those traits. Ear placement is another agronomic trait of critical importance for lodging (Shah and Ali, 2015). Interestingly, both QPM and non-QPM varieties had moderate

Table 13. Mean ranks for maize varieties palatability evaluation by farmers at five sites

Variety	Chisina 2	Njelele 2	Nemangwe 3	Nemangwe 5	Ngomeni
MH 1410	6.38	4.68	4.69	6.68	5.74
MH 1416	4.55	5.59	3.97	5.27	4.80
MH 1429	6.13	6.46	6.05	4.46	4.85
MQ 623	6.08	5.68	5.32	6.20	6.64
PAN 413	7.30	6.02	8.93	8.89	6.31
PHB 3253	7.20	6.59	6.60	8.39	7.92
SC 403	7.50	7.20	6.76	4.59	5.16
SC 513	6.20	7.95	7.89	8.59	8.38
SC 527	6.08	6.66	8.05	6.71	6.95
SC 535	8.03	5.93	6.68	6.00	7.74
SC 643	6.93	6.52	5.85	6.84	7.19
VPO 5195	5.60	8.72	7.20	5.38	6.32
Sample size (*N*)	30	41	37	28	37
Friedman's statistic	22.77	40.72	64.14	53.39	45.04
Adjusted for ties	24.93	44	69.33	58.08	48.39
Degrees of freedom	11	11	11	11	11
P value using χ^2 approximation	0.009	<0.001	<0.001	<0.001	<0.001

Table 14. Chi-square contingency table for QPM and non-QPM palatability triangulation tests

Site	χ^2 value	Critical value (D.F.$_{2;0.05}$)	*P* value
Chisina 2	4.80	5.991	0.09
Njelele 2	0.00	5.991	1.0
Nemangwe 3	3.70	5.991	0.15
Nemangwe 5	1.70	5.991	0.39

ear height though differences existed. According to Dugje *et al.* (2014) plant and ear heights as growth parameters offer distinctiveness to a particular variety in terms of uniformity and stability.

Convincingly, QPM varieties had some similar agronomic traits to those of non-QPM varieties. These traits included grain yield, plant vigour, plant height, days to 50% anthesis and silking, days to physiological maturity and number of kernel rows per ear. In terms of days to physiological maturity, QPM and non-QPM varieties were in the range of early to medium maturity, which is good for escaping drought and for an early supply of food. Across seasons, yield attained ranged from 1.8 to 3.2 t/ha and days to 50% anthesis was in the range of 60–66 days (Table 8). Number of days to flowering is essential as it indicates the days to physiological maturity of a variety. Although some QPM varieties such as OPV5195 (an open pollinated variety) had low yield, some better QPM hybrids were identified. This is understandable because hybrids normally perform better than OPVs as they exhibit heterosis (Malik *et al.*, 2010). In general, both QPM and non-QPM varieties have other good traits such as grain yield, plant height, days to flowering and physiological maturity, ear texture and plant vigour.

In terms of adaptation, Bhatnagar *et al.* (2003) and Bello *et al.* (2014) echoed the same sentiments, namely that QPM varieties with wide environmental adaptation and competitive yield in the tropics and sub-tropics have been developed. In this regard, notably the QPM varieties SC535, SC527, SC643 and MQ623 (Figs 1–3) clearly demonstrated that QPM varieties can perform at par or much better than non-QPM varieties in terms of grain yield across different environments, thereby indicating their wider environmental adaptation. With regard to agronomic performance, QPM varieties performed similarly to non-QPM local checks as they were similar in terms of good height, days to 50% anthesis, silking and physiological maturity. This clearly suggests that the QPM varieties evaluated in this study, especially the varieties SC535, SC527, SC643 and MQ623, could be adopted by farmers as they outperformed popular local non-QPM varieties in terms of yield and agronomic performance (Tables 6–8). Furthermore, results obtained in this study indicated that QPM varieties SC643 and MQ623 were equally good, as they exhibited good agronomic performance in that they were able to tolerate the El Nino-induced drought during the 2015/16 cropping season (Table 7). These findings support the main objective of this study, as farmers are much more interested in the yield and agronomic performance of a variety than in its nutritional composition which they cannot measure. From farmers' overall variety ear characteristics scoring it is clear that farmers like varieties that are high yielding and stable. It can be deduced from the results that the QPM and non-QPM varieties SC527, SC643 and SC535 received the best overall ear characteristic mean ranks from the farmers. This is most probably because these varieties had perfect perceived farmer agronomic traits in terms of ear texture, and ear and kernel size that translate to yield.

The good agronomic and yield performance exhibited by the QPM varieties SC527, SC535, SC643 and MQ623 will directly benefit farmers by enhancing maize production as well as in providing them with the direct benefits of balanced protein nutrition from QPM varieties. It is also clearly evident that breeders have been working hard to produce QPM varieties with favourable agronomic traits. This is mainly because the *opaque-2* gene in QPM had unfavourable pleiotropic effects, such as low yield and soft endosperm associated with it, rendering it highly susceptible to pests and disease (Vasal, 2000; Sofi *et al*., 2009). In accordance with the findings of Upadhyay *et al.* (2009), QPM genotypes recorded significantly higher grain yield than most of farmers' favourite non-QPM local checks. With such findings, seed companies can easily determine that the top three genotypes, SC527, SC535 and SC643, are good alternatives for the currently grown non-QPM varieties, as these will provide bumper harvests as well as quality protein nutrition for food and feed. The QPM varieties MQ623 and SC643 can also be singled out as drought-tolerant QPM varieties as they performed relatively well in terms of grain yield during the 2016/15 cropping season which was characterized by the El Nino-induced drought.

Moreover, QPM is important as a cheap alternative source of quality protein, as maize is the commonest of the food sources which constitute the greater portion of the daily diets of communities in SSA and other maize-dependent developing countries. Furthermore, QPM is better in this respect than most commonly-grown legume grains such as common beans (*Phaseolus vulgaris* L.), groundnuts (*Aranchis Hypogea* L.), and cowpeas (*Vigna unguiculata* L.), which have good quality protein but contain a lot of anti-nutritional factors (ANF) such as trypsin inhibitors, lectins and tannins which inhibit protein digestibility and utilization (López-Barrios *et al*., 2014).

Although farmers ranked varieties differently during sensory evaluation tests, they failed to distinguish between the varieties which they had ranked among the top three in taste scores. With these findings it can be argued that these QPM varieties suit the local diet well, as the triangulation results indicated that QPM and non-QPM varieties cannot be separated in terms of taste. This is in line with Ahenkora *et al.* (1999), who found that overall acceptability and palatability of QPM and non-QPM varieties were not significantly different, indicating that all these varieties had an acceptable taste. Hence as a preference factor, taste should not hinder the adoption of QPM by farmers. Therefore, QPM varieties may be considered to be as equally acceptable to consumers as non-QPM local varieties. Ultimately QPM is the way to go in order to improve food security and the protein nutrition of maize-dependent communities, especially resource-poor rural communities, since some QPM genotypes were at par in performance with the best non-QPM varieties and in some instances were much better than the local checks.

Conclusions

QPM varieties SC527, SC535, SC643 and MQ623 were comparable to non-QPM and local checks in terms of yield, stability and agronomic performance. These QPM varieties received good overall ear characteristics mean rankings from farmers through PVS. Moreover, farmers failed to distinguish between QPM and non-QPM varieties in terms of taste. Farmers consider yield when selecting varieties, and the high-yielding QPM varieties (SC527, SC535, SC643 and MQ623) are likely to be adopted by farmers in southern Africa.

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