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IMPROVEMENT IN YIELD OF BREAD WHEAT CULTIVARS RELEASED IN ETHIOPIA FROM 1949 TO 1987

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ABSTRACT

Thirteen bread wheat (*Triticum aestivum* L.) cultivars popular in the highlands of Ethiopia and representative of the period from 1949 to 1987 were studied for two cropping seasons in Ethiopia to estimate progress made in improving grain yield. The selected cultivars were grown with the effects of other genetic changes minimized by using fungicides to control foliar diseases, nets to prevent lodging, and periodic hand weeding to control weeds. Adequate levels of nutrients were also supplied. Significant differences were observed among cultivars for all crop parameters studied. The grain yield of bread wheat cultivars released since 1949 has increased at a mean rate of 77 kg ha^{-1} yr^{-1} (2.21%) as measured in central Ethiopia and 50 kg ha^{-1} y^{-1} (1.77%) under warmer and drier conditions in southeastern Ethiopia. Grain yield was significantly and positively correlated with harvest index, grains m^{-2}, spikelets $spike^{-1}$ and grains $spike^{-1}$. Genetic improvement has substantially increased the grain yield of rainfed bread wheat in the highlands of Ethiopia, resulting from an improved harvest index associated with an increased number of grains $spike^{-1}$ and, as a result, grains m^{-2}. Wheat breeders in Ethiopia should continue to emphasize spike fertility as a selection criterion for high grain yield.

Key Words: **Ethiopia, grain yield, *Triticum aestivum* L., wheat**

RÉSUMÉ

Treize cultivars de blé à pain (*Triticum aestivum* L) populaires dans les hauts-plateaux éthiopiens et représentatifs de la période de 1949 à 1987 ont été étudiés durant deux saisons de cultures en Ethiopie pour évaluer le progrès réalisé dans le rendement en grains. Les cultivars choisis étaient produits en s'assurant que les effets d'autres changements génétiques étaient minimisés par l'utilisation de fungicides pour controler les maladies folières, par des filets pour empècher la verse; et par des déserbages manuels pour controler les mauvaises herbes. Des niveaux adéquats de substances nutritives ont aussi été fournis. Des différences significatives ont été observées parmis les cultivars pour tous les paramètres étudiés. Le rendement en grains du cultivar de blé à pain disséminé depuis 1949 a augmenter à un taux moyen de 77kg ha^{-1} yr^{-1} (2.21%) d'après les chiffres obtenus en Éthiopie centrale et 50 kg ha^{-1} yr^{-1} (1.77%) sous des conditions plus chaudes et sèches dans le sud-est de l'Éthiopie. Le rendement en graines était significativement et positivement correlé à l'index de récolte, aux grains par metre carré, aux épis d'épillets par metre carré et aux graines par épis. L'amélioration génétique a substentiellement augmenté le rendement en graines du blé à pain dépendant des précipitations des hauts plateaux éthiopiens, résultant en un indice de récolte

amélioré associé à une augmentation du nombre des graines par épis et, cela a mené à une augmentation en grains par metre carré. Les producteurs de blé en Éthiopie devraient continuer à mettre l'accent sur la fertilité des épis comme critère pour un fort rendement de blé.

Mots Clés: **Éthiopie, rendement en graines, *Triticum aestivum* L., blé**

INTRODUCTION

Wheat (*Triticum* spp.) is one of the staple food grains in the highlands of Ethiopia. Bread wheat (*Triticum aestivum* L.), believed to be a relatively recent introduction to Ethiopia, is grown principally on well drained soils in the highlands, and exhibits wider adaptation and higher yield potential in Ethiopia than the indigenous durum wheats (*T. durum* Desf) (Tesfaye and Jamal, 1982; Getinet, 1988; Hailu, 1991). Bread wheat is produced exclusively under rainfed conditions both by peasant farmers and by state farms. Currently, close to one-half of the national wheat area (ca. 800 000 ha) is occupied by bread wheat (Getinet, 1988; Hailu, 1991).

