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Genetic gain of maize (*Zea mays* L.) varieties in Ethiopia over 42 years (1973 - 2015)

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Currently under production, thirty-eight Ethiopian maize varieties released majorly for three agro-climatic zones over the past thirty-nine, twenty-nine and twelve years for the high altitudes, mid–altitudes and low altitudes, respectively, were conducted at three different research center's field trials, using randomized complete block design with three replications in 2015 main cropping season to estimate the genetic gains made on yield and yield related traits. The regression analysis indicated average annual and annual relative genetic gains of 62.3 (0.19%), 59.0 (0.57%) and –2.64 (–0.16%) in kg ha^{-1} yr^{-1} for grain yields, respectively, at Ambo Plant Protection Research Center (APPRC), Bako National Maize Research Center (BNMRC) and Melkassa Agricultural Research Center (MARC). Correlational analysis on the field studied traits indicated positively significant associations of grain yields with grain filling rate, ear length, number of kernels per row, number of ears per plant, biomass production rate, biomass yield and harvest index; also, negatively significant associations were shown for days to anthesis and days to silking at APPRC. Grain yield showed positively significant associations with ear length, plant height, grain filling rate, thousand kernel weight, biomass production rate and harvest index at BNMRC, while those only with harvest index were shown at MARC. Relatively considerable genetic gains and inconsiderable genetic reductions due to grain yields, grain yield related traits and grain yields associations with the other studied maize breeding traits had been observed across the released maize varieties from the three agro–ecological zones of Ethiopia.

Key words: Annual genetic gains, annual relative genetic gains, correlational analysis, highland maize, lowland maize, mid–altitude maize, regression analysis.

INTRODUCTION

Maize (*Zea mays* L.) arrived in Africa through various introductions as long ago as 500 years (McCann, 2005).

Since its introduction to Africa, maize has thus become the number one crop in Africa both in cultivated area and

total grain production (FAOSTAT, 2015). It is believed that maize was first introduced to Ethiopia in the 16th or 17th century (Haffnagel, 1961). Since its introduction, it has gained importance as a food and feed crop in the country, which has remained being considered as one of the priority crops in an effort to meet the food demand of the country's increasing population.

In Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowlands to the highlands (Kelemu and Mamo, 2002). Amongst the cultivated major cereal crops of Ethiopia, maize ranks second to *teff* [*Eragrostis tef* (Zucc.)] in area and first in production. Maize remained to be the largest and most productive crop, leading the major cereal crops in Ethiopia since the mid–1990s in terms of both crop yield and production. Over the last decades, maize coverage has reached 2.4 million ha from being a mere garden crop to an economical cereal crop in Ethiopia. The trends in national maize productivity levels show a small but consistent increase from about 1.5 t ha^{-1} in the early 1990s to 2.3 t ha^{-1} in the late 2000s (CSA, 2015).

Maize research in Ethiopia started in the early 1950s and passed through distinct stages of research and development (Kebede et al., 1993). Since 1973, the maize research program of Ethiopia has been receiving International Maize and Wheat Improvement Center (CIMMYT) germplasms (Mosisa et al., 2001). In the late 1990s, the breeders began to develop inbred lines from different source materials using the pedigree breeding method. Currently, the maize breeding program introduces fixed or intermediate (semi–processed) inbred lines from international research institutes such as the CIMMYT and International Institute of Tropical Agriculture (IITA) (Legesse et al., 2012).

In Ethiopia, right from the beginning of the comprehensive maize breeding program in the early 1980s, the maize breeding program has passed through many distinct stages of research and development (Degene and Habtamu, 1993). Progressively in the 1990s, the multidisciplinary approach was consolidated. Currently, the strategic focus of Ethiopia's public sector maize breeding programs are to develop improved maize varieties and hybrids for three specific types of agro–ecological zones (low, medium and high altitude maize growing areas of the country); four types of varieties (extra–early, early, intermediate, and late maturing varieties); and four types of attributes (yield improvement, drought tolerance, earliness and disease resistance) (Ethiopian Agricultural Research Organization (EARO), 2000; Ministry of Agriculture and Rural Development (MoARD), 2004–2016; Dawit et al., 2010).

In the last four decades, more than 40 improved varieties of maize including hybrids and Open Pollinated Varieties (OPVs) have been developed and released by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the CIMMYT (Zeng et al., 2014). Despite maize suited diverse agro–climate subsists, and

strategic maize breeding efforts were made, the production of maize in the country remained low; with the estimated national average yield of 3.25 t ha^{-1} (CSA, 2014), which is low in light of the potential productivity of the world average of 5.64 t ha^{-1} with a productivity record of 10.73 t ha^{-1} by the US for the year 2014/15 (United States Agency for International Development–Foreign Agricultural Service (USDA–FAS), 2016).

Quantifying breeding achievements in yield and associated traits and understanding the crucial characteristics of the crop associated with the genetic gains achieved through breeding is an essential step for improving the current knowledge of yield limiting factors and the design for the future breeding strategies. Historical series of maize varieties have been deployed and used to assess the genetic gains achieved during a period of time through breeding in several countries: in Argentina by Echarte et al. (2013), USA by Russell (1985), Duvick (2005a), Jason et al. (2013) and Chen et al. (2016), and Africa by Badu–Apraku et al. (2013, 2014) and Omolaran et al. (2014). However, in Ethiopia there are few and scanty information that exist on the genetic gains in grain yield and other agronomic traits during the maize breeding eras for the released and registered highland, mid–altitude and lowland maize varieties in Ethiopia.

Periodic evaluation of genetic improvement of improved maize varieties will help identify traits of potential value for future breeding enhancement and target them for higher productivity for the majority of subsistence farmers engaged in the production of the maize crop. With these, the objectives of this study were to estimate the genetic gain made over decades and to identify changes in morpho–physiological characters associated with genetic improvements in grain yield potential of maize varieties.

MATERIALS AND METHODS

Description of experimental sites and materials

The experiment was conducted on three sets of seven (7) highland, twenty (20) mid–altitude and eleven (11) lowland maize varieties that have been released in Ethiopia and currently under production over the past forty–two (42) years; they were grown at APPRC (08°57'N, 38°07'E, altitude 2225 m), BNMRC (09°06'N, 37°09'E, altitude 1650 m) and MARC (08°25'N, 39°20'E, altitude 1550 m) respectively. A total of thirty–eight (38) maize varieties used in the experiment are summarized in Table 1.

