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Heritability, Genetic Advance and Correlations in 254 Maize Doubled Haploid Lines × Tester Crosses under Drought Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMMAN designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AMAA and AMAG managed the literature searches. Author EHMH managed the experimental process and performed data analysis. All authors read and approved the final manuscript.

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ABSTRACT

One of the major advantages of doubled haploid lines (DHL) is the maximum genetic variance between lines for testcross performance from the first generation. Two hundred fifty four testcrosses were produced as a result of crossing between 254 DHL's and an inbred line tester. The objectives were: (i) to determine the genotypic (GCV) and phenotypic (PCV) coefficients of variation, heritability (h^2_b) and genetic advance (GA) from selection under water stressed at flowering (WSF) and grain filling (WSG) and under well-watered (WW) and (ii) to identify the traits of significant correlation with grain yield under water stressed environments. A split plot design in lattice (16 x 16) arrangement was used with two replications, where three irrigation treatments (WW, WSF and WSG) were allotted to main plots and genotypes (254 top crosses) to sub-plots. A separate analysis of variance of RCBD was also performed under each irrigation treatment for estimating the genetic parameters. The PCV and GCV estimates were high for plant height (PH), ear height (EH) and grain yield/plant (GYPP), low for other studied traits, except for barren stalks

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(BS) which was of medium magnitude. The highest h^2 estimate (>90%) was exhibited by days to anthesis (DTA), days to silking (DTS), PH, EH and leaf rolling (LR) under all environments and anthesis silking interval (ASI) under WW, while the lowest h^2 estimate (< 46%) was shown by BS and ears plant^{-1} (EPP) traits. For DTA, DTS, BS, EPP, GYPP and grain yield/ha (GYPH) traits, heritability was increased in stressful environments (WSF or WSG), while for ASI and LR, the opposite was true. The highest GA (>30%) was shown by PH followed by EH and GYPP, while the lowest GA (<1%) was shown by EPP. The best selection environment for GYPP and GYPH was the stressed one (WSF or WSG). GYPH or GYPP of top crosses showed significant and negative genetic correlations with DTA, DTS, ASI, BS and LR and significant positive correlations with EPP and PH in all environments.

Keywords: Correlation analysis; selection gain; genetic variance; broad-sense heritability; doubled haploids; water stressed.

1. INTRODUCTION

Egypt ranks the fifth in the world with respect of average productivity of maize (*Zea mays* L.) after USA, France, Germany and Italy [1]. However, the local production of maize is not sufficient to satisfy the local consumption and Egypt imports about six million tons of maize grains every year.

To reach self-sufficiency of maize production in Egypt, efforts are devoted to extend the acreage of maize; in the desert and to improve the maize productivity per unit area. However, growing maize in the sandy soils of low water-holding capacity would expose maize plants to drought stress, which could result in obtaining low grain yields under such conditions. Moreover, the expected future shortage in irrigation water necessitates that maize breeders should pay great attention to develop drought tolerant maize hybrids that could give high grain yield under water-stress environments.

During the last few decades, considerable efforts have been devoted to improve yield performance of maize under drought stress conditions through breeding, and to understand the mechanisms involved in drought tolerance [2]. In that context, CIMMYT developed some tropical maize drought tolerant populations while maintaining their yield potential under favorable conditions [3]. Developing such populations requires adoption of proper techniques of identifying and selecting tolerant genotypes to soil water stressed. This also requires identifying traits most suitable for selecting drought tolerant maize.

Several investigators emphasized the role of maize genotypes in drought tolerance. Tolerant genotypes of maize were characterized by having shorter anthesis-silking interval (ASI) [4], more ears plant^{-1} [5,6] and greater number of kernels/ear [6,7]. The presence of genotypic differences in drought tolerance would help plant breeders in initiating successful breeding programs to improve such a complicated character.

