

Trait association for improved grain yield of extra-early maturing maize hybrids evaluated in the forest and transitional zones of Ghana

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Abstract

The present study used sequential path analysis and factor analysis to determine the interrelationship between grain yield and other agronomic traits of 100 extra-early maturing maize genotypes. The objective was to identify traits with the greatest influence on grain yield for use as selection criteria in future breeding programmes. The coefficient of correlations revealed that grain yield correlated positively with ear aspect, days to anthesis, days to silking, plant height, and number of ears harvested per plot and plant stand. Grain yield was however, negatively correlated to husk cover and ear number per plant. Path analysis identified plant height and number of ears harvested per plot to have a positive direct effect on grain yield while ear number per plant had a negative direct effect on grain yield. Also, plant stand, number of ears harvested per plot and ear aspect were identified to have the greatest influence on yield by factor analysis.

Keywords: Correlation; factor analysis; multiple traits; path analysis; *Zea mays*.

Abbreviations: ASI_ anthesis-silking interval; DA_ days to anthesis; DS_ days to silking; EA_ ear aspect; EH_ ear height; EHARV_ number of ears harvested per plot; EPP_ ear number per plant; GY_ grain yield; HC_ husk cover; n_ sample size; PH_ plant height; PS_ plant stand; RL_ root lodging; R_ residual; R²_ coefficient of determination; SL_ stalk lodging.

Introduction

Maize is one of the most important crops for the agricultural sector and for food security of Ghana. It is the number one crop in terms of area planted and accounts for 50-60% of total cereal production (MiDA, 2010). Annual maize production in the country has increased at an estimated rate of 4.95 % per annum from 2000 to 2014 at a yield of 1.74 t ha⁻¹ (MoFA, 2013; Index Mumdi, 2015). This is quite low compared to the world average yield of 5 t ha⁻¹ (FAOSTAT, 2014). The marginal increase in production over the last decades has come as a result of expansion in the area harvested rather than from increases in yield per unit area. The area harvested has increased steadily from 7 to 10 million hectares from 2000 to 2014 (Index Mumdi, 2015). Increasing production through expansion in the area of land harvested cannot be sustainable given the increase in the demand for agricultural land for other activities per crop in response to population increase. Therefore, it is of great importance to adopt improved technologies to maximize yield. Maize grain production, the primary trait of interest of most breeding programmes is the final outcome of a combination of different plant structures and their interactions with the environment. Since grain yield is quantitatively inherited, it is more difficult to predict than other traits. Thus, grain yield is often partitioned into components or traits that have explanatory value for predicting grain yield (Ross, 2002). Also, the use of secondary trait with grain yield, rather than selection for grain yield alone, has been shown to increase selection

efficiency in maize grown under stress by 20 to 50 % (Bänziger and Lafitte, 1997; Edmeades et al., 1997; Chapman and Edmeades, 1999). Traits such as number of grains per row; 100-grain weight, cob diameter, plant height, ear weight and ear length, are commonly used to predict grain yield (Ross, 2002; Mohammadi et al., 2003; Maman et al., 2004; Samonte et al., 2006). Yield related traits such as biomass, harvest index, plant architecture, and resistance to biotic and abiotic constraints may also indirectly affect yield by affecting the yield component or by other unknown mechanisms (Quarrie et al., 2006). In maize, effective improvements in grain yield have been achieved through the use of selection indices involving useful secondary traits under diverse environments (Edmeades et al., 1998; Menkir and Akintunde, 2001; Badu-Apraku et al., 2003; Badu-Apraku, 2011). Generally, selection based on an index, which is a function of multiple traits that are under selection allows the breeder to consider the mutual effects of several traits on yield at the same time, rather than the independent effects of the individual traits involved. The reliability of a selection index, however, depends greatly on the relative significance of the contribution of each trait on the formation of yield. As the number of traits under consideration in a breeding programme increases, it becomes challenging to determine which traits are most important to yield improvement. In this case, a breeder's in-depth knowledge of interrelationships between grain yield and its contributing components can significantly improve the efficiency of the breeding

programme through the use of appropriate selection indices (Mohammadi et al., 2003).