Owing to the suited diverse agro–climatic conditions in Ethiopia, maize growing areas are broadly classified into four ecological zones: high altitude moist (1800–2400 m), mid–altitude moist (1000–1800 m), low altitude moist (< 1000 m) and moisture stress (500–1800 m) (EARO, 2000; Mandefro et al., 2001). The strategic focus of Ethiopia's public sector maize breeding programs is highlighted by efforts to develop improved maize varieties and hybrids for three specific types of zones categorized as highland (1800–2400 m), mid–altitude (1000–1800 m) and lowland (500–1800 m) (MoARD, 2004–2016; Dawit et al., 2010). Accordingly, the experiment was done on the three different agro–ecological maize–growing zones of the country.

Table 1. Descriptions of Ethiopian highland, mid–altitude and lowland maize varieties used for the experiments.

Variety name	Variety type	Year of release	Breeder (Maintainer)	Altitude (m)	Seed color
Highland maize varieties					
Alemaya Composite	OPV	1973	Haramaya University	1600–2200	White
Kuleni	OPV	1995	EIAR/BNMRC	1700–2200	White
Rare–1	OPV	1997	Haramaya University	1600–2200	White
AMH800	Hybrid	2005	EIAR/APPRC	1800–2500	White
AMH850	Hybrid	2008	EIAR/APPRC	1800–2600	White
AMH851	Hybrid	2009	EIAR/APPRC	1800–2600	White
AMH760Q	Hybrid	2012	EIAR/APPRC	1600–2400	White
Mid–altitude maize varieties					
Abobako	OPV	1986	EIAR/BNMRC	500–1000	White
BH140	Hybrid	1988	EIAR/BNMRC	1000–1800	White
Guto–LMS	OPV	1988	EIAR/BNMRC	1000–1700	White
BH660	Hybrid	1993	EIAR/BNMRC	1600–2200	White
BH540	Hybrid	1995	EIAR/BNMRC	1000–2000	White
PHB3253	Hybrid	1995	Pioneer Hi–Bred	1000–2000	White
Gibe–1	OPV	2001	EIAR/BNMRC	1000–1700	White
BH670	Hybrid	2002	EIAR/BNMRC	1700–2400	White
Gambela Composite	OPV	2002	EIAR/BNMRC	300–1000	White
BH543	Hybrid	2005	EIAR/BNMRC	1000–2000	White
HB30G19	Hybrid	2006	Pioneer Hi–Bred	1000–2000	White
SC627	Hybrid	2006	Syngenta	1000–2000	White
HQPY545	Hybrid	2008	EIAR/BNMRC	1000–1800	Yellow
BH661	Hybrid	2011	EIAR/BNMRC	1600–2400	White
P2859W	Hybrid	2011	Pioneer Hi–Bred	1000–2000	White
Gibe–2	OPV	2011	EIAR/BNMRC	1600–1800	White
P3812W	Hybrid	2012	Pioneer Hi–Bred	1000–2000	White
BH546	Hybrid	2013	EIAR/BNMRC	1000–1800	White
BH547	Hybrid	2013	EIAR/BNMRC	1000–1800	White
P3506W	Hybrid	2015	Pioneer Hi–Bred	800–1800	White
Lowland maize varieties					
Melkasa1	OPV	2001	EIAR/MARC	1000–1750	Yellow
Melkasa2	OPV	2004	EIAR/MARC	1200–1700	White
Melkasa3	OPV	2004	EIAR/MARC	1200–1700	White
Melkasa4	OPV	2006	EIAR/MARC	1000–1600	White
Melkasa5	OPV	2008	EIAR/MARC	1000–1700	White
Melkasa6Q	OPV	2008	EIAR/MARC	1000–1750	White
Melkasa7	OPV	2008	EIAR/MARC	1000–1750	Yellow
MHQ138	Hybrid	2012	EIAR/MARC	1000–1800	White
MH130	Hybrid	2012	EIAR/MARC	1000–1800	White
MH140	Hybrid	2013	EIAR/MARC	1000–1800	White
Melkasa1Q	OPV	2013	EIAR/MARC	1000–1750	Yellow

Source: MoARD (2004–2016).

Experimental design and field management

All the experiments were laid out in a Randomized Complete Block Design (RCBD) with three replications. The three sets of experimental units consisted of four (4) rows of 5.25 m long (with spacing of 0.75 m between rows × 0.25 m between plants), 5.1 m (0.75 m between rows × 0.30 m between plants) and 5 m (0.75 m between rows × 0.25 m between plants), respectively, at APPRC, BNMRC and MARC.

Planting for the three sets of experiments were undertaken on June 05 and 08, 2015 respectively at BNMRC for the mid–altitude maize varieties and at APPRC for the highland maize varieties;

while on July 09, 2015 for the lowland maize varieties at MARC by hand sowings two seeds per hill, which were later thinned to one plant per hill. The same field managements were used for the three sets of experiments, on which pre–emergence herbicides (Atrazine at the rate of 4 L ha^{-1} for broad leaved weeds and Primagram at the rate of 4 L ha^{-1} for grass weeds), nitrogen fertilizer in the form of Urea and phosphorus fertilizer in the form of Diammonium Phosphate were applied as per the specific recommendations for the areas. Similarly, hand weeding was done twice at 25 and 45 days after emergence; and weed slashing was done once at the flowering stages.

Statistical analysis

All measured parameter's field data were subjected to an Analysis of Variance (ANOVA) using SAS statistical software version 9.00 (SAS, 2002) to estimate the prevalent variation among the test varieties. Treatments and replications were the class variables, while the response variables were the traits considered for the data collected. The ANOVA Model:

$$Y_{ij} = m + G_i + B_j + e_{ij}$$

Where:
Y_{ij} = Observed value of genotype i in block j
m = Grand mean of the experiment
G_i = Effect of genotype i
B_j = Effect of block j
e_{ij} = Random error effect of genotype i in block j