Several investigators studied the correlations between yield and other plant attributes under soil moisture stress in order to practice rapid and accurate indirect selection for drought tolerance. A strong negative association was reported between grain yield and each of anthesis– silking interval [4] and barren stalks [5]. Likewise, a strong positive association was found between grain yield and both number of ears plant^{-1} [6,8, 9] and number of kernels/row [6,10]. These investigators suggested that such traits could be used as indicators of drought tolerance in maize.

Breeding for tolerance to drought is difficult because the genetic mechanism that controls the expression of such tolerance in crop plants is poorly understood and because of the polygenic nature of such a complicated character [11]. Selection for increased drought tolerance was associated with a significant reduction in anthesis-silking interval (ASI) and barrenness, and an increase in ears plant^{-1}, stay green and harvest index [12-19].

Two hundred fifty four maize doubled haploid (DH) lines developed by DuPontPioneer *via* the *in vivo* (inducer) technique from the crosses between drought tolerant inbreds and good general combiners. Two hundred fifty four top-cross hybrids were produced as a result of crossing between the 254 DH lines and the inbred line tester PHDMF that showed drought tolerance performance and high general combining ability. The objectives of the present study were: (i) to determine the change in genotypic and phenotypic coefficients of variation, heritability and genetic advance from selection from well-watered to water stressed at flowering and grain filling and (ii) to identify the traits of significant correlation with grain yield under water stressed environments.

2. MATERIALS AND METHODS

This study was carried out in the summer seasons of the years 2011 and 2012 in DuPontPioneer Research Station at Sandanhur, Benha, Qaliubiya, Egypt. The station is located at 30° 25' 8" N, 31° 11' 24" E and Altitude is 74 m above sea level.

2.1 Plant Materials

Seeds of 254 maize (*Zea mays* L.) doubled haploid lines (DHL's) resulted *via* the inducer technique (embryo rescue) used by DuPontPioneer from the crosses between the drought tolerant inbreds (PHM6T – PHJFN – PH1723) and the good general combiners (PH12J4 – PH1CGY – PHM7E) were obtained from Research Department of the Pioneer Hi-Bred Inc. Seeds of 254 test cross hybrids were produced as a result of crossing between the 254 double haploid lines and the inbred line tester PHDMF that shows drought tolerance performance and high general combining ability. Two hybrids; one single cross hybrid (PHN11) and one three-way cross hybrid (PHR77) with high yield potential and drought tolerance performance (Table 1) were used as checks in the evaluation experiment. All the genotypes used were obtained from the germplasm of DuPontPioneer.

2.2 Methods

2.2.1 First season (Crossing blocks)

On the 1st of April 2011, the 254 DH lines and the tester parent PHDMF were planted at DuPontPioneer Research Station, Sandanhur, Benha, Qaliubiya, in a crossing block to produce the top crosses (single cross hybrids). The DH lines (females) were planted in 4 meters long rows and 4 ranges each range about 63 to 64 rows, while the tester inbred line PHDMF (male) was planted in one range of 65 rows which is equivalent to (1:4) (Tester: DH lines).

During the flowering stage, the female shoots were covered before the emergence of the silks in 10 plants for each DH inbred line to control the hybridization process and eliminate contamination with pollen grains. In the same stage, the male tassels of the tested inbred PHDMF were covered one day before artificial pollination to make sure that the pollen captured in the bags was the required pollen. The result of this year was seeds of 254 single cross hybrids (top crosses) that were used in the second year of this study.