In Ethiopia, wheat cultivar improvement commenced in 1949, and has concentrated on increasing grain yield potential, adaptability, lodging and disease resistance, and tolerance to several environmental stresses (Tesfaye and Jamal, 1982; Hailu, 1991). A number of bread wheat cultivars with high yield potential have been recommended for production in the Ethiopian highlands. According to a recent estimate, more than 75% of the national bread wheat area is occupied by improved cultivars (Tanner and Mwangi, 1992).

This paper examines gains in grain yield under rainfed conditions of bread wheat cultivars released for use in the highlands of Ethiopia since the national wheat improvement programme began in 1949. The objectives of this study were: 1) to assess changes in the grain yield of bread wheat brought about by the national programme; and 2) to identify correlated selection criteria to facilitate future progress in enhancing grain yield.

MATERIALS AND METHODS

Thirteen bread wheat cultivars representative of the period from 1949 to 1987 were evaluated in this study (Table 1). Of these cultivars, Israel is the earliest release, having been introduced pre-1949 (i.e., prior to the initiation of the national improvement programme), and is still being grown by peasant farmers in some areas of Ethiopia. From 1988 through 1992, no bread wheat cultivars were released in Ethiopia.

The yield experiments were conducted on a reddish-brown clay soil (eutric Nitosol) at the Holetta Research Centre in 1989, and on a dark-

TABLE 1. Origin, selection site, and year of release of 13 bread wheat cultivars included in the yield study

Cultivar	Origin	Selection site	Year of release
Israel	N/A[a]	N/A	pre-1949
Laketch	CIMMYT[b]	Debre Zeit	1970
Romany	Kenya	Holetta	1970
Mamba	Kenya	Holetta	1973
Romany B.C.	Kenya/Mexico	Holetta	1974
Enkoy	Kenya	Holetta/Debre Zeit	1974
Dereselign	CIMMYT	Debre Zeit	1974
K6290-Bulk	Kenya	Kulumsa	1977
K6295-4A	Kenya	Holetta/Debre Zeit	1980
ET13	Ethiopia	Holetta	1981
Dashen	CIMMYT	Holetta	1984
HAR 416	CIMMYT	Holetta	1987
HAR 407	CIMMYT	Holetta	1987

[a]: Specific details unknown.
[b]: International Centre for Maize and Wheat Improvement (based in Mexico).

brown clay-loam soil (an intergrade between a luvic Phaeozem and an eutric Nitosol) at the Kulumsa Research Centre in 1989 and 1990.

Holetta and Kulumsa were selected to represent two different bread wheat production environments in the Ethiopian highlands. Holetta (alt. 2400 m a.s.l., latitude 8°5'N, longitude 38°15'E) is situated in the central highlands of Shewa Region, while Kulumsa (alt. 2200 m a.s.l., latitude 7°55'N, longitude 39°10'E) is in the southeastern highlands of Arsi Region. Comparison of long-term climatic data for the two sites reveals that Kulumsa receives approximately 37% less rainfall than Holetta during the June to November cropping season, and mean temperatures during the growing season are higher at Kulumsa, particularly the mean monthly minima (Table 2). Wind velocity during the growing season at Kulumsa is about double that of Holetta (Table 3), and dry, desiccating winds have a detrimental effect on grain filling of wheat grown at Kulumsa (IAR, 1989). Pan evaporation data, a measure of potential evapotranspiration, substantiate Kulumsa's status as a moisture-limited environment relative to Holetta (Table 3).

Each experiment was laid out in a randomized complete block design with four replications. Plots consisted of 8 rows at 20 cm spacing and 5 m in length. Wheat seed (source: Holetta R.C.)

TABLE 2. Monthly rainfall and monthly mean air temperatures during the growing season at the Holetta and Kulumsa Research Centres in Ethiopia (mean of 1967-1990)

Month	Rainfall (mm)		Air temperature (°C)			
			Minimum		Maximum	
	HRC[a]	KRC	HRC	KRC	HRC	KRC
June	111	83	7.3	11.0	22.2	22.5
July	257	132	9.0	10.2	19.4	20.5
August	274	137	9.2	10.8	19.2	19.9
September	137	110	7.9	10.4	20.0	21.3
October	23	34	4.7	10.4	21.6	22.9
November	9	12	2.4	8.7	22.1	23.1
Mean	—	—	6.8	10.3	20.8	21.7
Total	811	508	—	—	—	—

[a]: HRC - Holetta Research Centre; KRC - Kulumsa Research Centre.

