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Breeding Progress for Grain Yield in a Decade of Highland Maize Breeding in Ethiopia

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Abstract

The high altitude sub-humid agro-ecology, including the highland transition and true highlands, is next to the mid-altitude agro-ecology with greater production in Ethiopia. The crop is increasingly grown to typical highlands of Ethiopia where it has been a minor crop in the past. Since the establishment of the highland maize breeding program at Ambo Plant Protection Research Center in 1998 as a collaborative project between CIMMYT and National Agricultural Research Systems in east and central African countries, seven (six hybrids and one OPV) cultivars were released for wide production. This study was, therefore, initiated with the objective of determining the genetic gain of grain yield obtained from the release of the highland cultivars for the last one decade. The annual genetic gain in grain yield for breeding period of 2005-2016 was found to be 267 kg ha^{-1} $year^{-1}$.

Keywords: High lands; Crop; Ethiopia; Research; Breeding; Maize; Agricultural; Genetic gain

Abbreviations: CIMMYT: Collaboration with the International Maize and Wheat Improvement Center; EIAR: Ethiopian Institute of Agricultural Research; ASARECA: Association for Strengthening Agricultural Research in East and Central Africa; DAP: Di-ammonium Phosphate; GY: Grain Yield; CSA: Central Statistical Agency; OPV: Open Pollinated Variety; NARS: National Agricultural Research Systems; MERCI: Modernization of Ethiopian Research on Crop Improvement; masl: Meters Above Sea Level.

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Introduction

The demand for maize has been steadily growing in Ethiopia. Maize contributes to the greatest share of production and consumption along with other major cereal crops such as *tef (Eragrostis tef* (Zucc.) Trotter), wheat *(Triticum aestivum L.)* and *sorghum (Sorghum bicolor L.)*. Its production has been increasing over the years in the major maize producing regions of Ethiopia. In the 1980s, the total production was below 2 million tones and the maize area was slightly more than 1 million hectares [1]. However, significant increase in production and productivity were observed in the 1990s. The annual growth rates of yield per hectare, maize area, and total production were 3.1%, 7.1% and 11.3%, respectively [2]. Recent reports of the Central Statistical Agency of Ethiopia showed that maize was produced on about 2.1 million hectares giving a total production of about 7.2 MT with average yield of 3.4 in 2014 main cropping season [3]. In general, the area under maize has increased by about 50% and production by 68%, with the national average yield increasing from 1.6 to 3.4 t ha^{-1} over the last 25 years. Ethiopia's current national maize yield is 3.67 metric tons per hectare [4].

In Ethiopia, maize growing agro-ecologies are broadly classified into four major categories: mid-altitude sub-humid (1000-1800 metres above sea level [m.a.s.l.]), highland sub-humid (1800-2400 m.a.s.l.), lowland moisture stress areas (300-1000 m.a.s.l.) and lowland sub-humid (<1000 m.a.s.l.) [5]. Currently, the National Maize Research Program has three main breeding stations located in the above three major agro-ecologies excluding the lowland sub-humid agro-ecology. Several improved OPVs and hybrids with resistance to certain biotic stresses were released for large scale production across different agro-ecologies by these breeding centers of the National Maize Research Program of the Ethiopian Institute of Agricultural Research (EIAR). The high altitude sub-humid agro-ecology, including the highland transition and true highlands, is next to the mid-altitude agro-ecology with greater maize area and production in Ethiopia. This agro-ecology covers an estimated 20% of the land devoted to annual maize cultivation and consisted of more than 30% of small-scale farmers who depend on maize production for their livelihoods [6].

The Ethiopian highland maize breeding program is situated at Ambo to coordinate maize research and technology development for the highland agro-ecologies. This program was initiated in 1998 in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) and National Agricultural Research Systems (NARS) of east and central African countries including Ethiopia, Kenya, Tanzania, Uganda, Rwanda, and Burundi. Research and variety development of highland maize has generally lagged behind other agro-ecologies. In the region, maize varieties commonly grown beyond 2000 meters above sea level (m.a.s.l.) have been local varieties with low yield potential [7,8]. The crop has been increasingly grown to the highlands of Ethiopia where it had been a minor crop in the past [9]. Consequently, the highland maize breeding program was initiated to develop a pool of both highland conventional and QPM improved germ plasm for the region.

In addition to the collaborative project with CIMMYT, the program has also been supported by the Staple Crops Program of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) through grants to meet food security in the region. The synergetic research efforts of the member countries and partner institutions helped the release of cultivars adapted to the highland agro-ecologies in the region in general, and Ethiopia in particular [10,11]. To meet the needs for increasing maize production in the highlands, the breeding program released seven superior highland maize cultivars (six hybrids and one OPV) from 2005 to 2016. Therefore, this study was initiated with the objective of determining the genetic gain of grain yield obtained from the release of the highland cultivars for the last one decade.