The test of mean separation was employed depending on the significance of ANOVA. Mean separation was undertaken using Duncan's Multiple Range Test (DMRT) at the 5% level of significance. Correlation among all the traits was calculated using the means of each variety applying the PROC CORR procedure in SAS. Linear regression analysis was used to calculate the genetic gain for each trait considered in the study. The breeding effects were estimated as a genetic gain for grain yield and associated agronomic traits in maize improvement by regressing mean of each character for each variety against the year of release of the variety using the PROC REG procedure in SAS. The relative gain achieved over the year of release periods for each traits under consideration were determined as a ratio of genetic gain to the corresponding mean value of old variety and was expressed as a percentage using software program Microsoft Office (Excel 2010).
    The annual rate of gain was calculated as:

$$\text{Annual rate of gain (b)} = \frac{\text{Cov XY}}{\text{Var X}}$$

Where: Cov = Covariance
Var = Variance
X = the year of variety release
Y = the mean value of each character for each variety

The correlation between traits using means of each variety was calculated as:

$$\text{Correlation coefficient between X and Y (rxy)} = \frac{\text{Cov (X, Y)}}{\sqrt{\text{Var(X)Var(Y)}}}$$

Where:
 rxy = Correlation coefficient between X and Y
Cov (X, Y) = Covariance between X and Y
Var (X) = Variance of X
Var (Y) = Variance of Y

RESULTS

Analysis of variance of grain yield and other agronomic traits of Ethiopian highland, mid–altitude and lowland maize varieties

Analysis of variance for grain yield traits indicated significant (P≤ 0.05 and P≤ 0.01) differences for number of ears per plant, ear length, number of kernels per row, grain yield, biomass yield, biomass production rate and harvest index. In contrast, non–significant (P> 0.05) differences were observed among the seven highland maize varieties for ear diameter, number of kernel rows per ear and thousand kernel weight at APPRC, while highly significant (P≤ 0.01) differences were observed for all studied yield and productivity traits of the twenty mid–altitude maize varieties at BNMRC (Table 2). Results of the analysis of variance for the studied grain yield traits of the eleven lowland maize varieties at MARC indicated highly significant (P≤ 0.01) differences among varieties for the number of ears per plant, ear length, grain yield, biomass yield, biomass production rate and harvest index while significant (P≤ 0.05) differences among varieties were shown in number of kernels per row. Ear diameter and number of kernel rows per ear showed non–significant (P> 0.05) difference amongst the studied grain yield traits (Table 2).
    The analysis of variance for the growth and phenological traits of the seven highland maize varieties studied at APPRC showed highly significant (P≤ 0.01) differences that were observed for days to anthesis, days to silking, grain filling rate and ear height; whereas non–significant (P> 0.05) differences were observed for days to maturity, grain filling period and plant height. Further, the results of the analysis of variance for all growth and phenological traits of the twenty mid–altitude maize varieties and the eleven lowland maize varieties studied, respectively at BNMRC and MARC, showed highly significant (P≤ 0.01) differences (Table 3).

Genetic gains in grain yield and other agronomic traits of Ethiopian highland, mid–altitude and lowland maize varieties

Regression of the mean values of the highland maize varieties correspondingly with the year of releases over the past 39 years demonstrated positive and non–significant (P> 0.05) annual predictive and average relative genetic gain of 62.26 (1.24%) kg ha^{-1} yr^{-1} for grain yield and 76.37 (0.37%) kg ha^{-1} yr^{-1} for biomass yield at APPRC (Figure 1A and B).
    Positively significant (P≤0.05) annual and relative annual genetic improvement trend was made over the highland maize varieties for number of ears per plant by 0.0081 (0.90%) ear plant[-1] yr^{-1} while, negatively non-significant (P>0.05) genetic reductions of thousand kernel weight by **-0.43** (**-0.14%) g. yr^{-1} and ear diameter by

Table 2. Mean squares for the studied grain yield traits of Ethiopian highland, mid–altitude and lowland maize varieties evaluated at APPRC, BNMRC and MARC (2015).

Source	NEP	Ear Length	Ear Diameter	NKE	NKR	TKW	Grain Yield	Biomass Yield	BPR	Harvest Index
Highland maize varieties										
Variety (6)[a]	0.061**	1.858*	0.041ns	0.608ns	7.169*	2103.385ns	5871455**	15843554**	542.514**	48.353**
Error (12)	0.007	0.565	0.026	0.283	1.698	836.164	437775	2442467	69.809	3.246
Mean	1.122	19.938	4.623	13.286	38.31	303.629	6691.179	22918.44	132.125	28.958
CV (%)	7.332	3.769	3.513	4.003	3.401	9.524	9.888	6.819	6.324	6.222
R^2	0.824	0.64	0.46	0.565	0.683	0.607	0.89	0.829	0.829	0.886
Mid–altitude maize varieties										
Variety (6)[a]	0.177**	7.562**	0.307**	2.814**	16.793**	6307.135**	5627111**	28456387**	1288.482**	22.779**
Error (12)	0.056	0.718	0.095	0.349	6.52	338.264	1026574	7100042	344.206	3.285
Mean	1.312	19.151	4.928	15.393	41.637	326.97	8544.83	22840.95	158.006	37.372
CV (%)	18.033	4.424	6.261	3.84	6.133	5.625	11.857	11.666	11.742	4.85
R^2	0.636	0.853	0.625	0.802	0.565	0.903	0.735	0.670	0.654	0.779
Lowland maize varieties										
Variety (6)[a]	0.168**	2.441**	0.105ns	0.563ns	9.372*	704.267*	989364**	5140983**	175.528**	220.758**
Error (12)	0.005	0.662	0.048	0.294	2.965	174.238	122137	266761	19.477	26.681
Mean	0.855	13.882	3.674	12.87	27.585	181.206	1610.233	5973.738	56.665	27.568
CV (%)	8.602	5.86	5.947	4.214	6.243	7.284	21.704	8.646	7.788	18.737
R^2	0.942	0.656	0.549	0.492	0.632	0.671	0.817	0.909	0.824	0.819

[a] – Degrees of freedom. R^2 – Coefficient of determination. *,** – Significant at 0.05 and 0.01 level of probability, respectively. ns – non–significant. NEP – Number of Ears per Plant, NKE – Number of Kernel Rows per Ear, NKR – Number of Kernels per Row, TKW – Thousand Kernel Weight and BPR – Biomass Production Rate.

Table 3. Mean squares for the studied growth and phenological traits of Ethiopian highland, mid–altitude and lowland maize varieties evaluated at APPRC, BNMRC and MARC (2015).