A review of other research indicates a special importance to determining relationships between yield and its components and also emphasizes on, the type of germplasm used, environmental variations and applied statistical analyses used in this kind of study ultimately influence the results, interpretations and conclusions drawn (Kumar and Kumar, 2000; Mohammadi et al., 2003; Fakorede et al., 2011; Badu-Apraku et al., 2012; Filipovic et al., 2014). Statistical analyses commonly used to study the existing relationships among traits in crop science include simple correlation analysis, linear regression, factor analysis and path analysis (Mohammadi et al., 2003; Badu-Apraku et al., 2012; Filipovic et al., 2014). Simple correlation studies measures the degree of association between two random variables independent of other variables to be considered. Thus, when a large set of variables are involved, this method does not indicate the real interrelationship as the mutual-interference between the individual variables are not considered (Bhatt, 1973). Also, correlation coefficient, the main product of correlation studies simply measures the linear relationship between two variables without providing any information on the cause and effect of such relationships (Abozary, 2002).

Path coefficient analysis allows the separation of correlation coefficient into direct and indirect effects (effects exerted through other variables) through a standardized partial regression analysis of a closed system of linearly related variables (Wright, 1921). The aim of path coefficient analysis is to present an appropriate interpretation of correlation between variables, by creating cause and effect models (Solymanzadeh et al., 2007). However, most path analysis investigations ignore the importance of the causal relationships but usually use a model in which the bidirectional causation among variables is assumed. This conventional path analysis approach might result in multicollinearity, particularly when predictor variables in the model are highly correlated with other predictor variables (Hair et al., 1995). Multicollinearity can cause strange results when attempting to study how well individual predictor variables contribute to an understanding of the dependent variable as the effects of the predictor variables are usually confounded and this may lead to incorrect conclusion of the relationship between independent and dependent variables (Sharma, 1996; Hoe and Kim, 2004). To address this issue, sequential path analysis has been widely used by researchers for determining the relationship between yield and related traits in maize (Agrama, 1996; Mohammadi et al., 2003; Badu-Apraku et al., 2012) and in other crops such as rice (Samonte et al., 1998; 2006) and sorghum (Maman et al., 2004; Ezeaku and Mohammed, 2006).

As a multivariate statistical technique, factor analysis is used to examine the interrelationships among a set of variables with a view to selecting a few of those variables that might influence further responses on other variables. Even though most explanatory variables in biological sciences tend to correlate, relationships between yield components can be different, from absence of significant relationship to almost functional relationship and interaction in compensatory patterns (García Del Moral et al., 2003). In cases where yield components are suspected to interrelate in a complex fashion, factor analysis may be used to untangle the linear relationships into their separate patterns and also define how the patterns overlap by revealing traits that are involved in more than one pattern. Each pattern will appear as a factor delineating a distinct cluster of interrelated traits, factors identified then represent the causes of the patterns

they represent (Rummel, 1970) thereby providing a better understanding of the background structures of yield components as well as their contributions to the formation of principal factors that define yield. This study was aimed at using sequential path analysis and factor analysis to (1.) Determine the interrelationships among grain yield and other agronomic traits of 100 extra-early maturing maize hybrids and (2.) Identify traits with the greatest influence on grain yield for use as selection criteria in future breeding programme.

Results and Discussion

Analysis of variance

The combined analysis of variance showed the differences among environments (E) and genotypes (G) to be significant ($P \leq 0.05$) for almost all traits measured, except for ear number per plant for genotypes. Also, genotype by environment interactions (G x E) were found to be significant ($P \leq 0.05$) for almost all traits measured, except for anthesis-silking interval, grain yield, plant height, root lodging and plant stand (Table 1). These results indicated the presence of variability among genotypes, environments, and also the stability in the genotypic expression of anthesis-silking interval, grain yield, plant height, root lodging and plant stand across the test locations. The magnitude of environmental mean squares observed was higher than genotypic mean squares for all the traits under study (Table 1), indicating great influence of environment on these traits. This result is in agreement with the findings of Badu-Apraku et al. (1995; 2003) and Mohammadi et al. (2009) who also reported similar environmental and G x E effects. Significant G x E has been reported by Comstock and Moll, (1963) to reduce progress from selection of superior genotypes resulting from environmental effects that inhibits the expression of desired traits of genotypes evaluated across diverse environments, implying that the lack of significant G x E mean squares observed for anthesis-silking interval, grain yield, plant height, root lodging and plant stand makes these traits more reliable as part of an index for the selection of superior genotypes as compared with the other traits measured in this study. Table 2 presents basic descriptive statistics [mean, median, standard deviation and coefficient of variation (CV)] of grain yield and the other traits measured at all the three locations. A high value of coefficient of variation was obtained for grain yield (27.86), anthesis-silking interval (30.53), root lodging (47.39), stalk lodging (32.06), ear aspect (37.32) and husk cover (42.27). This result also revealed high levels of genotypic variability among the hybrids for grain yield, anthesis-silking interval, root lodging, stalk lodging, ear aspect and husk cover. The high levels of genetic variability observed for the traits studied with the exception of ear number per plant showed they could be utilized in selection criteria for yield improvement of the different genotypes.