TABLE 3. Pan evaporation, sunshine hours and wind velocity during the growing season at the Holetta and Kulumsa Research Centres in Ethiopia (mean of 1967-1990)

Month	Wind velocity[b] (km h^{-1})		Pan evaporation (mm d^{-1})		Sunshine hours (h d^{-1})	
	HRC[a]	KRC	HRC	KRC	HRC	KRC
June	4.0	8.0	4.0	5.2	5.3	7.0
July	3.6	8.6	2.7	4.5	2.9	5.1
August	3.6	7.1	2.7	4.2	3.2	5.0
September	3.8	6.6	3.7	4.4	4.6	4.9
October	4.6	10.4	4.7	7.1	7.8	5.9
November	4.6	10.9	5.1	7.0	9.2	7.5
Mean	4.0	8.6	3.8	5.4	5.5	5.9

[a]: HRC - Holetta Research Centre; KRC - Kulumsa Research Centre.
[b]: At 2 m above ground level.

treated with aldrin was sown by hand at the rate of 380 seeds m^{-2} on 27 June 1989 at Holetta and 30 June 1989 and 8 July 1990 at Kulumsa. Adequate fertilizer was applied, a prophylactic pest and disease control programme was followed, and nylon netting was used to prevent lodging. Rusts and other foliar diseases were controlled by periodically spraying the fungicides triadimefon at an active ingredient rate of 0.5 kg ha^{-1} and propiconazol at 0.4 kg a.i. ha^{-1}. At sowing, 60 kg N ha^{-1} and 26 kg P ha^{-1} were soil-incorporated as urea and triple superphosphate, respectively; an additional 60 kg N ha^{-1} (from urea) was top-dressed at the end of the tillering stage of the wheat plants. Weeds were hand-pulled periodically.

Yield components (spikes m^{-2}, spikelets $spike^{-1}$, grains $spikelet^{-1}$, grains $spike^{-1}$, grains m^{-2}) and plant height were determined from two central rows 1 m in length while grain and biomass yields were measured on the central six rows (4.8 m^2) of each plot. Harvest indices were calculated from these values. Kernel weights were obtained for 1000 kernel samples from each harvested plot. Grain yields were converted to t ha^{-1} at 12.5% moisture.

The average annual rate of gain for grain yield and the other measured parameters was estimated by regressing mean values for each cultivar against the respective year of release. Correlation coefficients between grain yield and the other parameters were computed using the annual means for each cultivar.

RESULTS AND DISCUSSION

During the growing seasons of 1989 and 1990, no unique weather conditions were observed that would have affected the expression of wheat yield at either Holetta or Kulumsa. Seasonal precipitation was 11.7% less at Holetta and 7.5% greater at Kulumsa relative to the respective long-term means (Table 2).

Cultivar by year interaction was not significant for any of the crop parameters measured at Kulumsa. Consequently, all parameters were included in a combined analysis across years for the Kulumsa site. Differences among cultivars were significant for all characters measured at both Kulumsa and Holetta.

Changes in grain yield. Mean grain yields were 4.96 t ha^{-1} at Holetta (Table 4) and 3.64 t ha^{-1} at

TABLE 4. Mean grain yield, harvest index, height, grains m^{-2} and grains $spike^{-1}$ for bread wheat cultivars evaluated at Holetta in 1989

