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Comparative Response of Conventional and Quality Protein Maize Hybrids to High Population Densities in the Southern Guinea Savanna of Nigeria

[1]*Bello, O. B. and [2]Mahamood, J.

[1]*Department of Biological Sciences, Fountain University, Osogbo, Osun State, Nigeria.*
[2]*Lower Niger River Basin Development Authority, Ilorin, Kwara State, Nigeria.*

Abstract

Optimum plant population is very important in enhancing high and stable grain yield especially in quality protein maize (QPM) production. A field trial was therefore conducted to compare the performance of six hybrids (three each of QPM and normal endosperm) at three population densities using a split-plot design at the sub-station of the Lower Niger River Basin Development Authority, Oke-Oyi, in the southern Guinea savanna zone of Nigeria during the 2010 and 2011 cropping seasons. Plant population densities (53,333, 66,666, and 88,888 plants ha^{-1}) constituted the main plots and the six hybrids were assigned to the subplots, replicated three times. Our results showed a differential response of maize hybrids to high densities, with plant populations above 53,333 plants ha^{-1} reduced grain yield, and this is more pronounced in QPM than normal endosperm hybrids. This is contrary to the results observed in many other countries. This might be that the hybrids were selected in low yield potential area at low plant densities, and hence not tolerant to plant density stress. It may also be due to low yield potential of the experimental site, which does not allow yield increases at high plant densities. Though normal endosperm hybrids 0103-11 and 0103-15 as well as QPM Dada-ba were superior for grain yield among the hybrids at 53,333 plants ha^{-1}, hybrid 0103-11 was most outstanding. Therefore, genetic improvement of QPM and normal endosperm hybrids for superior stress tolerance and high yield could be enhanced by selection at higher plant population densities.

Keywords: *Quality protein maize, normal endosperm, stress tolerance, grain yield.*

Introduction

Quality protein maize (QPM) contains higher usable protein (70-100% lysine and tryptophan) than the normal endosperm maize varieties (Buah *et al.,* 2009). Protein deficiency among children is common especially in the rural setting of Nigeria where meat, fish and eggs are beyond the means of the average family with low incomes. QPM adoption and utilization by farmers not only provide nutritionally superior maize grains as dietary staple, but also alleviate protein malnutrition (Olakojo *et al.*, 2007). Generally, maize (*Zea mays* L.) is most sensitive to variations in plant population density with highest grain yield potential among the grass family (Vega *et al.*, 2001). These attributes may be due to its

Email address: obbello2002@yahoo.com

relatively short flowering period, monoecious floral organization and low tillering ability that compensate for low leaf area and small number of reproductive units by branching (Sangoi *et al.*, 2002). Low plant population densities delays canopy closure and decreases light interception leading to high grain production per plant with low grain yield per unit area (Sharifi *et al.*, 2009; Maoveni *et al.,* 2011; Zamir *et al.,* 2011). Furthermore, high population heightens inter-plant competition for light, water and nutrients particularly during the period bracketing silking, favoring apical dominance, decreasing both the yield per plant and ratio of cob to tassel growth rate (Edmeades *et al.*, 2000; Reddy and Reddi, 2004).This may be detrimental to final yield which induces bareness and decreases the number of ears and kernel number. Optimum plant densities enhance effective plant growth (aerial and underground) through different utilization of solar radiation and nutrients (Hasanuzzaman *et al.*, 2009; Moraditochaee *et al.,* 2012). An optimum plant population density for maximum economic yield exists for all crop species and varies with cultivar and environment (Bruns and Abbas, 2005)

QPM hybrids are either superior or equal in productivity with normal endosperm hybrids (Yadav, 2006; Bisht *et al.*, 2012). Traditionally, maize varieties are selected at 53,333 plants ha^{-1} with a row width of 0.75 m and within a row distance of 0.25m at one plant per stand or 0.75 x 0.5m at two plants per stand in the savanna agro-ecology of Nigeria (Kamara *et al.*, 2006).To make progress in selection for tolerance to environmental stress such as high plant density or drought, needs to develop or select maize at high plant densities. The QPM hybrids in this study were developed under different population densities and their genes may change due to increase population pressure. This study was therefore conducted to compare the performance of QPM and normal endosperm hybrids at plant population densities higher than 53,333 plants ha^{-1} with the view to exploit maximize genetic yield potentials of these hybrids for stress tolerance in the savanna agro-ecology of Nigeria.