Correlations among traits measured

The correlation studies showed that grain yield (GY) was highly significant ($p < 0.01$) and positively correlated with ear aspect ($r = 0.77$), days to anthesis ($r = 0.41$), days to silking ($r = 0.35$), plant height ($r = 0.65$), ear height ($r = 0.69$), plant stand ($r = 0.48$) and number of ears harvested per plot ($r = 0.45$), implying that a hybrid with optimal ear appearance, longer days to anthesis and silking, taller plants, higher ear placement, and large number of plant stand and ears harvest-

Table 1. Mean squares derived from combined analysis of variance of measured traits of 100 extra-early maturing maize hybrids evaluated at three locations in the deciduous forest and forest-savannah transitional zones of Ghana in 2011 rainy season.

Source of variation	DF	Grain yield (t ha ⁻¹)	Days to silking	Days to anthesis	Anthesis-silking interval	Ear height (cm)	Plant height(cm)	Root lodging
Environment	2	87.27**	198.91**	419.66**	604.87**	37021.17**	82314.59**	61.65**
Reps(Environment)	3	12.47**	31.35**	40.95**	2.48 ^{ns}	1889.12**	3463.34**	1.41 ^{ns}
Blocks (Environment*Reps)	54	1.96**	6.20**	5.57**	1.70 ^{ns}	255.24**	471.36**	1.74*
Genotype	99	5.45**	18.53**	16.24**	1.87*	497.58**	944.57**	2.45**
Environment*Genotype	198	0.84 ^{ns}	5.03**	4.14**	1.56 ^{ns}	87.55**	172.59 ^{ns}	1.54 ^{ns}
Error	243	0.75	2.17	2.37	1.42	61.78	166.86	1.23

Rep is Replication; BLK is Block; * P ≤ 0.05, ** P ≤ 0.01, ns = not significant, respectively

Table 1 cont'd

Source of variation	DF	stalk lodging	Husk cover	Plant stand	Number of ears harvested per plot	Ear number per plant	Ear aspect
Environment	2	1175.50**	63.92**	678.97**	269.02**	0.35**	3.23**
Reps(Environment)	3	18.71**	0.12 ^{ns}	13.87 ^{ns}	34.66*	0.02 ^{ns}	0.25*
Blocks (Environment*Reps)	54	4.75**	0.04 ^{ns}	8.72 ^{ns}	10.25 ^{ns}	0.02 ^{ns}	0.17**
Genotype	99	5.36**	0.09**	17.25**	23.13**	0.02 ^{ns}	0.25**
Environment*Genotype	198	4.07**	0.06**	8.98 ^{ns}	10.42**	0.03**	0.12*
Error	243	2.54	0.04	7.34	7.50	0.02	0.09

Rep is Replication; BLK is Block; * P ≤ 0.05, ** P ≤ 0.01, ns = not significant, respectively.

Table 2. Descriptive statistics of grain yield and other agronomic traits measured in the study.

Trait	Mean	Median	Maximum	Minimum	Standard deviation	CV (%)
Grain yield (t/ha)	5.20	5.14	11.33	0.67	1.45	27.86
Days to anthesis	45.15	45.00	52.00	35.00	2.77	6.14
Days to silking	47.65	48.00	59.00	37.00	2.84	5.82
Anthesis-silking interval	2.54	3.00	10.00	0.00	1.79	30.53
Number of ears harvested per plot	22.07	23.00	38.00	9.00	3.61	16.38
Plant stand	22.19	23.00	35.00	8.00	3.53	15.89
Ear number per plant	1.01	1.00	2.00	0.52	0.16	15.85
Ear height (cm)	92.41	92.00	147.00	41.00	17.75	19.20
Plant height (cm)	183.50	185.00	264.00	95.00	25.81	14.07
Root lodging	1.27	1.00	9.00	0.00	1.37	47.39
Stalk lodging	2.57	2.00	16.00	0.00	2.80	32.06
Ear aspect	2.15	2.00	4.00	1.00	0.73	34.20
Husk cover	1.80	1.00	4.00	1.00	0.96	42.27