Cultivar[a]	Plant height (cm)	Harvest index (%)	Grains $spike^{-1}$ (no.)	Grains m^{-2} (no.)	Grain yield (t ha^{-1})
Israel	138b	23.4d	28.5fg	8721e	3.49f
Laketch	81i	38.0a	37.1b	14950bc	4.49de
Romany	138b	27.2cd	34.9bc	13490c	4.45e
Mamba	124c	32.6b	32.5cde	14070bc	4.73cde
Romany B.C.	144a	29.4bc	30.6ef	13730c	4.95cde
Enkoy	102f	33.5b	33.7cd	15360b	5.00cde
Dereselign	101f	27.3cd	27.4g	11730d	3.57f
K6290-Bulk	121d	31.0bc	31.8de	13870bc	5.04cd
K6295-4A	109e	32.7b	34.7bcd	14620bc	4.72cde
ET13	121d	31.6bc	34.0cd	14740bc	5.14c
Dashen	92g	40.9a	44.3a	17220a	6.37ab
HAR 416	88h	38.4a	42.4a	16830a	5.96b
HAR 407	88h	42.6a	45.1a	17570a	6.61a
Mean	111	33.0	35.1	14377	4.96
C.V.(%)	1.8	9.0	5.2	6.4	7.0

[a]: Cultivars are ordered from the oldest to the most recent releases.
Means within a column followed by the same letter do not differ significantly at the 5% level of the Duncan's Multiple Range Test.

Kulumsa (Table 5). Desiccating dry winds and higher minimum temperatures (Tables 2 and 3) during grain filling normally result in lower mean grain yields at Kulumsa relative to Holetta.

Israel and Dereselign at Holetta and Israel at Kulumsa had significantly lower grain yields than all other cultivars in the trial. HAR 407, one of the most recently released semidwarfs, had the highest grain yield (6.61 t ha^{-1} at Holetta and 4.82 t ha^{-1} at Kulumsa), representing an increase in yield of 89 and 71% relative to Israel, respectively.

Over the period of cultivar improvement from 1949 to 1987, represented by the 13 bread wheats included in this trial, grain yield increased from 3.49 to 6.61 t ha^{-1} at Holetta (Table 2), and from 2.82 to 4.82 t ha^{-1} at Kulumsa (Table 3), an increase in yield of 3.12 and 2.0 t ha^{-1}, respectively. These results agree with data from the annual national yield trials in which successive releases outyielded preceding cultivars (IAR, 1984; Getinet, 1988; IAR, 1989). In a similar experiment, the grain yield potential of irrigated spring bread wheat rose by 2.30 t ha^{-1} over a 32 year period in Mexico (Waddington *et al.*, 1986). For rainfed spring bread wheat, yield increased by 0.57 t ha^{-1} over a 98 year period in Western Australia (Perry and D'Antuono, 1989), 1.30 t ha^{-1} over 58 years in western Canada (Hucl and Baker, 1987), and 0.75 t ha^{-1} over a 50 year period in Argentina (Slafer and Andrade, 1989).

The annual rate of gain in yield was estimated from linear regressions of mean grain yields of cultivars on their respective years of release, using 1949 as the base year. The average annual rate of increase in yield over the 38 year period was 2.21% at Holetta ($b = 0.077 \pm 0.017$ t ha^{-1} yr^{-1}) (Fig. 1), and 1.77% at Kulumsa ($b = 0.050 \pm 0.009$ t ha^{-1} yr^{-1}) (Fig. 2). Using 1970 as the base year, the

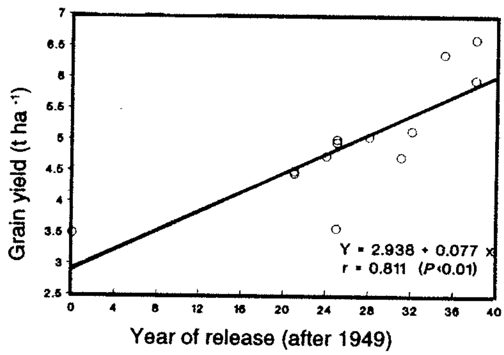

Figure 1. Genetic gain in grain yield of 13 bread wheat cultivars released in Ethiopia from 1949 to 1987 (evaluated in 1989 under 716 mm seasonal rainfall).

