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Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments

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ABSTRACT

Food insecurity and malnutrition are two major challenges facing rural populations in sub-Saharan Africa (SSA). Hybrids of quality protein maize (QPM) have a crucial role here to play because QPM contains increased lysine and tryptophan concentrations and has a higher biological value than the normal maize. Information on the combining ability and heterotic patterns of QPM inbreds is crucial for the success of hybrid programs in the sub-region. Ninety-one diallel crosses derived from 14 early maturing yellow-endosperm QPM inbreds were evaluated from 2010 to 2012 under *Striga* infested, drought, low-N and optimal environments in Nigeria. The objectives were to (i) examine the combining ability of the set of early yellow QPM inbreds, (ii) classify the inbreds into heterotic groups and identify the best testers (iii) compare the efficiencies of the heterotic grouping methods in classifying the inbreds and (iv) determine the grain yield and stability of the inbreds in hybrid combinations under the research environments. General (GCA) and specific (SCA) combining ability effects were important in the inheritance of grain yield and other traits of the inbreds. However, GCA was more important than SCA under each contrasting environment and across environments suggesting that the additive gene action was more important than the non-additive in the set of inbreds. The SCA effects of grain yield and the heterotic group's SCA and GCA of grain yield (HSGCA) methods classified the inbreds into three groups each, while the heterotic grouping based on GCA of multiple traits (HGCAMT) and the SNP-based genetic distance (GD) methods had two groups each across research environments. There was close correspondence among the classifications of all the grouping methods in terms of placement of inbreds into the same heterotic groups. The SNP-based method was the most efficient and was used to identify TZEQI 87 and TZEQI 91 as the best testers for the SNP-based heterotic groups 1 and 2. The hybrids, TZEQI 87 × TZEQI 93, TZEQI 77 × TZEQI 91 and TZEQI 80 × TZEQI 91 were identified as the most stable and high yielding across research environments and should be commercialized.

1. Introduction

Food insecurity and malnutrition are two major challenges confronting countries in sub-Saharan Africa (SSA). Maize (*Zea mays* L.) has a critical nutritional role to play because it is the most important staple food crop with the potential to combat food insecurity presently facing the sub region. Maize is consumed daily in large quantities in various local food preparations, and provides most of the calories, protein, vitamin, and mineral intake in the diets of the poor. In addition, maize is widely fed to babies (2 to 3 months old) until they are weaned at the age of 15 to 24 months and to pre-school children (3 to 5 years old) in several countries without protein supplements. Per capita maize consumption varied from 30 to 90 kg yr^{-1} in coastal countries of WCA and rose at an average of 0.5%/year from 1977 to 1988 in WCA (National Research Council, 1988, USA).

The normal maize has a major nutritional constraint as human food because its protein (about 10%) is deficient in lysine and tryptophan, which are two essential amino acids nutritionally important for both monogastric animals and human beings (Huang et al., 2004). The lysine and tryptophan content of 1.81 and 0.35% in the protein of normal maize endosperm is less than one-half of the concentration recommended for normal human nutrition by the Food and Agriculture Organization (FAO) of

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the United Nations (FAO/WHO/UNU Expert Committee, 1985; FAO/WHO Expert Consultation, 1990; Prasanna et al., 2001). Consequently, infants fed on normal maize without any balanced protein supplement suffer from malnutrition and develop diseases such as Kwashiorkor. Considerable progress has been made by the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute of Tropical Agriculture (IITA) in developing quality protein maize (QPM) germplasm with the opaque-2 (o2) gene, incorporated along with modifiers that contain twice the amount of lysine (>4.0%) and tryptophan (>0.8%) in the whole grain compared with normal maize (Krivanek et al., 2007). Therefore, maize cultivars combining high grain yield with elevated levels of lysine, tryptophan and the kernel structure of conventional maize have the potential to reduce food insecurity and malnutrition in the sub region.

The savannas of West and Central Africa (WCA) are characterized by low incidence of diseases and pests and high incident incoming solar radiation and therefore could contribute to the achievement of food security in the sub region. However, the agroecology is plagued by *Striga hermonthica* (Del.) Benth parasitism, recurrent drought, and low soil nitrogen (N) and to a lesser extent, lack of productive and adapted maize cultivars. *Striga* can cause total crop failure and many maize farmers in the savannas have been forced to abandon their farmlands due to severe infestation. Parasitism by *Striga* seems to have defied all cultural control options (Bebawi et al., 1984; Odhiambo and Ransom, 1994; Shaxson and Riches, 1998). The use of host plant resistance is considered the most economically feasible and sustainable approach for reducing the effects of *Striga* (DeVries, 2000).

Global warming and its associated effects have changed weather patterns in SSA leading to erratic and unreliable amount and distribution of rainfall, resulting in recurrent drought (Badu-Apraku et al., 2011a). Drought can reduce grain yield of maize by as much as 90% when it occurs at the most sensitive stage of the crop growth i.e. a few days before anthesis to the beginning of grain filling (NeSmith and Ritchie, 1992). Badu-Apraku et al. (2004) reported a grain yield loss of 53% under drought stress and 42% under *Striga* infestation. Consequently, breeding for early maturing cultivars with better tolerance to drought and resistance to *Striga* is crucial to improve productivity and ensure stable maize production in WCA.