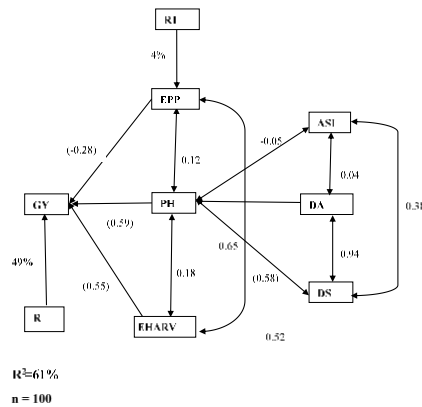


Fig 1. Path analysis diagram showing the contribution of number of ears harvested per plot (EHARV), plant height (PH), ear number per plant (EPP), anthesis-silking interval (ASI), days to anthesis (DA) and days to silking (DS) to grain yield (GY) formation. n sample size; R residual; R^2 coefficient of determination.

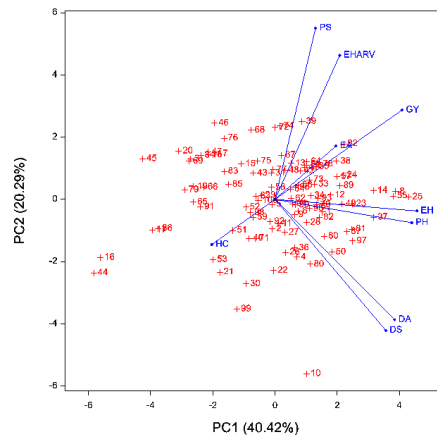


Fig 2. Principal component biplot of yield components of 100 extra-early maturing maize hybrids (names of entry codes are given in Supplementary Table 1) evaluated at three locations in Ghana. DA _days to anthesis; DS _days to silking; EA _ear aspect; EH _ear height; EHARV _number of ears harvested per plot; GY_ grain yield; HC _husk cover; PH _plant height; PS_ plant stand; RL _root lodging; SL _stalk lodging

ed possess high yield potential. The high correlation between grain yield and, plant and ear heights is also reported by Fakorede et al. (2011); khavari et al. (2011); Ashofteh et al. (2012) and Filipovic et al. (2014).

Grain yield was also negatively and significantly correlated with husk cover ($r = -0.31$) and ear number per plant ($r = -0.15$) (Table 3). This result suggests that a hybrid with poor score for husk cover and larger ear number per plant is likely to have low grain yield. An earlier report by Badu-Apraku et al. (2012), showed similar findings except for the negative correlation between grain yield and ear number per plant. The differences in results could be due to the environmental conditions (drought and low soil nitrogen environments) under which their experiments were conducted as against the environment (favourable condition) that was used in this study. Prolificacy in maize (ability of a variety to produce more than one ear per plant) has been reported to be useful in stressful environments (higher plant densities, low soil fertility and moisture stress) (Zuber and Grogan, 1956; Russell and Eberhart, 1968), and of limited importance under favourable environments (Russell, 1968; Otegui, 1995). Nonetheless, under both stressful and favourable environments some non-prolific varieties have been found to produce higher grain yields than those with prolific tendencies (Brathwaite and Brathwaite, 2002). According to Durieux et al. (1993), a prolific variety has a yield advantage

over a non-prolific variety only when it is able to develop larger apical ear. However, prolific varieties are sometimes limited in yield potential in favourable environments because the development of apical ears is restricted by the growth activity of the second ear (Russell, 1968). This may have been the cause of yield reduction associated with increasing ear number per plant as observed among the set of hybrids tested in this study.