2.2.2 Second season (Evaluation experiment)

On the 1st of May of the year 2012, the experimental location was prepared for planting by tractors to get a fairly fine soil to be convenient for the planting by planter. During the tillage process, superphosphate 15.5% at the rate of 30 kg P_2O_5 fed^{-1} (fed=feddan=4200 m^2) as well 25 kg K_2SO_4 fed^{-1} of potassium sulfate 48% were added to the soil. After the tillage was done, laser leveling was performed to the location. During the seedbed preparation, the seeds of the 254 hybrids and the two check cultivars were packed in small easy tear bags each of 45 kernels; also the planting arrangements were prepared to get ready for the planting process. On the 15th of May the seeds were planted by 4 rows Vacuum Plot planter SRES®; this type of planter is equipped with a device to bury the irrigation tubes (T-Tapes) under the soil. The large number of top crosses (254) that has been obtained in the first season plus two check cultivars with a total of (256) genotypes were sown in the field in two replicates; each experimental plot included two rows of 0.7 meter width and 4.0 meters long with a 1.0 meter long ally between ranges.

2.3 Experimental Design

A split-plot design in simple lattice (16 x 16) arrangement with two replications was used, where main plots were allotted to three irrigation regimes, *i.e.* well-watered (WW), water stressed at flowering (WSF) and water stressed at grain filling (WSG). Sub-plots were devoted to 256 genotypes (254 top crosses and 2 check cultivars).

2.4 Irrigation System

The irrigation method used in this study is one of the most advanced methods of irrigation systems in the world; it is one of the subsurface irrigation methods called T-Tape Drip Tape® by John Deer irrigation (16 mm/30 cm/1.3 LPH). It is a

Table 1. Pedigree and drought tolerance for all the genotypes used in the current study

Genotype	Pedigree	Drought tolerance
Doubled haploid lines (DHL) from DHL1 to DHL254	Doubled haploid lines resulting from crossing between the drought tolerant inbreds (PHM6T – PHJFN – PH1723) and the good general combiners (PH12J4 – PH1CGY – PHM7E)	Unknown
PHDMF	Inbred line tester	Tolerant
Topcrosses	254 top crosses resulted from crossing between the tester PHDMF and the DH lines (DHL1 to DHL254)	Unknown
Check cultivars:		
PH-30N11	Yellow single cross hybrid	Tolerant
PH-30R77	Yellow three-way cross hybrid	Tolerant

Source: All genotypes are owned by DuPont Pioneer, PH= Pioneer Hybrid

type of drip irrigation system which gives the chance to supply a specific amount of water for each plant separately, the main irrigation lines (Lay Flats) were allotted to the subsurface irrigation tubes (T-tapes), each main line is operated by a pressure reducing valve to control the water pressure in the irrigation system and to control the water regime application during the season.

Water availability during the water regime is very important to understand if the treatment is actually under stress or not. For that reason, a very sophisticated advanced tool (Diviner)® was allotted to the location after 15 days from planting; each treatment has 2 tubes fixed under the two replicates of the check cultivar PH-30N11 to take readings for the water content in the soil for 1.0 meter depth and each 10 cm a separate reading.

2.5 Agricultural Practices

During the season, chemical weed control was done by applying Gesbrim® (Atrazine) and Harness® (Acetochlor) as pre-emergence weed control and after 30 days, hand weed control was made by manual hoeing. Insect control was performed three times during the whole season by spraying the corn borers with Lambada Plus® 21% (chlorobirophose). Fertilization with nitrogen was done through the irrigation system using liquid fertilizer in the form of Urea at the rate of 150 kg N per feddan (357 kg N per hectare).

2.6 Water Regimes

Three different water regimes were used: 1.Well-watered (WW), where the full requirements of water during the whole season was supplied. 2. Water stressed at flowering stage (WSF), where irrigation water was withheld 10 days prior to anthesis and lasted for a complete 30-day period making a stress period of 25 days. 3. Water stressed at the grain filling stage (WSG), where irrigation water was withheld 10 days post 80% anthesis and lasted till harvest without any irrigation.