Nitrogen is a major requirement for high levels of maize productivity but it is the most limiting nutrient in tropical soils. A fertilizer rate of 90–120 kg N ha^{-1} is recommended for increased maize grain yield in SSA. However, fertilizer application rates are still far below the recommended doses in the sub region due to the unavailability or the exorbitant prices of inorganic fertilizer for resource-poor farmers. The estimated annual loss of maize yield due to low-N stress varies from 10 to 50% per year in SSA (Logrono and Lothrop, 1997). Breeding for tolerance to low-N offers the most economical and sustainable approach for increased maize yields in WCA.

Under field conditions, drought, *Striga*, and soil nutrient deficiencies can occur simultaneously and the combined effect can be devastating (Cechin and Press, 1993; Kim and Adetimirin, 1997). Bänziger et al. (2006) reported that drought and low-N are the most important stress factors that most frequently limit maize production, food security, and economic growth in SSA. Weber et al. (2012) indicated that complex interactions often occur among the stresses, such as drought hindering nutrient up-take, indicating the need to develop genotypes tolerant to these conditions. The development and use of germplasm with tolerance to multiple stresses are therefore crucial for increased productivity and sustainable maize production in SSA.

A large number of QPM inbred lines have been developed in the IITA Maize Program. However, there are no commercial early maturing QPM hybrids. An important requirement for a hybrid program to be commercially successful is the availability of information on the mode of inheritance, combining ability and heterotic patterns among the inbreds in the program. Results of the evaluation of single-cross hybrids derived from 14 early-maturing QPM inbred lines under well-watered, drought stress and low-N conditions in Eastern Africa showed significant mean squares of GCA for grain yield and other agronomic traits whereas SCA mean squares were not significant (Musila et al., 2010). This suggested that additive gene action for grain yield and other agronomic traits was the most important contributor to the heritable variation in agronomic traits in these genotypes. Results of other studies have indicated preponderance of additive over nonadditive gene action (Vasal et al., 1993a,b; Bhatnagar et al., 2004; Musila et al., 2010; Wegary et al., 2013). However, such important information is completely lacking on the gene action conditioning the grain yield of IITA's early QPM inbreds under drought, low-N or *Striga* infestation. There is, therefore, a need to study the genetics of the inheritance of grain yield and other traits of the IITA early-maturing QPM inbreds under the three stress conditions.

Classification of inbreds into heterotic groups is essential not only for maximizing their potential usefulness in the development of productive hybrids and synthetics but also for creating new heterotic groups. However, the heterotic patterns and the extent of diversity in the *Striga* resistant early QPM germplasm in the IITA Maize Program have not been determined. Furthermore, no early QPM inbred testers appropriate for developing stress-tolerant hybrids are available in SSA. Information on heterotic groups and the identification of testers in the early QPM inbreds would be invaluable to the hybrid program at IITA and the national programs in the sub region.

The objectives of the present study were to (i) examine the combining ability for grain yield and inheritance patterns of the set of tropical early QPM yellow inbreds (ii) classify the inbreds into heterotic groups using the SCA effects of grain yield, HSGCA, the HGCAMT and the molecular-based GD methods and identify the best testers; (iii) compare the efficiencies of the heterotic grouping methods in classifying the inbreds and (iv) determine the performance and stability of the inbreds in hybrid combinations under multiple environments.

2. Materials and methods

2.1. Conversion of normal endosperm maize inbreds to QPM

In an effort to mitigate the effects of the major constraints on maize production and productivity in WCA, since 1980 IITA has developed high yielding early and extra-early *Striga* resistant and/or drought and low-N tolerant normal endosperm populations, varieties, hybrids, and inbred lines. The strategy for converting normal inbreds into QPM focused primarily on crossing elite inbred lines to QPM donor sources to obtain materials with the opaque-2(o2) gene followed by repeated selfing with the selection of minor gene modifiers for kernel quality. Details on the procedure adopted in developing the 14 *Striga* resistant and/or drought tolerant early yellow maturing QPM inbreds have been described by Badu-Apraku et al. (2010). Briefly, 15 normal endosperm elite inbred lines, *Striga* resistant and/or drought tolerant were crossed to the broad-based early yellow QPM source population, Pool 18 SR in 2003, in an effort to introgress *Striga* resistance and drought tolerance genes into the early yellow QPM population and subsequently, to extract *Striga* and drought tolerant QPM inbreds. The F_1 crosses were backcrossed to the inbred parents during the major season of 2005 in Ibadan, Nigeria to obtain BC_1. The BC_1 ears were screened under the light box and kernels with the desirable endosperm modification were selected and advanced to the BC_2 stage during the dry season of 2005. The selection for the appropriate