The results also showed highly significant interrelationships between the following pairs of traits: Plant height and ear height ($r = 0.88$); Ear height and days to anthesis ($r = 0.63$); Days to anthesis and days to silking ($r = 0.94$); Plant height and days to anthesis ($r = 0.58$); Days to silking and plant height ($r = 0.52$); Ear height and days to silking ($r = 0.57$); Ear aspect and ear height ($r=0.60$); Ear aspect and plant height ($r=0.69$) and ear aspect and number of ears harvested per plot (Table 3). Mashark et al. (2004) reported similar significant positive correlation among days to silking, days to anthesis, ear height and plant height. Based on these results, it is important to note that among all the traits studied, ear aspect ($r = 0.77$) had the highest influence on grain yield followed by ear height ($r = 0.69$) and plant height ($r = 0.65$), which suggested that ear aspect, plant and ear heights determine to a great extent, the grain yield of the hybrids tested, making them important traits to consider in

Table 3. Pearson coefficients of correlation between pairs of measured agronomic traits of 100 extra-early maturing maize genotypes evaluated at three locations in the deciduous forest and forest-savannah transition zones of Ghana in 2011 rainy season.

Traits	GY	ASI	EA	DS	EH	EPP	EHARV	HC	PS	PH	DA	RL	SL
ASI	-0.09 ^{ns}	-											
EA	0.77 ^{**}	-0.33 ^{ns}	-										
DS	0.35 ^{**}	0.38 ^{**}	0.05 [*]	-									
EH	0.69 ^{**}	-0.02 ^{ns}	0.60 ^{**}	0.57 ^{**}	-								
EPP	-0.15 [*]	-0.13 ^{ns}	-0.01 [*]	0.13 ^{ns}	0.18 ^{ns}	-							
EHARV	0.48 ^{**}	-0.19 ^{ns}	0.55 ^{**}	0.03 ^{ns}	0.31 ^{**}	0.65 ^{**}	-						
HC	-0.31 ^{**}	0.25 ^{**}	-0.56 ^{**}	-0.08 ^{ns}	-0.25 ^{**}	-0.27 ^{**}	-0.23 [*]	-					
PS	0.45 ^{**}	-0.05 ^{ns}	0.35 ^{**}	-0.11 ^{ns}	0.17 ^{ns}	-0.32 ^{**}	0.49 ^{**}	-0.01 ^{ns}	-				
PH	0.65 ^{**}	-0.05 ^{ns}	0.69 ^{**}	0.52 ^{**}	0.88 ^{**}	0.12 ^{ns}	0.18 ^{ns}	-0.29 ^{**}	0.07 ^{ns}	-			
DA	0.41 ^{**}	0.04 ^{ns}	0.18 ^{**}	0.94 ^{**}	0.63 ^{**}	0.19 ^{ns}	0.10 ^{ns}	-0.18 ^{ns}	-0.10 ^{**}	0.58 ^{**}	-		
RL	-0.01 ^{ns}	0.04 ^{ns}	-0.05 ^{ns}	0.12 ^{ns}	0.04 ^{ns}	-0.05 ^{ns}	-0.23 [*]	-0.01 ^{ns}	-0.17 ^{ns}	0.13 ^{ns}	0.11 ^{ns}	-	
SL	-0.08 ^{ns}	0.12 ^{ns}	0.02 ^{ns}	0.17 ^{ns}	0.11 ^{ns}	-0.10 ^{ns}	-0.11 ^{ns}	0.03 ^{ns}	-0.02 ^{ns}	0.11 ^{ns}	0.14 ^{ns}	0.35 ^{**}	-

Rep is Replication; BLK is Block; * P ≤ 0.05, ** P ≤ 0.01, ns = not significant, respectively. ASI_ anthesis-silking interval; DA _days to anthesis; DS _days to silking; EA _ear aspect; EH _ear height; EHARV _number of ears harvested per plot; EPP _ear number per plant; GY_ grain yield; HC _husk cover; PH _plant height; PS_ plant stand; RL _root lodging; SL _stalk lodging

Table 4. Factor loadings of grain yield and agronomic traits of 100 extra-early maturing maize hybrids evaluated at three locations in the deciduous forest and forest-savannah transition zones of Ghana in 2011 rainy season.

