Research Application Summary

Variability and associations of grain filling traits with grain yield and yield components in CIMMYT maize inbred lines

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Abstract

Improved grain filling rate and grain filling duration are yield components that have potential to increase maize yield in early maize germplasm. These two factors have not been well studied in maize and thus cannot be easily exploited in improving maize yield. This study was therefore carried out to determine genetic variability of grain filling rate and grain filling duration and their associations with yield and yield components in early maize germplasm. Maize was planted early and late. Maize cobs were harvested weekly from a single plant per plot starting two weeks after pollination, and a sample of grains dried to constant weight and weighed. A log linear equation was fitted on the percentage dry matter content per sample per week and used to predict the lag phase duration (LPD), the linear phase duration (also called the effective grain filling duration) (EGFD) and the final phase duration (FPD). Across environments analyses of variance showed significant differences ($P<0.001$), high broad sense heritability, low error and G x E variance component but high genotype variance component for all traits recorded such as GY, GFR and EGFD except LA. There were significant differences between the mean of the high yielding group and the lower yielding group. The high yielding group flowered (both anthesis and silking) earlier. GY was positively correlated with 1000 kernel weight ($r=0.67$), GFR ($r=0.61$), EGFD ($r=0.47$) and TGFD ($r=0.52$) as well as ASI ($r=0.26$). However, GFR and EGFD were negatively correlated ($r= -0.40$. Therefore, selection for longer TGFP, high GFR and shorter ASI without extending DPM can improve the yield of early maize.

Key words: Anthesis, grain filling, maize yield, silking, yield components

Résumé

Le taux de remplissage en grains amélioré et la durée de remplissage en grain améliorée sont les composantes du rendement qui ont un potentiel pour augmenter le rendement du maïs dans du matériel génétique précoce du maïs. Ces deux facteurs n'ont pas été bien étudiés dans le maïs et ne peuvent donc pas être facilement exploités pour améliorer le rendement du maïs. Cette étude a ainsi été réalisée afin de déterminer la variabilité génétique du taux de remplissage en grains et de la durée de remplissage en grains et de leurs associations au rendement et aux composantes du rendement dans le matériel génétique précoce du maïs. Le maïs a été planté tôt et tard. Les épis de maïs ont été récoltés hebdomadairement à partir d'une seule plante par parcelle à partir de deux semaines après la pollinisation, et un échantillon de graines séchées à poids constant et pesé. Une équation log-linéaire a été ajustée sur le contenu en pourcentage de la matière sèche par échantillon par semaine et utilisée pour prédire la durée de la phase de latence (LPD), la durée de la phase linéaire (également appelée la durée efficace de remplissage en grains) (EGFD) et la durée de la phase finale (FPD). A travers des environnements, les analyses de la variance ont montré des différences significatives (P <0,001), une haute héritabilité au sens large, une faible erreur et une composante G x E de la variance, mais une grande composante de la variance du génotype pour tous les caractères enregistrés tels que GY, GFR et EGFD sauf LA. Il y avait des différences significatives entre la moyenne du groupe à haut rendement et le groupe à rendement faible. Le groupe à haut rendement fleurit (à la fois lors de la floraison et l'apparition des soies) plus tôt. GY était positivement corrélée avec le poids de 1000 grains (r = 0,67), GFR (r = 0,61), EGFD (r = 0,47) et TGFD (r = 0,52) ainsi que l'ASI (r = 0,26). Toutefois, GFR et EGFD étaient négativement corrélés (r = -0,40). Par conséquent, la sélection pour un TGFP plus long, une haute FGFP et une plus courte ASI sans étendre la DPM peut améliorer le rendement du maïs précoce.

Mots clés: Floraison, remplissage en grains, rendement du maïs, apparition des soies, composantes du rendement

Background

Despite the low yielding ability of early maize compared to late maturity ones, the land area planted to early maize has continued to rise in southern Africa (Langyintuo and Setimela, 2007). Early maturity maize plays a crucial role in the food and farming systems of many households since it provides food early in the season and escape late season drought, making it ideal for delayed planting. Early maturity maize is relatively smaller, has fewer leaves, short growing period and a shorter total grain filling duration, and hence reduced yield capacity. Genetic variability for most yield determining traits in maize have been fully exploited (Lee and Tollenar, 2007) except grain filling traits (Wang *et al*., 1999). Grain filling rate and grain filling duration could be used as indirect selection tools for high yield in early maize. However, these traits are not well studied (Wang *et al*., 1999) to support the breeding activities. The aim of this study was to determine genetic variability of grain filling rate and grain filling duration and their associations with yield and yield components in early maize germplasm.