TABLE 5. Mean grain yield, harvest index, height, grains m^{-2} and grains $spike^{-1}$ for bread wheat cultivars evaluated at Kulumsa in 1989 and 1990

Cultivar[a]	Plant height (cm)	Harvest index (%)	Grains $spike^{-1}$ (no.)	Grains m^{-2} (no.)	Grain yield (t ha^{-1})
Israel	132de	23.1f	25.7e	8171g	2.82g
Laketch	92hi	35.5b	36.6bc	13270bc	3.43de
Romany	142b	24.9ef	32.2d	9347f	3.15f
Mamba	136cd	26.2de	24.8e	11070e	3.08f
Romany B.C.	149a	21.0g	26.0e	9024fg	3.07f
Enkoy	114g	32.3c	31.9d	12390cd	3.53d
Dereselign	117g	37.1ab	26.3e	11220de	3.83c
K6290-Bulk	140bc	26.3de	33.5cd	10900e	3.46de
K6295-4A	128ef	26.1de	32.9d	12050de	3.33e
ET13	127f	26.9d	31.7d	13240bc	3.53d
Dashen	94h	38.0a	43.9a	13610b	4.50b
HAR 416	89i	37.0ab	39.8b	14930a	4.71a
HAR 407	88i	38.5a	43.9a	15050a	4.82a
Mean	119	30.2	33.0	11870	3.64
C.V.(%)	2.7	10.2	8.2	8.7	5.6

[a]: Cultivars are ordered from the oldest to the most recent releases.
Means within a column followed by the same letter do not differ significantly at the 5% level of the Duncan's Multiple Range Test.

annual rate of increase in yield was 2.53% at Holetta (b = 0.113 ± 0.026 t ha^{-1} yr^{-1}) and 2.61% at Kulumsa (b = 0.068 ± 0.016 t ha^{-1} yr^{-1}). The higher rates of gain in yield during the latter period (1970 to 1987) reflect a rapidly accelerating progress associated with the release of high-yielding semidwarfs from CIMMYT.

The yield levels and annual gains were lower at Kulumsa than at Holetta over the 38 year period of cultivar releases, indicating that apparent genetic progress was less under Kulumsa's environment, characterized by drier and warmer conditions accompanied by higher velocity winds, relative to Holetta (Tables 2 and 3). This result indicates that it may be more feasible to select for improved yield in an environment such as Holetta where the genetic potential for grain yield can be more fully expressed. Greater yield levels at Holetta may also be due in part to the fact that most of the cultivars had been developed at this site (Getinet, 1988; Hailu, 1991).

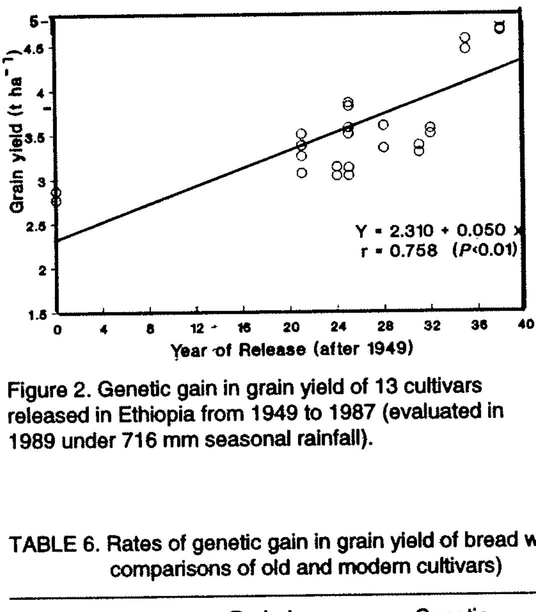

Figure 2. Genetic gain in grain yield of 13 cultivars released in Ethiopia from 1949 to 1987 (evaluated in 1989 under 716 mm seasonal rainfall).

The highest yields of 6.61 and 4.82 t ha^{-1} (Tables 4 and 5) at Holetta and Kulumsa are considerably lower than the yield potential of over 7.5 t ha^{-1} reported by Waddington *et al.* (1986) for irrigated spring bread wheat in Mexico. Yields in the current study are much larger, however, than the 1.59 t ha^{-1} reported by Perry and D'Antuono (1989) in the arid, rainfed environments of Western Australia. Intermediate grain yield levels were reported by Hucl and Baker (1987) in western Canada, and by Slafer and Andrade (1989) in Argentina for spring bread wheat cultivars adapted to their specific moisture-limited environments.