Traits	Communities	Factor loading		
		1	2	3
Days to anthesis	0.34	0.57	0.07	0.09
Days to silking	0.36	0.58	0.09	0.10
Ear aspect	0.76	-0.12	0.10	-0.86
Ear height	0.22	0.40	-0.17	-0.16
Number of ears harvested	0.46	0.00	-0.61	0.21
Grain yield	0.28	0.17	-0.39	-0.32
Plant height	0.22	0.36	-0.05	-0.27
Plant stand	0.49	-0.11	-0.66	-0.05
Husk cover	0.87	0.03	-0.02	0.02
% variance explained		42.40	20.29	11.95
% Cumulative variance		42.40	62.69	74.64

*values in bold indicate the most relevant character that contributed to the variation of the particular component.

breeding and selection of extra-early maturing maize hybrids in the target environments. Ear aspect, plant height, ear height, days to silking, days to anthesis and number of ears harvested per plot were positively correlated with grain yield and also positively correlated to each other. The strong correlation observed among these traits reveals the existence of collinearity in the data set, which may have affected the exact expression of the influence of each trait on grain yield of the hybrids. In the study, it was observed that an increase in number of ears harvested per plot and days to silking promoted higher grain yield, however, the interrelationships between these two traits and certain traits seem to have adverse effects on grain yield. For instance, although, ear number per plant is positively correlated to number of ears harvested, at the same time it is negatively correlated to grain yield (Table 3). This means that as ear number per plant increases, number of ears harvested per plot increases and as the ear number per plant increases grain yield decreases. Also, days to silking had significantly positive effects on grain yield and anthesis-silking interval, suggesting that the longer it takes a hybrid to silk the higher the grain yield, but at the same time higher anthesis-silking interval adversely affects the grain yield. These results show how such interrelationship among some yield-related traits must have masked the effects of others on grain yield formation. In such situations, simple correlation studies may be insufficient to explain the associations in a way that will enable breeders know the traits to concentrate on during selection. Similar findings on multicollinearity of yield components have been reported in different crops including date palm (*Phoenix Dactylifera* L) (Odewale et al., 2013) and bambara groundnut (*Vigna subterranean*) (Ofori, 1996).

Sequential path analysis of relationships among yield and yield-related traits across locations

The sequential stepwise multiple regression method used in this study reduced the number of collinear variables by selecting from the whole set of yield-related traits a set of traits which influence yield the most. Number of ears harvested per plot (0.55), plant height (0.59) and ear number per plant (-0.28) were identified as traits with high direct effects on grain yield. Together, these traits contributed 61% of the total variation in grain yield (Fig 1). This results implies that a larger yield response can be obtained if selection is based on plant height, number of ears harvested per plot and ear number per plant as compared to selection based on the other yield-related traits. Filipovic et al. (2014) reported highly significant genetic and phenotypic direct effects of plant height on grain yield. Also, plant height was reported by Badu-Apraku et al. (2012) to have a high significant influence on grain yield under drought. Days to silking (0.52), days to anthesis (0.58) and anthesis-silking interval (-0.05) were identified as traits with indirect effects on grain yield via plant height (Fig 1), suggesting that improvement in yield could be achieved indirectly by simultaneously selecting hybrids with increased plant height, longer days to anthesis and silking, and reduced anthesis-silking interval. The identified traits (plant height, number of ears harvested per plot, ear number per plant, days to anthesis and silking and anthesis-silking interval) with the greatest influence on grain yield will provide breeders with a set of key traits to target in selection programmes to make the most progress in grain yield improvement instead of selection based on grain yield alone.

Factor analysis

Figure 2 presents the genotype by trait principal component biplot showing the interrelationship among traits measured across the three locations. In the biplot display, the rays connecting the traits to the biplot origin are described as trait vectors. The cosine of the angle between two vectors approximates the correlation between the traits they represent (Kroonenberg, 1995). The closer the angle is to 90 degrees, the stronger the correlation. An angle of 0 or 180 degrees reflects a correlation of 1 or -1, respectively. The biplot revealed a positive correlation between grain yield and ear aspect, plant stand, number of ears harvested per plot, ear and plant heights. Also, grain yield had a strong negative correlation with husk cover (Fig 2). Furthermore, the biplot revealed a strong positive correlation between grain yield and ear aspect; between plant stand and number of ears harvested per plot; between ear height and plant height; between days to silking and days to anthesis, indicating that information obtained on one of these traits may be sufficient to provide reliable information on the genotypes. Factor analysis was performed in order to better understand the common structure observed among yield components as well as their contribution to the formation of principal factors that define yield. Three main factors were extracted from principal component analysis of nine yield-related traits (days to anthesis, days to silking, ear aspect, number of ears harvested per plot, grain yield, plant height, ear height, plant stand and husk cover). The proportions of the total variance explained by each of the three factors were 42.40%, 20.29% and 11.95%, respectively (Table 4). Together, the three factors accounted for 74.64% of the total variation observed among the hybrids. Factor loadings greater than or equal to 0.30 were considered as the point where selected traits made significant contribution to the formation of a factor. The first factor was positively correlated to days to silking (0.58), days to anthesis (0.57), ear height (0.40) and plant height (0.36). This factor was referred to as the flowering component. The second factor was negatively correlated to grain yield (-0.39), plant stand (-0.66) and number of ears harvested per plot (-0.61). This factor was referred to as the reproductive component. The third factor had negative correlation to ear aspect (-0.86) and grain yield (-0.32). The third factor was called the ear appearance component.