Literature Summary

The term 'early maturity maize' refer to maize genotypes that take up 65 days to anthesis and 130 days to maturity as according to CIMMYT classification (Magorokosho *et al*., 2009). Grain yield in maize is a function of grain number, size and weight (Lee and Tollenaar, 2007). Grain number is determined by plant growth rate during silking, ear length and number of kernel rows per ear. Kernel weight is a heritable trait dependent on dry matter accumulation (Borras *et al*., 2009). Grain filling starts after fertilization and progress until physiological maturity (Lee and Tollenaar, 2007). Grain filling occurs in three stages that is, lag phase (rapid cell division and differentiation), linear phase (rapid dry matter accumulation) and maturation phase drying. Over 90% of the total dry matter in the grain is accumulated during the linear phase (Lee and Tollenaar, 2007). The length of the linear grain filling phase is therefore considered the effective grain filling period duration. Grain filling rate is influenced by accumulation of photo-assimilates and their partitioning (Lee and Tollenaar, 2007). Indirect selection is effective in improving complex traits such as grain yield. However, genetic variability for grain filling rate and effective grain filling duration have not been fully exploited to improve productivity.

Study Description

Eighteen CIMMYT maize inbred lines were planted at CIMMYT-Harare, in alpha-lattice design with two replications. Two environments were created by early planting one trial with irrigation and having the second trial under rain fed conditions. Maize cobs (ears) were harvested weekly from a single plant per plot starting two weeks after pollination. From each cob, 10g of grain fresh mass were oven dried at 60^{o}C for 24h to a constant weight. The procedure was repeated weekly until the maize reached physiological maturity. A log linear equation Y= ln (x) + a, was fitted on the percentage dry matter content per sample per week, where Y is the percentage of dry matter at sampling time x, b is the slope of the curve (rate of percentage dry matter increase on a log scale) and x is the sampling point in time. The start of the linear phase is when the maize kernels reach 87% moisture content and end when the kernels reach 36% moisture content (Borras *et al*., 2009). The equation was used to predict the lag phase duration (LPD), the linear phase duration (also called the effective grain filling duration) (EGFD) and the final phase duration (FPD). The grain filling rate (GFR) (g day^{-1}) was calculated as the final grain yield per plant divided by the EGFD. Days to physiological maturity (DPM) were recorded as the days from sowing until the kernels develop a black layer at the point of their attachment to the cob. The total grain filling duration (TGFD) was calculated by subtracting the days to silking from the DPM. Days to anthesis (AD), silking date (SD), anthesis-silking interval (ASI), plant height (PH), number of rows per cob (RC), number of kernels per row (KR), total leaf number (TLN), leaf area (LA) and grain yield (GY) per plant were recorded.

Analyses of variance were performed on all traits using the mixed model as implemented in SAS software 9.2 version (SAS, 2009). A t-test was used to compare the mean performances for grain yield and other traits between the top nine and the bottom nine yielding group. Phenotypic and genotypic correlation coefficients and genotypic path analyses among grain yield and other traits were calculated as described by Singh and Chaudhary (2004).

Research Application

Across environments analyses of variance showed significant differences ($P<0.001$), high broad sense heritability, low error and G x E variance component but high genotype variance component for all traits recorded such GY, GFR and EGFD except LA.

There were significant differences between the mean of the high yielding group and the lower yielding group for grain yield ($P<0.001$), GFR ($P<0.05$), FPD ($P<0.05$), TGFD ($P<0.05$) and 1000 kernel weight ($P<0.01$). The high yielding group had an average yield of 3.4t/ha while the lower yielding group had 2.4t/ha.

The high yielding group of inbred lines had 42.6% more grain yield, 23.6% more grain filling rate, 10.7% longer EGFD, 4 days longer TGFD and 24% more kernel weight. Furthermore, the top yielding group flowered (both anthesis and silking) 6 days earlier. GY was positively correlated with 1000 kernel weight (r=0.67), GFR (r=0.61), EGFD (r=0.47) and TGFD (r=0.52) as well as ASI (r=0.26). However, GFR and EGFD were negatively correlated (r= -0.40) (Table 1). ASI was positively correlated with KR, while KR was positively correlated with GFR (r=0.64).