Materials and Methods

Germplasm used, experimental design and cultural practices

Field experiments were conducted at the research station of the Lower Niger River Basin Development Authority, Oke-Oyi, in the southern Guinea savanna zone, Ilorin, Nigeria (Latitude 8^0 30'N, 8^0 36'E and Longitude 4^0 31'N, 4^0 33'E) during the year 2010 and 2011 cropping seasons. The soil type is loamy sand, Typic Paleustalf (United State Department of Agriculture, USDA soil taxonomy). Six hybrids comprised of three QPM (Mama-ba, CIDA-ba and Dada-ba,) and three normal endosperms (0103-07, 0103-11 and 0103-15) were planted on 30th July, 2010 and 26th July, 2011 at three plant densities using a split-plot design with three replications; each plot consisted of four rows 5m long. Plant densities of intra-row spacing 15cm (88, 888 plants ha^{-1}), 20cm (66, 666 plants ha^{-1}) and 25cm (53, 333 plants ha^{-1}) constituted the main plots and the six hybrids were assigned to the subplots. The plots were over-planted and hand-thinned to one plant per stand to achieve the desired target density at two weeks after planting (WAP). At planting, fertilizer was applied at the rate of 40 kg/ha each of N, P, and K. Additional N fertilizer, in the form of urea, was applied at the rate of 60 kg N/ha five WAP. Weed control was carried out by applying five liters per hectare of pre-emergence herbicides (3 kg l^{-1} Metolachlor and 170 g l^{-1} Atrazine) and supplemented by a regime of hand weeding at six WAP.

Field measurements

Agronomic parameters collected per plot were plant height measured as the distance from the ground level to the flag leaf using a measuring tape. Days to 50% silking was taken as the date when 50% of the plants in a plot had extruded silk. Anthesis-silking interval was calculated as the difference between days to anthesis and silking. The total number of plants and ears were counted in each plot at harvest. The number of ears per plant was then calculated as the total number of ears at harvest divided by the total number of plants harvested. The percentage root lodging was recorded at the two central rows, as the percentage of plants that are leaning more than 45° from the upright position. Grain yield per plot was determined at 12.5% moisture content from which grain yield per hectare was estimated.

Statistical analyses

Data collected and estimated were subjected to analyses of variance (ANOVA) first on individual year basis before combined ANOVA over years, using the SAS GLM Proc (SAS, 2007) to compute mean squares for each character according to a split-split-plot model. The degree of variation was determined using % coefficient of variation $P < 0.05$. Treatment means were separated by means of least significant difference (LSD) at 0.05 percent probability.

RESULTS

Mean squares from combined analysis of variance

Effect of year, year x population density and year x population density x hybrid interactions were not significant for grain yield and other yield components (Table 1). However, density, hybrids and density x hybrids interactions differed significantly for all the agronomic characters except percentage root lodging.

Days to silking and Anthesis-silking interval

Days to silking increased with increase in plant population in all the hybrids (Table 2). QPM hybrids attained silking earlier than normal endosperm hybrids with significant advantage of 12.5% at plant population density of 53,333 plants ha^{-1}. Within the QPM and normal endosperm hybrids, Dada-ba and 0103-15 were earliest to attain anthesis in 56 and 60 days respectively, with significant advantage of 5% at all level of stresses. Averaged across genotypes, silking was delayed by three and seven days as plant population increased from 53,333 to 66,666 and 88,888 plants ha^{-1} respectively. Similarly, anthesis- silking interval (ASI) increased with increase in plant density among all the hybrids. It

Table 1: Combined analysis of variance of response to plant density of grain yield and yield components of three QPM and three conventional maize hybrids in Nigeria (Ilorin, 2010 & 2011)