2.7 Soil and Water Analyses

The soil of the experimental site contained clay (49.35%), silt (18.92%), fine sand (15.08%) and coarse sand (16.65%). Soil type was clay; SP was 74%; pH was 7.14 and EC was 0.70 dSm^{-1}. The soluble cations of soil Ca, Mg, Na and K were 2.61, 1.30, 2.40 and 0.69 $mEqu^{-l}$ and the soluble anions Cl, CO_3^{2-} and SO_4^{2-} were 4.10, 2.20 and 0.70 $mEqu^{-l}$, respectively. Irrigation water pH was 7.15 and EC was 0.47 dSm^{-1}. The soluble cations of water Ca, Mg, Na and K were 3.70, 0.60, 9.18 and 0.64 $mEqu^{-l}$ and the soluble anions Cl, CO_3^{2-} and SO_4^{2-} were 1.40, 2.20 and 10.50 $mEqu^{-l}$, respectively.

2.8 Meteorological Data

A weather station was installed at the location to collect the required weather data for the site. On May, June, July, August and September, minimum temperature was 20, 23, 25, 25 and 25; maximum temperature was 32, 35, 36, 36 and 36, mean temperature was 26, 29, 30, 30 and 30, and average relative humidity was 39, 48, 55, 49 and 49%, respectively.

2.9 Data Recorded

1. Days to 50% anthesis (DTA)
2. Days to 50% Silking (DTS)
3. Anthesis-silking interval (ASI)
4. Plant height (PH)
5. Ear height (EH)
6. Leaf rolling (LR)

7. Barren stalks (BS%)
8. Ears plant-1 (EPP)
9. Grain yield plant-1 (GYPP)
10. Grain yield ha-1 (GYPH) (ton/ha)

2.10 Biometrical and Genetic Analyses

All the data were subjected to analysis of variance (ANOVA) of split plot experiment using Minitab 17 software and of lattice design (16 × 16). Comparisons of means were made using least significant difference (LSD) test at *P*=0.05 and 0.01 levels of confidence according to Steel et al. [20]. Each treatment was analyzed separately as randomized complete blocks design for the purpose of estimating genetic parameters. Expected mean squares at separate and across the three treatments were estimated from ANOVA table (Table 2) according to Hallauer and Miranda [21].

Table 2. Analysis of variance and expected mean squares (EMS) for each of the three treatments

SOV	df	MS	EMS
Genotypes	g-1 = 255	M_2	$\delta^2_e + r\,\delta^2_g$
Error	(r-1) (g-1) = 255	M_1	δ^2_e

Genotypic (σ^2_g), phenotypic (σ^2_{ph}) variances were calculated as follows:

$$\sigma^2_g = (M_2 - M_1) / r,$$
$$\sigma^2_{ph} = \sigma^2_g + (\sigma^2_e / r),$$

Where

r = number of replications.

2.10.1 Heritability in the broad sense

Heritability in the broad sense (h^2_b %) for a trait in a separate environment was estimated according to Singh and Chaudhary [22] using the following formula:

$$h^2_b\,\% = 100 \times (\delta^2_g / \delta^2_p)$$

Where:

σ^2_g = genetic variance, and δ^2_p = phenotypic variance.

2.10.2 Expected genetic advance from selection

Expected genetic advance from selection for all studied traits as a percent of the mean was calculated according to Singh and Chaudhary [22] as follows:

$$GA\,(\%) = 100\,K\,h^2\sigma_{ph} / \overline{x},$$

Where: $\overline{x}$ = General mean, σ_{ph} = Square root of the denominator of the appropriate heritability, h^2 = The applied heritability, K = Selection differential (k = 1.76, for 10% selection intensity, used in this study).

2.10.3 Correlations

The genotypic correlation coefficients (r_g) were calculated between grain yield and other studied traits under each of well water (WW), water stressed at flowering stage (WSF) and water stressed at grain filling stage (WSG) environments using the following formula:

$$r_g = \delta^2_{gxy} / (\delta^2_{gx} \,.\, \delta^2_{gy})^{1/2}$$

Where:

δ^2_{gxy} = the genotypic covariance of two traits X and Y.
δ^2_{gx} and δ^2_{gy} = the genotypic variance of the two traits X and Y , respectively.