Source	Days to Anthesis	Days to Silking	Days to Maturity	GFP	GFR	Plant Height	Ear Height
Highland maize varieties							
Variety (6)[a]	14.825**	24.079**	26.873ns	10.968ns	906.221**	309.464ns	719.052**
Error (12)	2.516	2.341	33.611	32.825	75.211	115.708	37.778
Mean	93.619	95.571	173.524	79.905	83.75	259.952	142.929
CV (%)	1.694	1.601	3.341	7.17	10.355	4.138	4.3
R^2	0.783	0.856	0.435	0.364	0.868	0.746	0.918
Mid–altitude maize varieties							
Variety (19)[a]	30.126**	36.852**	6.74**	23.891**	1034.726**	1153.942**	1289.366**
Error (38)	2.239	2.646	1.348	4.089	205.054	75.963	64.795
Mean	74.933	75.95	144.567	69.633	122.656	297.84	154.253
CV (%)	1.997	2.142	0.803	2.904	11.675	2.926	5.218
R^2	0.872	0.88	0.726	0.757	0.717	0.895	0.913
Lowland maize varieties							
Variety (10)[a]	106.339**	133.358**	835.024**	445.424**	1406.018**	107.697**	272.564**
Error (20)	1.803	2.885	12.579	13.57	64.856	27.352	13.027
Mean	62.576	64.485	105.182	42.848	41.928	121.303	58.97
CV (%)	2.146	2.634	3.372	8.597	19.208	4.311	6.121

Table 3. Contd.

R^2	0.968	0.959	0.971	0.943	0.918	0.671	0.914

[a] – Degrees of freedom; R^2 – Coefficient of determination; [**] – Significant at 0.01 level of probability; [ns] – non–significant; GFP – Grain Filling Period and GFR – Grain Filling Rate.

$$y = 62.263x + 5019$$
$$R^2 = 0.3555$$

A

$$y = 76.374x + 20867$$
$$R^2 = 0.1982$$

B
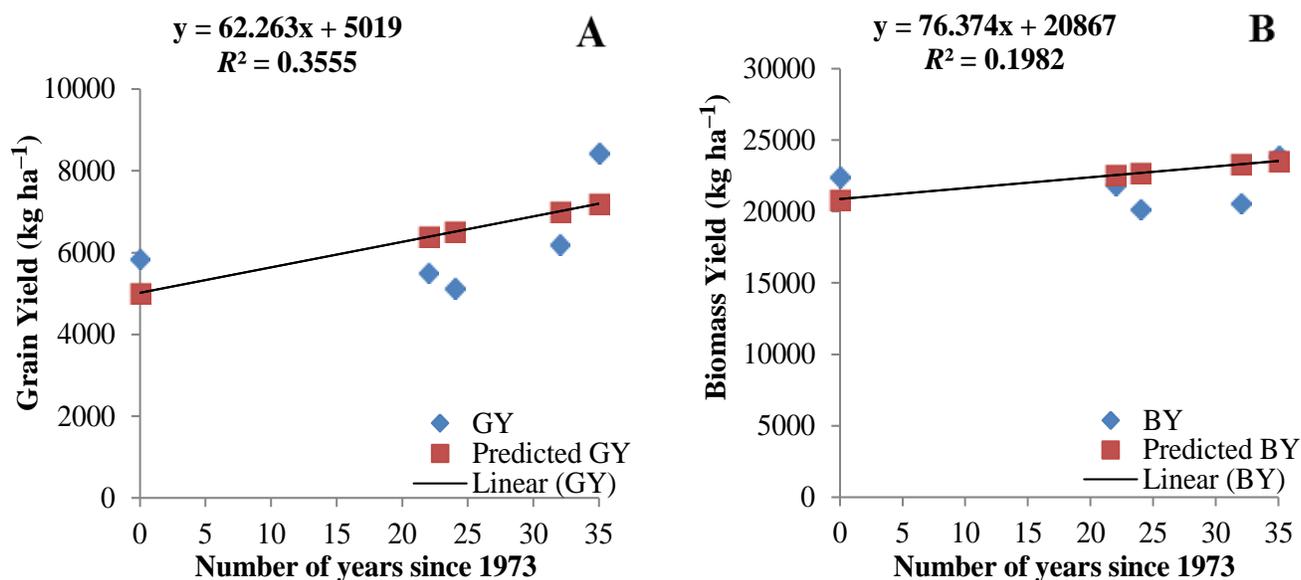
Figure 1. Genetic gain in grain yield (A) and biomass yield (B) of the highland maize varieties released from 1973 to 2012.

-0.0088 (-0.18%) cm yr^{−1} were shown in Table 4. Grain filling rate indicated positively non–significant (P> 0.05) annual and relative genetic gain of 0.76 (1.19%) kg ha^{−1} day^{−1} yr^{−1}. Similarly, days to anthesis and silking indicated negatively non–significant (P> 0.05) annual and relative genetic gain of −0.10 (−0.11%) days yr^{−1} and −0.13 (−0.13%) days yr^{−1}, respectively for the highland maize varieties at APPRC (Table 4).

The regression of the mean values of the mid–altitude maize varieties correspondingly with the year of releases over the past 29 years demonstrated positively non–significant (P> 0.05) annual predictive and average relative genetic gain of 58.97 (0.78%) kg ha^{−1} yr^{−1} for grain yield and 95.63 (0.45%) kg ha^{−1} yr^{−1} for biomass yield at BNMRC (Figure 2A and B).

Positively non–significant (P> 0.05) annual genetic improvement trends were also made over the mid–altitude maize varieties for thousand kernel weight by 1.12 (0.36%) gm. yr^{−1}, ear length by 0.03 (0.17%) cm yr^{−1} and ear diameter by 0.0076 (0.16%) cm yr^{−1} (Table 4). Negatively significant (P≤ 0.05) genetic annual predictive and average relative genetic improvements on shortening the durations by −0.18 (−0.24%) days yr^{−1} for days to anthesis and −0.19 (−0.24%) days yr^{−1} for days to silking were made; while positive and highly significant (P≤ 0.01) genetic improvement was made over the mid–altitude

maize varieties upon prolonging the duration for grain filling period by 0.20 (0.30%) days yr^{−1} at BNMRC (Table 4).

Regression of the mean values of the lowland maize varieties correspondingly with the year of releases over the past 12 years demonstrated positive and non–significant (P>0.05) annual predictive and average relative genetic gain of 32.64 (0.57%) kg ha^{−1} yr^{−1} for biomass yield. Differently, demonstrated negative and non–significant predictive average annual rate of decrease was shown by −2.64 (−0.16 %) kg ha^{−1} yr^{−1} for grain yield at MARC (Figure 3A and B).