	Mean squares					
Source	Days to silking (days)	Anthesis-silking Interval (days)	Plant height (cm)	Lodging	Ears per plant	Grain yield (t ha^{-1})
Replicate	3.4	0.5	1.1	5.3	0.6	134.7*
Year	0.3	12.6	10.3	13.4	2.6	0.7
SE±	0.1	1.6	10.3	0.1	1.7	11.4
Density	235.7**	126.8*	314.3**	267.6**	362.7**	153.9*
Year x Density	2.6	12.5	11.2	0.7	11.4	0.4
SE±	12.4	10.2	7.3	0,6	0,2	12.7
Hybrids	173.3**	231.3*	100.1*	123.7*	231.4**	111.3*
Year x Hybrid	2.4	1.2	0.5	4.0	3.4	1.2
Density x Hybrids	123.4*	210.5*	210.8**	14.8	311.6**	210.64**
Years x Density x Hybrid	10.3	3.6	0.9	1.5	7.3	0.6
SE±	0.4	0.7	10.3	13.2	0.8	11.3
%CV	4.6	23.6	2.8	5.4	24.7	30.2

*, **, significant at the 0.05 and 0.01 probability levels.

Table 2: Plant population density on flowering period s of three QPM and three conventional maize hybrids in Nigeria (Ilorin, 2010 & 2011)

	Days to silking (days)				Anthesis silking interval (days)			
	Plants ha^{-1}							
Year	53,333	66,666	88,888	Mean	53,333	66,666	88,888	Mean
2010	60	63	67	63	2	3	4	3
2011	60	62	66	63	2	2	4	3
SE$\pm$	10.5	7.6	3.7	11.3	10.8	3.6	5.2	10.2
QPM hybrids								
Mama-ba	59	62	66	62	2	3	5	3
CIDA-ba	57	61	64	61	2	3	4	3
Dada-ba	56	59	62	59	2	3	4	3
Normal hybrids								
0103-07	63	65	69	66	1	4	5	3
0103-11	63	66	70	66	1	3	4	3
0103-15	60	65	68	64	1	3	4	3
SE$\pm$	0.45	2.21	0.76	11.54	10.34	0.34	15.32	11.05
Mean	60	63	67	63	2	3	4	3
$LSD_{(0.05)}$	1.2	2.4	3.1	1.1	0.7	0.9	0.6	ns

It is noteworthy that at plant population of 53,333 plants ha^{-1}, all the normal hybrids only had one (1) day for ASI, and above 53,333 plants ha^{-1}, there was significant increase in ASI among all the hybrids.

Plant height and root lodging

Plant height increased with increase in plant population from 53,333 to 66,666 plants ha^{-1} but reduced drastically at 88,888 plants ha^{-1} in all the hybrids (Table 3). Plant height increased by four (4) percent (%) with increase in plant population from 53,333 to 66,666 plants/ ha^{-1}, and reduced by 12% at 88,888 plants ha^{-1}. There was no significant difference in plant height between the QPM and normal hybrids at all level of stresses. At 53,333 plants ha^{-1} however, QPM Mama-ba has the shortest height (170 cm) compared to all the hybrids, and maximum height of 180 and 193cm were recorded in normal and QPM hybrids respectively. Root lodging also increased with increase in plant population in all the hybrids. At 53,333 plants ha^{-1}, QPM hybrids had lower percentage root lodging compared to normal hybrids, with QPM Dada-ba having the lowest root lodging of 9%. Among all the hybrids, the year 2010 recorded higher percentage of root lodging than 2011.