3. RESULTS AND DISCUSION

3.1 Genotypic and Phenotypic Coefficient of Variation

Estimates of genotypic and phenotypic coefficient of variation for studied traits under well-watered (WW), water stressed at flowering (WSF) and water stressed at grain filling (WSG) conditions are presented in Table 3 and Figs. 1 and 2.

In general, there was a tendency towards higher values of PCV than GCV for most studied traits under all environments (WW, WSF and WSG), indicating little effect of environment. The exception was for BS trait, where PCV was greater than GCV, indicating high effect of environment. The highest estimates of PCV and GCV (>20 and 17%, respectively) were expressed by PH trait, followed by EH and GYPP, indicating that selection would be effective for these traits. In contrast, the lowest PCV and GCV were shown by EPP, ASI, LR, DTA, GYPH and DTS (< 5.0%), indicating that selection for these traits would be less effective than for the former traits. The PCV and GCV for BS trait were of medium magnitude, so selection for such trait would be of medium effectiveness.

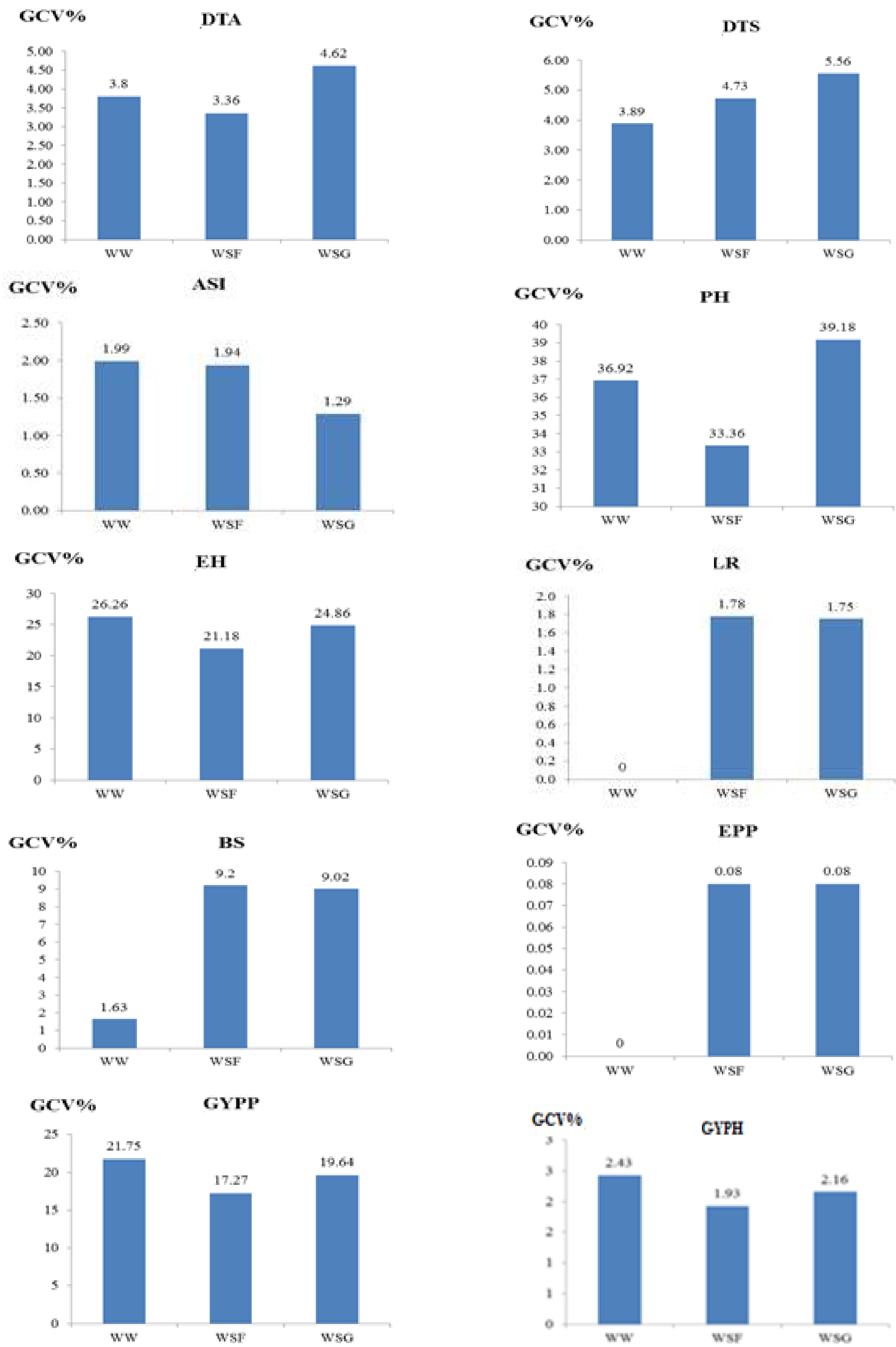

Fig. 1. Genotypic coefficient of variation (GCV%) for studied traits of maize top crosses under WW, WSF and WSG conditions