Positively significant (P≤ 0.05) annual and relative annual genetic improvement trends were made over the lowland maize varieties by 0.07 (0.53%) rows–ear yr^{−1} for number of kernel rows per ear while positively non–significant (P> 0.05), annual and relative annual genetic improvement trends were made by 0.02 (0.53%) cm yr^{−1} for ear diameter, 0.04 (0.14%) kernels–row yr^{−1} for number of kernels per row, and 0.03 (0.05%) kg ha^{−1} day^{−1} for biomass production rate. Exceptionally compared to the other studied yield traits, negatively non–significant (P> 0.05) annual and relative annual genetic gain reductions were shown over the lowland maize varieties by −1.25 (−0.66 %) gm. yr^{−1} for thousand kernel weight, −0.02 (−1.97%) ear plant[−1] yr^{−1} for number of ears

Table 4. Relative genetic gains of grain yield and other agronomic traits of Ethiopian highland, mid–altitude and lowland maize varieties evaluated at APPRC, BNMRC and MARC (2015).

Trait	Highland Maize Varieties				Mid–altitude Maize Varieties				Lowland Maize Varieties			
	b	RGG (% yr^{-1})	R^2	Intercept	b	RGG (% yr^{-1})	R^2	Intercept	b	RGG (% yr^{-1})	R^2	Intercept
DA	−0.10	−0.11	0.40	96.44	−0.18[*]	−0.24	0.29	78.06	0.44	0.74	0.09	59.44
DS	−0.13	−0.13	0.38	99.06	−0.19[*]	−0.24	0.26	79.24	0.47	0.77	0.08	61.17
DM	−0.09	−0.05	0.17	175.99	0.01	0.01	0.01	144.31	0.69	0.69	0.03	100.29
GFP	0.02	0.02	0.01	79.49	0.20[**]	0.30	0.42	66.25	0.27	0.66	0.01	40.94
GFR	0.76	1.19	0.34	63.41	0.54	0.48	0.07	113.38	−0.68	−1.46	0.02	46.78
PH	0.20	0.08	0.08	254.16	0.24	0.08	0.01	293.73	−0.06	−0.05	0.00	121.76
EH	0.43	0.33	0.14	131.24	−0.43	−0.26	0.04	161.55	0.50	0.89	0.05	55.46
NEP	0.0081[*]	0.90	0.59	0.90	0.0007	0.05	0.00	1.30	−0.02	−1.97	0.11	0.99
EL	0.02	0.09	0.09	19.49	0.03	0.17	0.03	18.6	−0.0022	−0.02	0.00	13.90
ED	−0.0088	−0.18	0.20	4.79	0.0076	0.16	0.05	4.80	0.02	0.53	0.17	3.54
NKE	−0.0124	−0.09	0.13	13.62	−0.0061	−0.04	0.00	15.51	0.07[*]	0.53	0.39	12.40
NKR	0.07	0.02	0.40	36.33	0.02	0.06	0.01	41.22	0.04	0.14	0.01	27.32
TKW	−0.43	−0.14	0.05	315.22	1.12	0.36	0.05	307.89	−1.25	−0.66	0.11	190.05
GY	62.26	1.24	0.36	5018.97	58.97	0.78	0.16	7539.35	−2.64	−0.16	0.00	1628.93
BY	76.37	0.37	0.20	20867.25	95.63	0.45	0.08	21210.44	32.64	0.57	0.01	5742.26
BPR	0.51	0.43	0.26	118.36	0.70	0.48	0.10	145.59	0.03	0.05	0.00	56.48
HI	0.17	0.71	0.33	24.31	0.11	0.32	0.14	35.46	−0.37	−1.24	0.03	30.23

b – Regression coefficient. R^2 – Coefficient of determination. RGG – Annual relative genetic gains. [*],[**] – Significant at 0.05 and 0.01 level of probability, respectively. DA – Days to Anthesis, DS – Days to Silking, DM – Days to Maturity, GFP – Grain Filling Period, GFR – Grain Filling Rate, PH – Plant Height, EH – Ear Height, NEP – Number of Ears per Plant, EL – Ear Length, ED – Ear Diameter, NKE – Number of Kernel Rows per Ear, NKR – Number of Kernels per Row, TKW – Thousand Kernel Weight, GY – Grain Yield, BY – Biomass Yield, BPR – Biomass Production Rate and HI – Harvest Index.
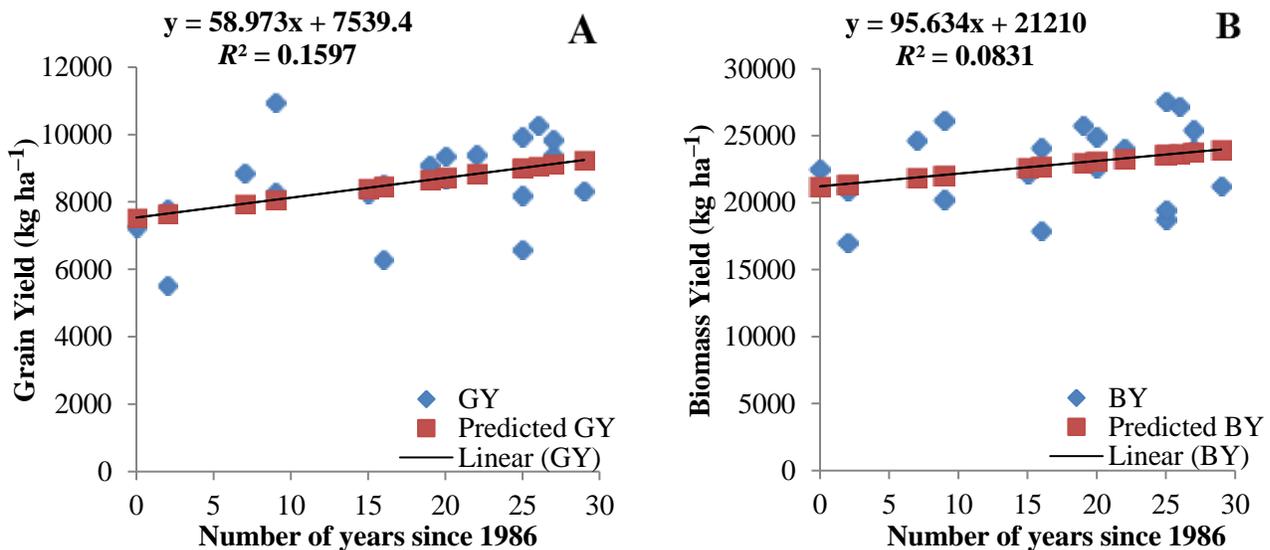
Figure 2. Genetic gain in grain yield (A) and biomass yield (B) of the mid–altitude maize varieties released from 1986 to 2015.