Ears per plant and grain yield

High plant density stimulated barrenness in all the hybrids (Table 4). Number of ears per plant decreased with increase in plant density among the hybrids. At plant population of 53,333 plants ha^{-1}, there was no significant difference between and within the QPM and normal endosperm hybrids. Ears per plant above 53,333 plants ha^{-1} were reduced by 18% and 36% at 66,666 and 88,888 plants ha^{-1} respectively. High grain yields were recorded for all the hybrids at plant population of 53,333 plants ha^{-1} and reduced as the density increased. The conventional hybrids had higher yield values compared with the QPM hybrids. Plant densities above 53,333 plants ha^{-1} reduced grain yield by 25% for plant population of

Table 3: Plant population density on plant height and lodging of three QPM and three conventional maize hybrids in Nigeria (Ilorin, 2010 & 2011)

	Plant height (cm)				Lodging			
	Plants ha^{-1}							
Year	53,333	66,666	88,888	Mean	53,333	66,666	88,888	Mean
2010	181	187	159	175	12	13	15	14
2011	179	187	159	175	12	13	16	13
SE$\pm$	20.7	11.6	8.3	3.5	0.9	10.6	5.3	12.6
QPM hybrids								
Mama-ba	170	178	165	171	10	14	15	13
CIDA-ba	182	190	177	183	12	14	16	14
Dada-ba	193	199	157	183	9	14	16	13
Normal hybrids								
0103-07	178	189	155	174	13	12	15	13
0103-11	178	181	154	171	14	12	16	14
0103-15	180	183	145	170	12	14	16	14
SE$\pm$	14.7	10.5	9.6	10,7	7.3	2.9	10.5	2.9
Mean	180	187	159	175	12	13	16	14
$LSD_{(0.05)}$	3.6	2.7	2.4	3.9	3.7	1.6	0.7	0.6

66,666 plants ha^{-1} and by 43% for plant population of 88,888 plants ha^{-1}. Dada-ba (4.5 t ha^{-1}) and 0103-11 (4.9 t ha^{-1}) had significantly different grain yield per hectare among QPM and normal endosperm hybrids respectively, which also varied significantly between and within the hybrids. On average across years, there was no significant difference among the hybrids for grain yield, but grain yield in 2011 was higher than 2010 at both densities 53,333 and 88,888 plants ha^{-1}.

DISCUSSION

In the present study, there was a differential response of the hybrids irrespective of the endosperm attributes (QPM and normal endosperm) to high plant population densities which are also in line with the findings of Abolhassan *et al.* (2005). Turgut *et al.* (2005) earlier reported that population density and hybrids that differed significantly for almost all the yield attributes indicated that certain hybrids may perform better at prescribed row spacing. Days to silking and anthesis-silking interval traits are mostly used in screening genotypes for tolerance to stresses. Anthesis-silking interval is a measure of nicking (synchronization) of pollen shed with silking. At high plant densities, the QPM hybrids that attained silking earlier than normal endosperm hybrids indicated earliness to maturity and they could be manipulated for drought escape in the breeding programme. High value of days to silking recorded at high density in all the hybrids might be due to the fact that short row spacing provided unsuitable environment for proper root development and resulted to delay in silking. Modares *et al.* (1998) also reported that decreased row spacing took more days to silk in their observed traits.

However, high plant population increased ASI for all hybrids but differences were not significant between the QPM and normal endosperm hybrids at plant populations of 88, 888 plants ha^{-1}. The normal hybrids that had shorter

Table 4: Plant population density on three QPM and three conventional maize hybrids in Nigeria (Ilorin, 2010 & 2011)

	Ears per plant						Grain yield	
					Plants ha^{-1}			
Treatment	53,333	66,666	88,888	Mean	53,333	66,666	88,888	Mean
2010	1.0	0.9	0.7	0.9	4.3	3.3	2.4	3.3
2011	1.0	0.9	0.7	0.9	4.4	3.3	2.6	3.4
SE$\pm$	15.6	10.2	9.4	13.7	10.4	0.7	1.5	13.6
QPM hybrids								
Mama-ba	1.0	0.8	0,6	0.7	4.2	3.1	2.8	3.4
CIDA-ba	1.1	1.0	0.8	1.0	4.0	3.4	2.5	3.3
Dada-ba	1.0	1.0	0.6	0.9	4.5	3.3	2.7	3.5
Normal hybrids								
0103-07	1.0	0.7	0.7	0.8	4.2	3.3	1.7	3.1
0103-11	1.1	0.8	0.7	0.9	4.9	3.5	2.6	3.7
0103-15	1.1	1.0	0.8	1.0	4.5	3.2	2.7	3.5
SE$\pm$	13.5	8.4	14.8	10.5	0.7	2.9	12.3	0.9
Mean	1.1	0.9	0.7	0.9	4.4	3.3	2.5	3.4
$LSD_{(0.05)}$	ns	0.1	ns	0.1	0.3	0.2	0.1	0.2