The direct effects on grain yield of GFR (0.93), TGFD (0.80) and ASI (0.23) were positive and large, accounting for the correlation between GY and these traits (Table 2). However, direct effects of TGW, EGFD, RC, KR, PH, LPD, FPD, TLN, AD, SD and LA were either negligible or negative. TGFD had an indirect effect (0.41) on grain yield via TGW whereas ASI had an indirect effect (0.14) on grain yield via GFR (Table 2).

Yield difference between the high and low yielding groups of inbred lines is attributed to GFR, TGFD and 1000 kernel weight. Variability for other traits including LA, RC and KR have been fully exploited through breeding efforts (Lee and Tollenaar, 2007). However, the genetic variability for GFR, EGFD, TGFD and ASI still holds much promise in further genetic improvement of grain yield (Wang *et al*., 1999). Improving the yield of early maize can be achieved by increasing the GFR and lengthening the TGFD within the days to physiological maturity and shortening ASI. Shorter ASI improves kernel set and increases the GFR and hence yields. Longer filling duration imply more dry matter accumulation and hence high kernel weight that translate into high yield. The high yielding ability of late maturity hybrids is attributed to long TGFP thus increasing the filling period without extending the days to physiological maturity can improve grain yield. Grain yield depends on kernel weight, which in turn is influenced by dry matter accumulation rate (GFR). However, the existence of the negative correlation between GFR and EGFD complicates their simultaneous improvement. Further, there is need to find out if some hybrids could compliment high GFR from one inbred parent and longer EGFD from another. Positive direct effects of GFR, TGFD and ASI that were equal or higher than the genotypic correlations suggest that direct selection of these traits will improve grain yield (Singh and Chaudhary, 2004). The lower error term and the GxE

Table 1. **Genotypic (lower diagonal) and phenotypic (upper diagonal) correlation coefficients.**

	Grain yield (g per plant)	1000 kernel weight (grams)	Grain filling rate (g per day)	Effective grain filling duration (days)	Lag phase duration (days)	Final phase duration (days)	Total grain filling duration (days)	Rows perear	Kernels perear	Plant height (cm)	Total leaf number	Leaf area (cm^2)	Anthesis date	Silking date	Anthesis-silking interval (days)
Grain yield (g per plant)	1.00	0.60	0.61	0.42	-0.05	0.21	0.49	0.28	0.34	0.12	-0.02	0.20	-0.45	-0.48	0.25
1000 kernel weight (grams)	0.67	1.00	0.11	0.55	-0.16	0.15	0.49	-0.23	-0.29	-0.13	-0.34	-0.10	-0.45	-0.40	-0.05
Grain filling rate (g per day)	0.61	0.15	1.00	-0.44	0.55	0.15	0.18	0.49	0.61	0.23	0.47	0.16	-0.36	-0.48	0.53
Effective grain filling duration (days)	0.47	0.53	-0.40	1.00	-0.62	0.06	0.43	-0.28	-0.32	-0.14	-0.54	0.02	-0.16	-0.07	-0.29
Lag phase duration (days)	-0.06	-0.19	0.57	-0.63	1.00	-0.12	0.36	0.04	0.17	0.12	0.58	0.22	-0.49	-0.59	0.47
Final phase duration (days)	0.25	0.15	0.07	0.23	-0.18	1.00	0.37	0.48	-0.05	-0.75	-0.47	-0.23	-0.36	-0.30	-0.13
Total grain filling duration (days)	0.52	0.52	0.21	0.45	0.34	0.43	1.00	-0.04	-0.18	-0.35	-0.16	0.16	-0.86	-0.83	0.14
Rows per ear	0.30	-0.21	0.59	-0.34	0.05	0.61	-0.07	1.00	0.41	-0.03	0.21	0.24	0.05	0.01	0.10
Kernels per ear	0.36	-0.38	0.79	-0.45	0.27	-0.04	-0.20	0.43	1.00	0.26	0.37	0.27	0.15	0.06	0.28
Plant height (cm)	0.11	-0.24	0.30	-0.21	0.16	-0.90	-0.40	-0.06	0.26	1.00	0.71	0.29	0.36	0.27	0.24
Total leaf number	-0.01	-0.32	0.55	-0.60	0.61	-0.58	-0.20	0.22	0.46	0.77	1.00	0.25	0.22	0.03	0.64
Leaf area (cm^2)	0.37	-0.13	0.38	-0.01	0.35	-0.34	0.23	0.36	0.50	0.42	0.31	1.00	0.02	0.01	0.02
Anthesis date	-0.48	-0.47	-0.42	-0.15	-0.51	-0.42	-0.87	0.05	0.14	0.38	0.24	0.05	1.00	0.96	-0.12
Silking date	-0.51	-0.42	-0.55	-0.04	-0.61	-0.35	-0.83	0.03	0.05	0.29	0.05	0.05	0.97	1.00	-0.39
Anthesis-silking interval (days)	0.26	-0.06	0.64	-0.39	0.49	-0.18	0.05	0.08	0.37	0.25	0.72	-0.01	-0.12	-0.36	1.00