per plant, −0.0022 (−0.02%) cm yr^{-1} for ear length and −0.37 (−1.24%) kg ha^{-1} yr^{-1} for harvest index (Table 4). Positively non–significant (P>0.05) annual genetic gain

reductions were made over the lowland maize varieties by 0.44 (0.74%) days yr^{-1} for days to anthesis and 0.47 (0.77%) days yr^{-1} for days to silking while non–significant
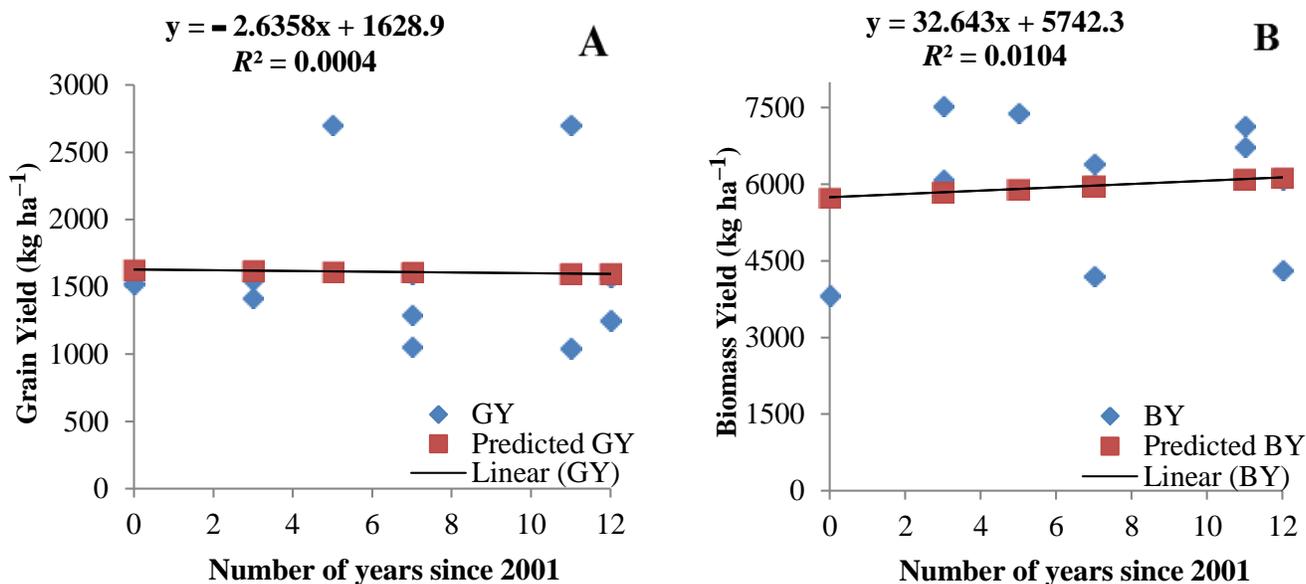
Figure 3. Genetic gain in grain yield (A) and biomass yield (B) of the lowland maize varieties released from 2001 to 2013.

Table 5. Correlation of agronomic parameters with grain yield of Ethiopian highland, mid–altitude and lowland maize varieties evaluated at APPRC, BNMRC and MARC MARC (2015).

Trait	Highland Maize Varieties	Mid–altitude Maize Varieties	Lowland Maize Varieties
DA (P value)	−0.82* (0.0233)	−0.20 (0.4009)	−0.20 (0.5638)
DS (P value)	−0.91** (0.0041)	−0.20 (0.3957)	−0.24 (0.4752)
DM (P value)	−0.55 (0.1986)	0.29 (0.2208)	0.10 (0.7805)
GFP (P value)	0.09 (0.8400)	0.38 (0.1017)	0.26 (0.4319)
GFR (P value)	0.99** (<0.0001)	0.97** (<0.0001)	0.40 (0.2229)
PH (P value)	0.17 (0.7157)	0.52* (0.0181)	0.22 (0.5163)
EH (P value)	−0.11 (0.8198)	0.28 (0.2347)	0.05 (0.8805)
NEP (P value)	0.85* (0.0161)	0.01 (0.9651)	0.32 (0.3382)
EL (P value)	0.89** (0.0072)	0.56* (0.0110)	0.49 (0.1304)
ED (P value)	−0.23 (0.6140)	0.08 (0.7389)	−0.07 (0.8354)
NKE (P value)	−0.30 (0.5120)	0.09 (0.7069)	−0.21 (0.5408)
NKR (P value)	0.94** (0.0018)	0.41 (0.0690)	0.39 (0.2336)
TKW (P value)	0.36 (0.4287)	0.48* (0.0311)	0.10 (0.7805)
BY (P value)	0.82* (0.0234)	0.90** (<0.0001)	0.42 (0.2006)
BPR (P value)	0.90** (0.0055)	0.91** (<0.0001)	0.54 (0.0841)
HI (P value)	0.91** (0.0043)	0.59** (0.0064)	0.69* (0.0194)

(P> 0.05) negative annual genetic and relative genetic gain reduction of −0.68 (−1.46%) kg ha^{-1} day^{-1} yr^{-1} was made for grain filling rate at MARC (Table 4).

Correlation of grain yield and other agronomic traits of Ethiopian highland, mid–altitude and lowland maize varieties

Correlation coefficients for the grain yield among the seven highland maize varieties released over the past 39 years had shown a positive and highly significant

(P≤0.01) associations with grain filling rate (r= 0.99**), ear length (r= 0.89**), number of kernels per row (r= 0.94**), biomass production rate (r= 0.90**) and harvest index (r= 0.91**); while grain yield was positive and significantly (P≤0.05) associated with number of ears per plant (r= 0.85*) and biomass yield (r= 0.82*). Differently, highly significant (P≤ 0.01) and negative association for days to silking (r= −0.91**); and significant (P≤0.05) and negative association for days to anthesis (r= −0.82*) were shown with the grain yield at APPRC (Table 5).