Materials and methods

Study sites, experimental design and field management

Three sets of a trial consisting of five hybrids and one open pollinated variety (OPV) for highland sub-humid agro ecology had been organized and sent for planting at three highland sub-humid representative locations, *viz*., Ambo agricultural Research Center (8°57' N, 38°07' E, 2225 m above sea level [masl]), Kulumsa Agricultural Research Center (8°13' N, 39°13' E, 2180 masl), and Holetta Agricultural Research Center (9°00' N, 38°30' E, 2400 masl). The experiments were conducted under rain-fed conditions during the main rainy season of 2016 at all the three locations. The long-term total annual rainfall of Ambo is 1115 mm, and average minimum and maximum temperatures are 11.7°C and 25.4°C, respectively. The long-term total annual rainfall at Kulumsa is 824 mm, with average minimum and maximum temperatures of 10°C and 23°C, respectively. As for Holetta, the long-term total annual rainfall is 1065 mm and 6.4°C and 22.1°C are the average minimum and maximum temperatures, respectively.

The experiments were laid out in randomized complete block design, with three replicates. Each entry was planted in a two-row plot of 5.25 m long, and 0.75 m apart with a distance of 0.25m between plants within a row. The trials were hand planted with two seeds per hill, and later thinned out to one seed per hill to get a total plant population of 53,333 per hectare. Fertilizers were applied as Di-ammonium Phosphate (DAP) and urea as per the specific recommendations of the areas (Table 1).

Agro-ecology	Testing locations	Cultivar name	Type	Year of release	Maturity group
Highland sub humid agro-ecology of Ethiopia	Ambo Holetta Kulumsa	Hora (AMB02SYN1)	Open pollinated variety	2005	Intermediate
		Arganne (AMH800)	Top-cross hybrid	2005	Intermediate
		Wenchi (AMH850)	3-way cross hybrid	2007	Intermediate
		Jibat (AMH851)	3-way cross hybrid	2009	Intermediate
		Webi (AMH760Q)	3-way cross QPM hybrid	2012	Late
		Kolba (AMH853)	3-way cross hybrid	2016	Intermediate

Table 1: High land maize cultivars and testing sites used for the study.

Data collection and analysis

Unshelled grain weight obtained from a plot was used to estimate grain yield (GY). The field weight was adjusted to 80% shelling percentage and 12.5% grain moisture content and expressed in t ha^{-1}. Grain yield data were subjected to both individual and combined analysis of variance using PROC GLM procedure in SAS 9.1 [12]. Then the mean yield obtained at Ambo for each cultivar was used for regression analysis. The relationship between grain yield of maize cultivars and year of breeding (expressed as number of years since the first release in 2005) was determined using regression analysis.

Results and discussion

Analyses of variance and performance of cultivars

The combined analysis of variance for grain yield of the six maize cultivars evaluated at three locations is presented in Table 2.

Sources of variation	df	Mean Squares	*F* - Value	Pr > F
Location-Loc	2	59.2989796	106.96	<.0001
Replication$_{\text{(within Loc)}}$	6	1.2256870	2.21	0.0695
Genotypes-Geno	5	6.6202463	11.94	<.0001
Geno*Loc	10	1.7571974	3.17	0.0069
Error	30	0.5543826		
$R^2_{\text{(model)}} = 0.91$				

Table 2: Anova of combined analysis for grain yield.

The analysis showed highly significant differences ($p< 0.01$) in grain yield performances among the cultivars. There were also significant variations among the three locations ($p< 0.01$) and their interaction with genotypes ($p< 0.01$). This implied that there was genotype x environment (G x E) interaction affecting the performance of the cultivars resulting in rank differences from location to location.

Across locations analyses showed average grain yield of nearly 6.0 t ha^{-1} with maximum and minimum yields of 7.1 t ha^{-1} and 5.0 t ha^{-1}, respectively. A maximum grain yield of 9.8 t ha^{-1} was recorded at Ambo while a minimum (3.7 t ha^{-1}) was noted at Kulumsa. About 50% of the six cultivars at Ambo, 33% at Holetta and 50% at Kulumsa had higher grain yield than their overall mean for the respective locations. Also, in the combined means, 50% of the six cultivars had better grain yield value than across locations grand mean Table 3.