Traits loaded on the first two factors were considered to have influenced the data set the most. These traits included days to silking, days to anthesis, ear height, grain yield, plant stand and number of ears harvested per plot. Since grain yield is equally correlated with the second (0.39) and third (0.32) factors, there is an association between grain yield and the other traits that define these two factors (Table 4). Therefore, it can be concluded that plant stand, number of ears harvested per plot and ear aspect may be very important in selecting extra-early maturing maize hybrids for superior grain yield. This result is in agreement with a report by Tollenaar, (1992) which suggests that since early maturing varieties are normally smaller, produce less leaves, have lower leaf area per plant and presents fewer self-shading problems than late maturing ones, it is important to have a greater number of plants per area for early maturing hybrids to generate the leaf area index that provides maximum interception of solar radiation to attain maximum grain yield.

Both path and factor analyses identified the following groups of traits to be related: days to anthesis, days to silking, plant height and grain yield and, number of ears harvested per plot and grain yield (Table 4 and Fig 1). These result revealed the existence of common structure of yield

components and the possibility of explaining the variability observed in one component based on other remaining components studied. In this study, the degree of prediction of the variability of one trait based on the other traits ranged between 87.00 % for husk cover to 22.00 % for plant and ear heights. Only 28.00 % of variability in grain yield of the hybrids could be explained by the other remaining traits (Table 4). This indicates that grain yield was influenced by other external factors aside the traits studied. Apparently, the results of the combined ANOVA across locations for grain yield showed large mean square for environment (87.27) as compared to genotypic mean square (5.45) (Table 2). This suggests that prevailing environmental conditions at the evaluation sites during the period of this experiment may have been the greatest cause of variability observed among the hybrids for grain yield. Several field evaluations of maize varieties have revealed existence of environmental influences on yield and many important yield components (Filipovic et al., 2013; Fakorede et al., 2011; Badu-Apraku et al., 2012) and as such the need to identify traits associated with improved grain yield performance under target growing conditions.

A comparison of the results of all the multivariate analyses performed in this study revealed a strong association between grain yield and ear aspect, except for path analysis which did not identify ear aspect as a trait with significant influence on grain yield. Failure of the path analysis to identify ear aspect as an important contributor to grain yield, may be attributed to the differences in the different statistics used by the two methods. Path analysis uses partial regression coefficients while the other methods (simple correlation, principal component biplot and factor analysis) uses correlation among traits to identify traits of importance. Also, it is important to note that while path analysis recognizes multicollinearity among traits, the other methods like the biplot only displays the relationship among traits graphically, based on their correlations (Badu-Apraku et al., 2012). For this reason, ear aspect may have been eliminated from the stepwise regression analyses due to the high correlation between ear aspect and plant stand, number of ears harvested per plot, plant and ear heights, as showed by the biplot.

Materials and Methods

Field evaluation

The experiment was conducted during the 2011 major season at three locations namely, Fumesua (70° 38'N, 3° 07'E, 60 m altitude), Ejura (70° 38'N, 10° 37'E, 229 m altitude) and Kpeve (30° 20'N, 0017'E, 69 m altitude) in the deciduous forest and forest-Savannah transition zones of Ghana, respectively. The germplasm used for the study were 100 extra-early maturing maize varieties (maize varieties that reaches physiological maturity within 80 to 85 days), comprising of 98 single-cross hybrids and two (2) open pollinated varieties (Akposoe and Dodzi) as checks.