Correlation coefficients for the grain yield among the

twenty mid–altitude maize varieties released over the past 29 years had shown a positive and highly significant (P≤0.01) associations with grain filling rate (r= 0.97**), biomass yield (r= 0.90**), biomass production rate (r= 0.91**) and harvest index (r= 0.59**), while grain yield was positive and significantly (P≤0.05) associated with plant height (r= 0.52*), ear length (r= 0.56*) and thousand kernel weight (r= 0.48*) at BNMRC (Table 5).

Correlation coefficients for the grain yield among the eleven lowland maize varieties released over the past 12 years had shown a positive and significant (P≤ 0.05) association only with harvest index (r= 0.69*) at MARC (Table 5).

DISCUSSION

Analysis of variance of grain yield and other agronomic traits of maize varieties

The highly significant mean squares observed for grain yield and other measured traits over the breeding period indicate that genetic differences exist among cultivars within each breeding period over Ethiopian released highland, mid–altitude and lowland maize varieties. The analysis of variance for grain yield traits indicated significant (P≤0.01) differences on the number of ears per plant and grain yield among the varieties released in Ethiopia over highland, mid–altitude and lowland maize varieties. These findings were in agreement with the genetic gain study findings of highly significant (P≤ 0.01) differences on the number of ears per plant and grain yield which were indicated both under multiple stress and non–stress environments at Nigeria, Ghana and Benin by Badu–Apraku et al. (2014); and both under Striga–infested, Striga–free and across different research environments in Nigeria and Benin by Badu–Apraku et al. (2013). While Omolaran et al. (2014) on another finding from Nigeria reported significant (P≤0.05) differences on the number of ears per plants and grain yields both under different levels of nitrogen and maize hybrids, other grain yield traits of Ethiopian released highland and lowland maize varieties that showed non–significant (P> 0.05) differences over the number of kernel rows per ears. Contrariwise Omolaran et al. (2014) reported highly significant (P≤0.01) differences over the number of kernel rows per ear both under different levels of nitrogen and maize hybrids.

Genetic gains in grain yield and other agronomic traits of maize varieties

Maize genetic gains in grain yield and other measured traits for Ethiopian released maize varieties currently under production within breeding periods in the present studies prompted the examination of the archived and predicted genetic gains that the Ethiopian released highland and mid–altitude maize varieties over the past 39 and 29 years demonstrated positive genetic gains for the grain and biomass yields. Comparably numerous estimates of genetic yield gain of maize hybrids have been shown, without exception, that genetic yield gains during the past 70 years have been positive and linear. Estimates of the average annual gain vary but tend to fall in the range of 65–75 kg ha^{-1} according to Duvick (2005a). This agrees with a recent result from USA by Chen et al. (2016) who evaluated commercial maize hybrids released over 38 years that reported increased breeding progress over the grain yield by an average of 66 kg ha^{-1} yr^{-1}. However, the present studies for the Ethiopian released lowland maize varieties during the past 12 years differently demonstrated genetic reduction for grain yield, while only minimal genetic gain for biomass yield were shown.

The highland and mid–altitude maize varieties demonstrated that non–significant and significant genetic gain improvements on duration reductions had been possible for days to anthesis and silking, while non–significant genetic gain decrease was made upon duration reduction for days to anthesis and silking for the lowland maize varieties. In the history of the maize breeding programs of some countries, there have been consistent as well as inconsistent trends made possible on reducing the durations of days to anthesis and silking. Many researchers agree for growth and flowering traits that days to silking and anthesis have not significantly changed over time respectively according to (Russell, 1985; Duvick, 1997, 2005a). On the contrary, Omolaran et al. (2014) and Badu–Apraku et al. (2014) reported over the three different breeding eras, that days to anthesis were significantly and consistently lowered over the newly released ones than the oldest released ones. This clearly indicates that throughout the history of the maize breeding program there has been a continual trend made possible on reducing the durations of days to anthesis and silking in many countries.

Highly significant genetic improvement was made upon prolonging grain filling period for the mid–altitude maize varieties, while non–significant genetic improvements were made for the highland and lowland maize varieties. The first two shown findings agreed with Campos et al. (2006) who reported for maize that the grain filling period has been non–significantly improved over the past fifty years of breeding in the U.S. corn–belt. Non–significant genetic reduction of grain filling rate was made for the lowland maize varieties, while genetic increases of grain filling rate were made for the highland and mid–altitude maize varieties. The shown genetic gain increases and reduction of grain filling rates were the ones that have played the role for the realized grain yield as well as thousand kernel weight potentials over the Ethiopian released maize varieties. It was obvious that kernel set must be followed by kernel filling to ensure that yield

potential is realized. Kernels near the tip of the ear will often abort after several weeks of growth if drought–affected. Remobilized assimilate stored in the stem prior to and during the flowering period normally plays a role in buffering filling rate only in the last half of filling (Edmeades, 2013).

Non–significant genetic improvements for number of ears per plant over the mid–altitude maize varieties and reduction for number of ears per plant over the lowland maize varieties were shown, while significant genetic improvement was shown for number of ears per plant over the highland maize varieties. Unlike the lowland maize varieties, comparable results on different hybrids maize varieties grown in USA reported that number of ears per plant was found to increase over the decades (Crosbie, 1982; Russell, 1985; Duvick et al., 2004). Similarly, in Nigeria and Benin significant improvement was observed in number of ears per plant for the different maize cultivars of the three breeding periods when grown in Striga–*infested* and Striga–*free*. That the genetic gains increase made in the number of ears per plant were 0.006 and 0.002 ear plant^{-1} yr^{-1} over the evaluated different maize cultivars respectively, under Striga–*infested* and Striga–*free* conditions. Nevertheless, the different maize cultivars evaluated under Striga–*free* condition, the number of ears per plant were ranged equally from 0.9 ear plant^{-1} yr^{-1} for cultivars during the breeding period 1 (1988–2000) to 0.9 ear plant^{-1} yr^{-1} for cultivars during the breeding period 3 (2007–2010), while under Striga–*infested* conditions the number of ears per plant was ranged from 0.8 to 0.9 ear plant^{-1} yr^{-1} over the two similar breeding periods (Badu–Apraku et al., 2013). Badu–Apraku et al. (2014) also reported the number of ears per plant on maize, that the genetic gains were changed significantly by 0.52 and 0.70 ear plant^{-1} yr^{-1} during the three breeding eras respectively; under multiple stress and non–stress environments evaluated at 16 and 35 different sites.