Cultivars	Locations			
	Ambo	Holetta	Kulumsa	Combined
AMB02SYN1 (HORA)	6.34	4.35	4.21	4.97
AMH800 (ARGANE)	6.96	4.35	3.75	5.02
AMH850 (WENCHI)	7.84	4.92	6.44	6.40

AMH851 (JIBAT)	8.83	5.97	4.65	6.48
AMH760Q (WEBI)	8.38	4.97	3.66	5.67
AMH854 (KOLBA)	9.83	6.69	4.87	7.13
G. Mean	8.03	5.21	4.60	5.95
P	**	***	**	**
Lsd $_{(0.05)}$	2.05	0.91	1.22	0.80
CV $_{(\%)}$	12.3	8.3	16.6	12.6

Table 3: Mean table for grain yield (t ha^{-1}) at individual and across site analyses in 2016.

It is important to note here that the inferior performance of cultivars at two (Holetta and Kulumsa) of the three locations was attributed to the adverse effects of frost damage and late sowing, respectively, during the evaluation year.

Genetic gain estimate for grain yield

The genetic gain for grain yield was determined based on the yield data obtained from location-Ambo in 2016. The reason of using only Ambo data was because of the expectation that the cultivars could not express their inherent yield potential under stress conditions experienced at the other two locations. From the regression analysis, it was depicted that the annual genetic gain for grain yield from 2005 to 2016 was 267 kg ha^{-1} year^{-1} (Figure 1), while the average rate of annual increases in grain yield (Relative genetic gain = % per year) was -0.05 %. The low rate of annual increase could be due, in part, to slow rate of variety release by the breeding program and narrow genetic variability for yielding potential of the parents constituted in the released highland cultivars. Genetic gain study by [13] showed the improvement in grain yield of maize inbred lines, on average, was estimated to be 1.4 % per year, or 39.3 kg ha^{-1} year^{-1}. Grain yield improvement in tropical maize inbred lines is lower than 2% per year [14] or 6 % per breeding cycle [15] reported for temperate maize inbred lines. According to [13], the lower yield improvement rate in CIMMYT's tropical maize inbred lines is probably due to the germ plasm used for the development of the inbred lines as well as the smaller scope of resources invested in tropical maize improvement in Africa.

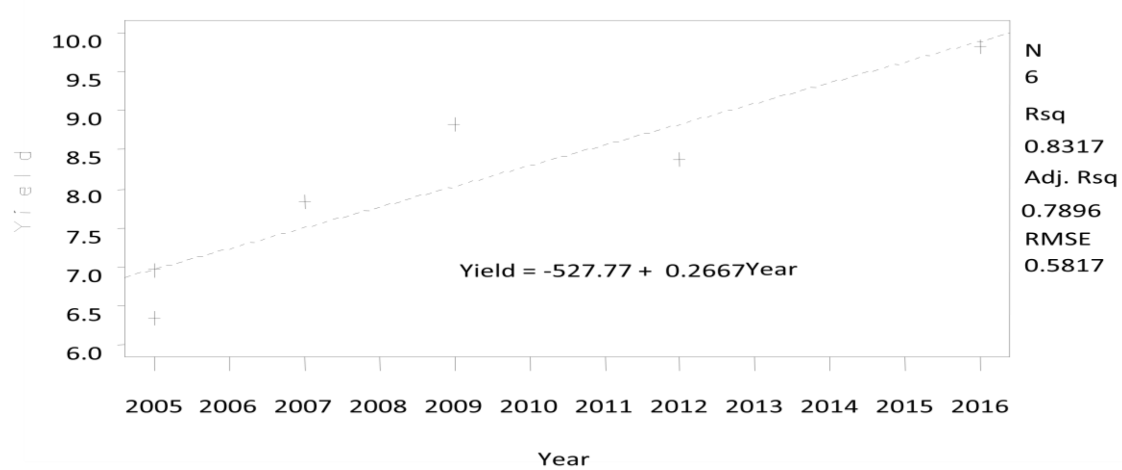

Figure 1: Regression analysis of mean grain yield on year of release of highland maize cultivars in a trial conducted at Ambo in 2016.

Conclusion

The study depicted that the annual genetic gain for grain yield from 2005 to 2016 was 267 kg ha^{-1} year^{-1}, while the average rate of annual increases in grain yield (Relative genetic gain = % per year) was -0.05 %. Consequently, generating maize inbred lines using fast methods (e.g., elite inbred line recycling, and/or DH technology) which enable the development of large number of fixed inbred lines within short period of time for cultivar development, together with maintenance of genetic diversity by incorporation of exotic source germ plasm in newly developed inbred lines and monitoring the genetic diversity will be important to ensure long-term genetic gain.

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