shorter ASI than the QPM, demonstrates that loss of synchrony between male and female inflorescence was less pronounced in the normal hybrids at dense stands which suggests greater tolerance of normal endosperm to density stress than the QPM hybrids. Short ASI has been reported to be an indicator of stress tolerance imposed at flowering, and is also a valuable diagnostic trait for cultivar performance under stress than days to silking *per se* because it is largely independent of maturity differences among cultivars (Edmeades *et al.*, 2000). While QPM hybrid Mama-ba and normal endosperm hybrid 0103-07 had the ASI highest value of five days at 88, 888 plants ha^{-1}, the lowest value of one day was recorded in the three normal endosperm hybrids (0103-07, 0103-11 and 0103-15). These findings are supported by those of Sangoi *et al.* (2002) who reported that increase in plant population lengthened the ASI more drastically in the conventional hybrids. Some researchers (Bolanos and Edmeades, 1996) revealed that an increase in ASI is characteristic of maize under environmental stress, such as N-deficiency, drought and higher plant density. In an independent research, Sangoi *et al.* (2002) and Lashkari *et al.* (2011) reported that increase in ASI reduces number of kernels per ear. Earlier workers (Carcova and Otegui, 2001; Ahmad *et al.,* 2011) also observed that an asynchronous flowering can limit grain production per ear due to lack of pollen, loss of silk receptivity or early kernel abortion.

Plant height is important trait for breeding of new varieties of maize, for green and dry matter production, as well as for grain yield (Bello *et al.*, 2012). It is also an important component that determines the growth attained during the growing period (Zamir *et al.*, 2011). There was a differential response of the maize hybrids to high plant densities for plant height, although high plant densities generally reduced at 88,888 plants ha^{-1} of all the hybrids that were evaluated during this study. These results were also conform to the findings of previous researchers who observed that increased population density causes plant stems to become thinner and often taller (Gozubenli *et al.*, 2004; Sener *et al.*, 2004; Abolhassan, *et al.*, 2005; Turgut *et al.*, 2005; Sharifi *et al.*, 2009; Ahmad *et al.,* 2011; Muktar *et al.*, 2012). QPM hybrid Mama-ba was the tallest and Dada-ba the lowest plants at 53,333 plants ha^{-1}. Short statured plants recorded could be due to the genetic constitution of the hybrids to overcrowding and higher intra-specific competition for resources. This trend implies that as the number of plants increased in a given area the competition among the plants for nutrients uptake and sunlight interception also increased respectively, according to Sangakkara *et al.*, (2004), Zhang *et al.*, (2006) and Zamir *et al.*, (2011). Higher plant densities above 53,333 ha^{-1} however increased root lodging. This was more pronounced in normal endosperm than in QPM hybrids. This indicated that the QPM hybrids were more tolerant to high plant population for root lodging than conventional hybrids. Differences among hybrids were the largest at 88,888 plants ha^{-1} with no significant difference between the QPM and conventional hybrids. Higher percentage of root lodging recorded in the year 2010 recorded than 2011 in this study also agree with Sangoi *et al.* (2002) and Kamara *et al.* (2006) who reported increased stalk and root lodging in normal endosperm hybrids when grown above optimum densities. However, weak stems that encouraged lodging was observed during this research which might be due to closer spacing that might lead to etiolation (Carena and Cross, 2003). Other factors like crop variables, amount of water expected during growing season and distribution may also be responsible.

Ears per plant are measure of prolificacy and very strongly related to grain yield. High plant density that stimulated barrenness in all the hybrids in this study indicated that reduced barrenness at high plant densities is linked to tolerance of maize hybrids to high plant densities. Earlier studies suggested that plant distribution could decrease 'plant to plant' competition for available water, nutrient and light; increase radiation interception and biomass production which invariably provide minimum competition and maximum yield at any given plant density (Andrade *et al.*, 2002; Ipsilandis *et al.*, 2005). Sangoi *et al.* (2002) also reported that high plant densities above 50,000 plants ha^{-1} stimulated barrenness in Brazilian maize hybrids.