Positively non–significant genetic improvements respectively, over the highland and mid–altitude maize varieties, and negatively non–significant genetic reductions over lowland maize varieties were shown for harvest index. The demonstrated research findings for the genetic improvements for harvest index towards the released maize varieties agreed that the harvest index did consistently change over time; and that in Argentina the harvest index over the evaluated Argentinean maize hybrids, have increased from 0.41 to 0.52 kg ha^{-1} yr^{-1} on those maize hybrids varieties grown under the optimal conditions over those past 30 year period of 1960–1990 (Echarte and Andrade, 2003; Echarte et al., 2004). From another study, particularly at higher plant densities in Iowa–USA, the harvest index showed a significant relative improvement of 0.1 kg ha^{-1} yr^{-1} over the maize varieties released for the past 61 year period of 1930–1991 (Duvick, 1997). On the contrary in Iowa–USA, for the long–term genetic gain in maize yield for the

conditions of the U.S. corn–belt, the harvest index have remained constant over maize hybrids released between the 1930s–2000s for the past 70–80 years (Duvick, 2005b; Tollenaar and Lee, 2006). Another recent study on the commercial hybrid maize varieties released in the USA over the eight commercial DeKalb hybrid maize varieties released over 38 year period from 1967–2005 compared at 2 locations, 2 nitrogen fertilizer rates and 3 plant densities, showed that the harvest indices were similar across hybrid maize varieties except for low values with the 1967 and 1975 released hybrid maize varieties at West Lafayette, USA; and with the 1975 and 1982 released hybrid maize varieties at Wanatah, USA (Chen et al., 2016).

Relationship of grain yield and other agronomic traits of maize varieties

Genetic improvements of grain yield in the Ethiopian released highland and mid–altitude maize varieties over the past 39 and 29 years; grain filling rate, ear length, biomass production rate, biomass yield and harvest index were equally amongst the possible contributors oneness associated positively and significantly with the grain yields. Days to anthesis and days to silking were also amongst the possible contributors oneness associated negatively and significantly with the grain yields while, number of ears per plant and number of kernels per row were amongst the possible contributors oneness being positively and significantly associated with the grain yields over the Ethiopian released highland maize varieties. Equally, thousand kernel weights were the other ones amongst the possible contributors being associated positively and significantly with the grain yields over the Ethiopian released mid–altitude maize varieties. While only the harvest index were the ones among the possible contributors being associated positively and significantly with the grain yields over the Ethiopian released lowland maize varieties for the past 12 years.

For maize, grain yield is a function of number of plants per area, the proportion of these plants that produce a harvestable ear, kernel number per ear, and the weight of each individual kernel. Similar findings to the Ethiopian released highland and mid–altitude maize varieties were reported from Nigeria by Omolaran et al. (2014) on maize genetic gains studies under different nitrogen regimes, for highly significant and positive associations of grain yield with the number of kernels per row and thousand kernel weight; while highly significant and negative associations of grain yield with the days to anthesis, days to silking and plant height were identified. Other similar findings from Canada, for a significant and positive association of grain yield with thousand kernel weight (Lee and Tollenaar, 2007), and grain yield with number of kernels (Tollenaar et al., 1992); and from Nigeria and Benin by

Badu–Apraku et al. (2013) grain yield with plant height were also reported. Meanwhile, other considered and analyzed success result studies on conventional maize crop improvements over the past 50 years for drought tolerance also indicated the negative association between grain yield and reduced interval between anthesis and silking (Campos et al., 2004).

As regards the Ethiopian released lowland maize varieties, harvest index was shown to be associated positively and significantly with the grain yields, and harvest index trait was also considered as being the ones among the possible contributors towards the grain yield genetic declinations. However, unlike the Ethiopian released lowland maize varieties, comparable results on grain yield improvement in Argentina has been associated with an increase in harvest index trait (Echarte and Andrade, 2003). In contrast to yield improvement in Argentina, previous studies (Crosbie, 1982; Duvick, 1997, 2005b; Tollenaar et al., 1994) have also shown that increase in ERA–hybrid grain yield in the USA can be attributable to changes in light interception due to increased leaf area index and changes in light utilization due to more erect upper leaves, maintenance of green leaf area and leaf photosynthesis during the grain filling period rather than yield per plant and harvest index. Similarly, Tollenaar and Lee (2006) reported from the USA that the yield increase was not associated with a change in maximum harvest index.

Conclusions

We studied the changes in yield gains on a morpho–physiological basis with respect to yield and yield component traits for 38 Ethiopian released maize varieties over the past 42–year periods which is currently under production in Ethiopia in the highland, mid–altitude and lowland Ethiopian major maize growing agro–ecology zones of the regions. The average rate of increase in grain yield corresponding to annual genetic gain was 62.26 (1.24%) kg ha^{-1} yr^{-1} over the tested 7 released highland maize varieties and 58.97 (0.78%) kg ha^{-1} yr^{-1} over the tested 20 released mid–altitude maize varieties. Differently, the other tested 11 released lowland maize varieties indicated average rate of decreases in grain yield was by −2.64 (−0.16) kg ha^{-1} yr^{-1} corresponding to annual genetic gain. Other tested phenological traits, and yield and yield components indicated a significant and positive annual genetic gain increase for number of ears per plant over the released highland maize varieties and grain filling period over the released mid–altitude maize varieties; while significant and negative annual genetic improvement were also observed in shortening the days to anthesis and days to silking over the released mid–altitude maize varieties. However, an average rate of decreases had been indicated in grain yield; a significant and positive annual genetic gain increase was indicated for number of kernel

rows per ear over the released lowland maize varieties. Generally, the results of the present studies indicated that considerable genetic gains over the phenological traits, and inconsiderable genetic reductions over the yield and yield components have been made across the released highland, mid–altitude and lowland maize varieties for the three agro–ecological zones of Ethiopia. Typically, targeting one or few of those identified maize breeding traits relatively contributed to considerable genetic gains and reductions could be used for further improvements in the breeding program.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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