Genotypic and phenotypic correlations were calculated based on genotype means across locations. The r critical values at 10%, 5% and 1% levels are 0.39, 0.46 and 0.58, respectively.

Table 2. Direct and indirect effects of grain filling and related traits on grain yield.

	1000 kernel weight (grams)	Grain filling rate (g per day)	Effective grain filling duration (days)	Lag phase duration (days)	Final phase duration (days)	Total grain filling duration (days)	Rows perear	Kernels perear	Plant height (cm)	Total leaf number	Leaf area (cm^2)	Anthesis date	Silking date	Anthesis-silking interval (days)
1000 kernel weight (grams)	-0.02	0.00	-0.01	0.00	0.00	-0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00
Grain filling rate (g per day)	0.14	0.93	-0.37	0.52	0.06	0.20	0.54	0.73	0.28	0.51	0.35	-0.39	-0.51	0.59
Effective grain filling duration (days)	-0.06	0.05	-0.12	0.07	-0.03	-0.05	0.04	0.05	0.03	0.07	0.00	0.02	0.00	0.05
Lag phase duration (days)	0.19	-0.57	0.64	-1.00	0.18	-0.35	-0.05	-0.27	-0.16	-0.61	-0.36	0.51	0.61	-0.49
Final phase duration (days)	-0.06	-0.03	-0.09	0.07	-0.38	-0.17	-0.23	0.02	0.35	0.22	0.13	0.16	0.13	0.07
Total grain filling duration (days)	0.41	0.17	0.35	0.27	0.34	0.80	-0.06	-0.16	-0.32	-0.16	0.19	-0.69	-0.66	0.04
Rows per ear	-0.02	0.06	-0.03	0.00	0.06	-0.01	0.10	0.04	-0.01	0.02	0.03	0.01	0.00	0.01
Kernels per ear	0.03	-0.06	0.04	-0.02	0.00	0.02	-0.03	-0.08	-0.02	-0.04	-0.04	-0.01	0.00	-0.03
Plant height (cm)	-0.02	0.03	-0.02	0.01	-0.08	-0.03	-0.01	0.02	0.09	0.07	0.04	0.03	0.03	0.02
Total leaf number	0.07	-0.13	0.14	-0.14	0.14	0.05	-0.05	-0.11	-0.18	-0.23	-0.07	-0.06	-0.01	-0.17
Leaf area (cm^2)	-0.01	0.04	0.00	0.03	-0.03	0.02	0.03	0.05	0.04	0.03	0.09	0.00	0.00	0.00
Anthesis date	0.14	0.12	0.04	0.15	0.12	0.25	-0.02	-0.04	-0.11	-0.07	-0.01	-0.29	-0.28	0.03
Silking date	-0.10	-0.14	-0.01	-0.15	-0.09	-0.21	0.01	0.01	0.07	0.01	0.01	0.24	0.25	-0.09
Anthesis-silking interval (days)	-0.01	0.15	-0.09	0.11	-0.04	0.01	0.02	0.08	0.06	0.16	0.00	-0.03	-0.08	0.23

variance component suggest that these traits could be used to accurately predict grain yield in preliminary yield trials.

Recommendation

Selection for longer TGFP, high GFR and shorter ASI without extending DPM can improve the yield of early maize. The methodology for estimating GFR and EGFD need improvement by determining the actual start and end of linear phase. Dry matter at physiological maturity divided by EGFD should give an estimate of GFR independent of GY. Further work must establish inbred-hybrid correlations, heritability values and a selection index for grain yield.

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