The average annual increases in yield at Kulumsa and Holetta (over the 38 year period) were similar in magnitude to those reported by Fischer and Wall (1976), Waddington *et al.* (1986), and Hernandez (1988) for irrigated spring bread wheat in Mexico, and by Austin *et al.* (1980; 1989) for rainfed winter wheat in the United Kingdom (Table 6). The rates of gain reported under rainfed conditions in the current study were larger,

TABLE 6. Rates of genetic gain in grain yield of bread wheat due to cultivar selection (as estimated from comparisons of old and modern cultivars)

Region	Period	Genetic gain[a]	Base yield[b]	Reference
Holetta, Ethiopia	1949-87	77.00	3490	current study
Kulumsa, Ethiopia	1949-87	50.00	2820	current study
W. Australia	1884-1982	5.77	1022	Perry and D'Antuono, 1989
N. Dakota, USA	1911-79	10.40	1550	Deckerd *et al.*, 1985
Kansas, USA	1919-87	16.20	—	Cox *et al.*, 1988
United Kingdom	1935-78	30.93	2910	Austin *et al.*, 1980
United Kingdom	1935-78	44.19	4960	Austin *et al.*, 1980
United Kingdom	1908-86	40.90	6420	Austin *et al.*, 1989
Mexico	1950-75	77.76	5688	Fischer and Wall, 1976
Mexico	1950-82	60.00	—	Hernandez, 1988
N.W. Mexico	1950-82	59.00	5530	Waddington *et al.*, 1986
Canada	1927-85	14.60	2355	Hucl and Baker, 1987
Sweden	1910-76	15.10	6350	Ledent and Stoy, 1988
Argentina	1930-80	17.70	2660	Slafer and Andrade, 1989

[a]: In kg ha^{-1} yr^{-1}: yields in bushels acre^{-1} were converted using 1 bushel acre^{-1} = 70.6 kg ha^{-1}.
[b]: In kg ha^{-1}.

however, than those reported for rainfed bread wheat elsewhere in the world (Deckerd *et al.*, 1985; 1988; Hucl and Baker, 1987; Cox *et al.*, Slafer and Andrade, 1989). This is not entirely surprising considering that the Ethiopian bread wheat improvement programme has relied heavily on germplasm generated by the CIMMYT wheat programme. Therefore, the high rate of genetic gain can be attributed to release over a relatively short period of high-yielding, semidwarf, CIMMYT materials compared to the lower yielding, tall, traditional line. The more modest relative increases in yield reported for rainfed spring bread wheat in Western Australia (Perry and D'Antuono, 1989), western Canada (Hucl and Baker, 1987) and Argentina (Slafer and Andrade, 1989), undoubtedly reflect the more severe limitations on yield imposed by their respective climates, particularly due to the effects of moisture stress.

Changes in crop parameters other than grain yield. Although there were significant differences among the 13 cultivars in terms of biomass yield, there was no consistent temporal trend over the period of cultivar releases. In fact, the newest releases had biomass yields similar to the oldest cultivar, Israel (data not shown).

Mean harvest index was 33.0% at Holetta and 30.2% at Kulumsa (Tables 4 and 5). The smaller harvest indices recorded for most of the cultivars when grown at Kulumsa could be attributed to the effects of weather on the efficiency of dry matter partitioning by the crop. At both locations, the recently released semidwarfs (Dashen, HAR 416 and HAR 407) had significantly larger harvest indices than all the other cultivars except Laketch at Holetta and Laketch and Dereselign at Kulumsa. Israel had a significantly smaller harvest index than the other cultivars except Romany and Dereselign at Holetta and Romany and Romany B.C. at Kulumsa. Harvest index increased by 19 and 15 percentage units at Holetta and Kulumsa, respectively, over the 38 years of genetic improvement of yield (Tables 4 and 5).

Increased harvest index was associated with a significant reduction in plant height over the period of cultivar releases included in this study (Tables 4 and 5). The earliest releases, Israel, Romany, Mamba and Romany B.C., were among the tallest cultivars at both locations, while the three most recent releases, all semidwarfs, were the shortest. The major exception to this temporal trend was the semidwarf cultivar Laketch released in 1970.