Grain yield is a function of integrated effects of genetic make-up of cultivars and growing conditions as reported by earlier researchers (Sharifi *et al.*, 2009; Gözübenli, 2010; Abuzar,*et al.*, 2011; Ahmad *et al.*, 2011; Lashkari *et al.*, 2011; Shafi *et al.*, 2011) in maize. In the present study, highest grain yields potential exhibited by all the hybrids at plant population of 53,333 plants ha^{-1}, showed that all hybrids studied were not tolerant of high plant densities above 53,333 plants ha^{-1}. Though high population densities reduced grain yield in all the hybrids evaluated, but the normal endosperm hybrids showed some level of tolerance to high plant population than the QPM hybrids which may be attributed to genetic constitution of the hybrids. These results obtained are in agreement with observations made by many researchers that maize yield differed significantly under varying plant density due to differences in their genetic potential. (Gozubenli *et al.*, 2004; Sener *et al.*, 2004; Abdulai *et al.*, 2007; Ibeawuchi *et al.*, 2008; Ahmad *et al.*, 2011; Zamir *et al.*, 2011). Other workers (Sener *et al.* 2004; Varga *et al.* 2004; Luque *et al.* 2006; Peykarestan *et al.* 2012) also attributed to this genetic variation in the number of grains cob^{-1}, number of cobs plant^{-1}, 1000- grain weight and better root development. Also, high population densities that reduced grain yield may be due to competition between plants for obtaining light, water and nutrient elements, which are more obvious at high densities. At high population, incident radiation into the canopy decreased and delayed tasselling, thereby causes fewer grains per ear. Moraditochaee *et al.* (2012) reported increase in number of grain per cob with increasing plant density in maize.

Our results obtained are in contrary to those from other countries. For example, Widdicombe and Thelen (2002) reported maize hybrids having higher yields at 90,000 plants ha^{-1} in the Northern U.S. Corn Belt. The authors also suggested that 90,000 plants ha^{-1} was not the optimal plant population for the hybrids evaluated. The poor performance of maize hybrids in this study may be due to the fact that selection of maize in the Nigerian savannas is generally done at low plant densities of 53,333 plants ha^{-1}. This may have caused hybrids selected at this density to be intolerant to high plant populations. Researchers also observed that yield reduction ha^{-1} at high plant densities is due to the effects of interplant competition for light, water, nutrition and other potentially yield-limiting environmental factors, thus, a plant population above a critical density has a negative effect on yield/plant in maize (Xue *et al.*, 2002; Kamara *et al.,* 2006; Ahmad *et al.,* 2008; Ahmad *et al.,* 2011; Nik *et al.,* 2011; Zamir *et al.,* 2011).Thus, the optimum plant density depends upon environmental conditions and the cultivars used in the case of Guinea savanna ecology of Nigeria where the soils are poor due to land degradation arising from cropping intensification as earlier observed by Oikeh *et al.* (2003).

Conclusions

From the results of this study, plant spacing has varied effect on the growth and development in maize. Plant populations above 53,333 plants ha^{-1} reduced grain yield and this is more pronounced in QPM than normal endosperm hybrids. These variations may be due to the following factors;

- Hybrids were selected in low yield potential area at low plant densities; hence not tolerant to plant density stress.

- Low yield potential of the experimental site, which does not allow yield increases at high plant densities.

Though conventional hybrids 0103-11 and 0103-15 as well as QPM Dada-ba were superior for grain yield among the hybrids at 53,333 plants ha^{-1}, hybrid 0103-11 was most outstanding. Therefore, genetic improvement of QPM and normal endosperm hybrids for superior stress tolerance and high yield could be enhanced by selection at higher plant populations. Further studies on nutritional quality response of QPM hybrids to high population density at different nutrient management are very important.

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