A standard protocol was adopted at each site during the period of evaluation. Evaluations were done under rain-fed conditions. The genotypes were planted in 10 x 10 lattice design with two replications at each location. The genotypes were grown in 2-row plots of 5 m long, at an inter-row spacing of 75 cm and an intra-row spacing of 40 cm. Three seeds were planted per hill, and later the seedlings were thinned to two seedlings per hill at 4 to 5 leaf stage. Pre-emergence chemical weed control was practiced and comprised of an application of a combination of

Pendimethalin [N-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine] and Gesaprim [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] at 1.5 L ha⁻¹ and 1.0 L ha⁻¹ a.i., respectively, at planting. Hand weeding was also done when necessary to control weeds during the growing period. NPK 15-15-15 fertilizer was applied at the rate of 30 kg N ha⁻¹, 60 kg P₂O₅ ha⁻¹ and 60 kg K₂O ha⁻¹ as basal fertilizer at 1-2 weeks after planting and top-dressed with additional N at 60 kg N ha⁻¹ at four weeks after planting.

Data collection

Data were recorded at all the three locations for the following agronomic and morphological traits: days to anthesis (DA), days to silking (DS), plant height (PH), ear height (EH), root lodging (RL), stalk lodging (SL) and husk cover (HC). Plant height was measured as the distance from the base of the plant to the height of the flag leaf and ear height was measured as the distance from the base to the node bearing the uppermost ear. Days to anthesis and silking were calculated as the number of days from planting to when 50% of the plants had shed pollen and had emerged silks, respectively. Husk cover was rated on a scale of 1 to 5, where 1 = husks tightly arranged and extended beyond the ear tip and 5 = ear tips exposed. Anthesis-silking interval (ASI) was calculated as the difference between the number of days to silking and the number of days to anthesis. Root lodging (RL) was recorded as the number of plants leaning more than 30° from the vertical axis, and stalk lodging (SL) as the number of plants broken at or below the highest ear node. At harvesting, plant stand (PS), number of ears harvested per plot (EHARV), ear aspect (EA), ear number per plant (EPP), field weight and grain moisture were measured per plot at all locations. Plant stand was recorded as the total number of plants harvested per each plot. Number of ears harvested per plot were recorded as the total number of ears harvested per each plot. Ear aspect was scored on a scale of 1 to 5, where 1 = ears with undesirable features and 5 = clean, uniform, large, and well-filled ears. Ear number per plant was obtained by dividing the total number of ears harvested by the plant stand per plot. Field weight was measured as the weight of harvested cobs per plot in kilograms. Moisture percentage of grains was measured using a moisture meter. Grain yield (GY) in each experimental plot was corrected and calculated in tonnes per hectare at 15% grain moisture based on 80% shelling percentage.

Statistical analysis

Analyses of variance (ANOVA) were conducted separately on plot basis for all the traits measured for each location followed by a combined analysis across the three locations using PROC GLM in SAS (SAS Institute, 2001). In the combined analysis of variance, genotypes were considered as fixed effects, while environments, replications, genotype by environment interaction and all other sources of variation were considered as random effects. Data on ear aspect and husk cover were transformed by natural logarithm function before analyses. Pearson coefficients of correlation were calculated using the genotype means of traits measured to determine the causal relationships among traits across the three test locations. Sequential stepwise multiple regressions by Mohammadi et al. (2003) was used to organize the predictor variables into first- and second-order paths based on their respective contributions to the total variation in grain yield (GY) with minimum collinearity. The PROC CORR procedure of SAS was used to compute the correlation

coefficients and the PROC REG procedure for regression analysis. Also, the means of all the traits measured across the three locations were subjected to principal component analysis using correlation matrix procedure. Subsequently, factor analysis was performed using varimax rotation (Genstat, 2009).

Conclusion

The results of correlation studies of grain yield and the other agronomic traits revealed that grain yield correlated positively with ear aspect, days to anthesis, days to silking, plant height, ear height, number of ears harvested per plot and plant stand, but negatively correlated to husk cover and ear number per plant. With exception of husk cover and ear number per plant, the other traits that correlated positively to grain yield were also strongly associated to each other throughout the study. Plant height, number of ears harvested per plot, plant stand and ear aspect identified by path and factor analyses to have the greatest influence on grain yield could be considered as reliable traits for selection for yield improvement of extra-early maturing hybrids. The magnitude of environmental variance observed was greater than genotypic variance for all traits measured showing pronounced effects of environment on the traits, which may limit the heritability of the identified traits as well as reduce the correspondence of their phenotypic and genetic correlations. Thus, in order to enhance the reliability of secondary traits in selecting hybrids with higher yield there is the need to identify such traits under environmental conditions in which the hybrids will be grown.

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