Recent releases did not differ significantly from older cultivars in terms of the number of productive spikes m^{-2} or 1000 grain weights (data not shown).

Israel produced a significantly smaller number of grains m^{-2} than all of the other cultivars except Romany B.C. at Kulumsa (Tables 4 and 5). The number of grains $spike^{-1}$ was least for Israel and

TABLE 7. Relative genetic gains and correlations with grain yield for several wheat crop parameters of 13 bread wheat cultivars grown in 1989 at Holetta and in 1989 and 1990 at Kulumsa

Parameter•	Holetta		Kulumsa	
	RGG• (% yr^{-1})	Correlation (r)	RGG (% yr^{-1})	Correlation (r)
Grain yield	2.21**	—	1.77**	—
Biomass yield	0.22	0.409	0.21	-0.075
Harvest index	1.83**	0.864**	1.47**	0.847**
Plant height	-0.86*	-0.479	-0.78*	-0.802**
Spikes m^{-2}	0.67	0.144	0.26	-0.005
1000 grain weight	-0.15	0.196	-0.13	0.107
Grains m^{-2}	2.43**	0.912**	2.14**	0.826**
Grains $spike^{-1}$	1.37*	0.891**	1.70**	0.819**
Spikelets $spike^{-1}$	0.83*	0.925**	0.50*	0.526**
Grains $spikelet^{-1}$	0.40	0.463	0.94**	0.730**

•: Relative genetic gain.
*, ** Indicate significance at the 5% and 1% levels of probability, respectively.

Dereselign at Holetta, and Israel, Mamba, Romany B.C. and Dereselign at Kulumsa. The recently released semidwarfs exhibited a significantly increased number of grains spike^{-1} and grains m^{-2} at both locations compared to most of the older cultivars. The mean number of grains m^{-2} increased from 8721 to 17570 at Holetta and from 8171 to 15050 at Kulumsa over the 38 year period, representing increases of 101 and 84.2%, respectively. Over this period, mean number of grains spike^{-1} increased by 58% at Holetta and by 71% at Kulumsa.

Wheat grain yield exhibited a highly significant and positive correlation with harvest index at both locations, but was not significantly correlated with biomass yield at either location (Table 7). Grain yield was also strongly and positively correlated with grains m^{-2}. Partitioning grains m^{-2} into its two components, grains spike^{-1} and spikes m^{-2}, revealed a strong positive correlation between grain yield and grains spike^{-1} at both locations. Grain yield was significantly and positively correlated with the number of spikelets spike^{-1} at both locations and with the number of grains spikelet^{-1} at Kulumsa. By contrast, grain yield was not significantly correlated with productive spikes m^{-2} or 1000 grain weight. Grain yield was negatively correlated with plant height, but significantly so only at Kulumsa.

The relative annual gains for the crop parameters measured in this study are listed in Table 7. Significant positive temporal trends were exhibited by grain yield, harvest index, grains m^{-2}, grains spike^{-1}, and spikelets spike^{-1} at both locations, and by grains spikelet^{-1} only at Kulumsa. The rates of increase were smaller for most of the parameters at Kulumsa, reflecting the moisture-stressed character of that environment. Plant height showed a significant decreasing temporal trend at both locations.

The results of this study indicate that the measured gains in yield resulted from a continuous improvement in the number of grains spike^{-1}, and, therefore, grains m^{-2}. This feature was particularly pronounced in the recently released semidwarfs, similar to the findings of Waddington *et al.* (1986) for Mexican bread wheats possessing the *Rht* dwarfing genes that were released between 1962 and 1982.

From the present results, it can be concluded that the grain yield of rainfed bread wheat cultivars released for the highlands of Ethiopia has been substantially increased over 38 years of cultivar improvement. The improvement of yield was more pronounced in the cooler and more moist production environment of Holetta relative to Kulumsa, where desiccating winds accompany soil moisture stress during the grain filling period. The improvements resulted from an increase in harvest index associated with a larger number of grains spike^{-1} and, therefore, grains m^{-2}.

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