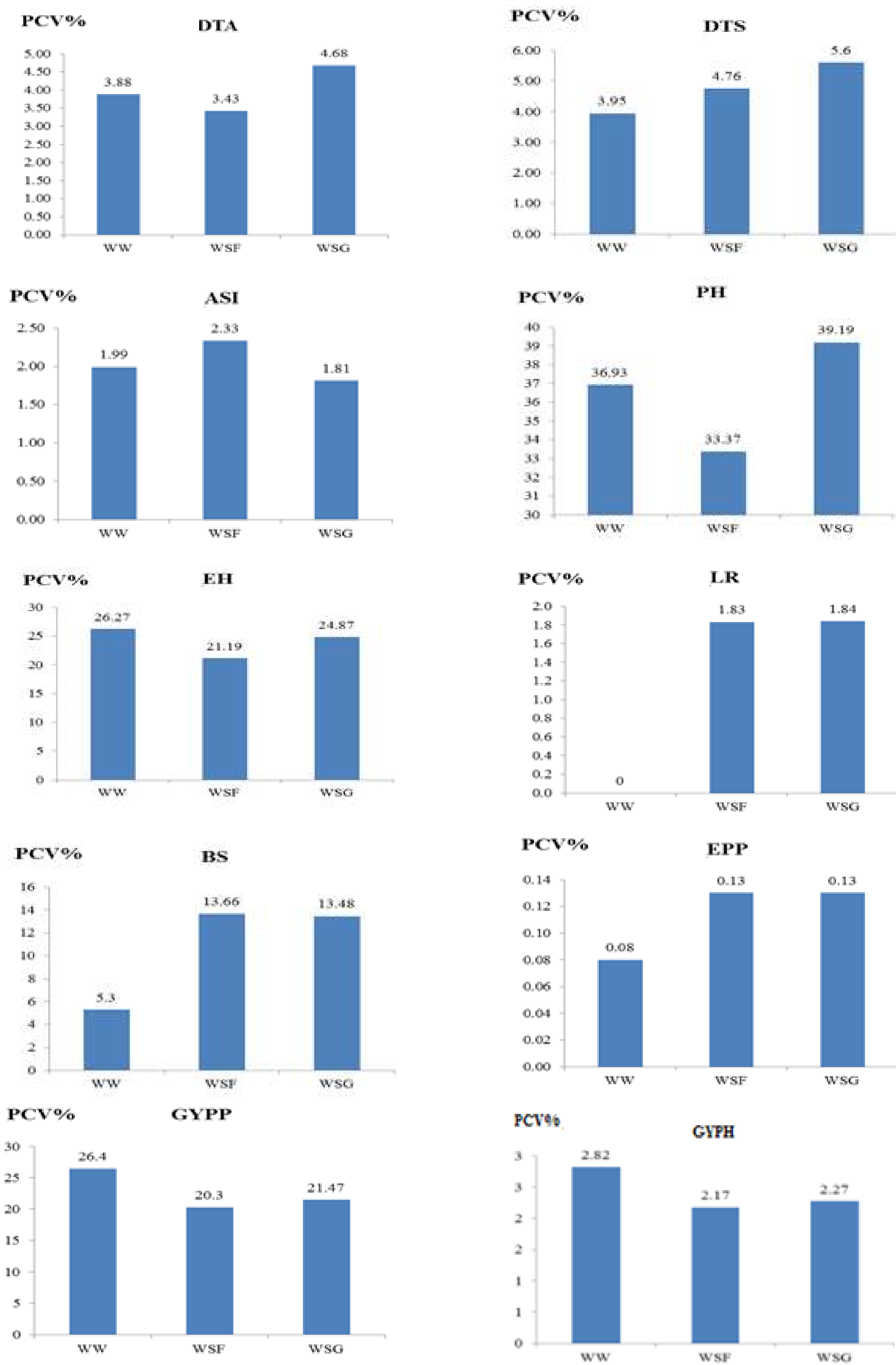

Fig. 2. Phenotypic coefficient of variation (PCV%) for studied traits of maize top crosses under WW, WSF and WSG conditions

Table 3. Genotypic (GCV%) and phenotypic (PCV%) coefficient of variation for studied traits of maize DHL's x tester crosses evaluated under well-watered (WW), water stressed at flowering (WSF) and water stressed at grain filling (WSG) conditions

Parameter	WW	WSF	WSG	WW	WSF	WSG
		DTA			**DTS**	
GCV%	3.80	3.36	4.62	3.89	4.73	5.56
PCV%	3.88	3.43	4.68	3.95	4.76	5.60
		ASI			**PH**	
GCV%	1.99	1.94	1.29	36.92	33.36	39.18
PCV%	1.99	2.33	1.81	36.93	33.37	39.19
		EH			**LR**	
GCV%	26.26	21.18	24.86	N/A	1.78	1.75
PCV%	26.27	21.19	24.87	N/A	1.83	1.84
		BS			**EPP**	
GCV%	1.63	9.20	9.02	0.01	0.08	0.08
PCV%	5.30	13.66	13.48	0.08	0.13	0.13
		GYPP			**GYPH**	
GCV%	21.75	17.27	19.64	2.43	1.93	2.16
PCV%	26.40	20.30	21.47	2.82	2.17	2.27

N/A = Not available

There was a tendency of increase in GCV and PCV values from well-watered to water stressed at flowering and grain filling for DTA, DTS, PH, BS and EPP and a tendency of decrease in GCV and PCV for ASI, EH, GYPP and GYPH (Figs. 3 and 4).

3.2 Heritability and Genetic Advance

Estimates of heritability in the broad sense (h^2_b) and genetic advance (GA) from selection based on 10% selection intensity for studied traits under well-watered (WW), water stressed at flowering (WSF) and water stressed at grain filling (WSG) conditions are presented in Table 4 above and Figs. 3 and 4.

Broad sense heritability (h^2_b) ranged from 0.001 and 9.48% for EPP and BS, respectively under well-watered to 99.98% for plant height under WW and WSF. The largest h^2_b estimates (> 90.0%) were shown by five traits, *i. e*. DTA, DTS, PH, EH and LR under all studied environments (WW, WSF and WSG) and one trait, *i. e*. ASI under WW conditions.

Table 4. Heritability in the broad sense (h^2_b) and genetic advance (GA) from selection for studied traits of maize DHL's x tester crosses evaluated under well-watered (WW), water stressed at flowering (WSF) and water stressed at grain filling (WSG) conditions

Parameter	WW	WSF	WSG	WW	WSF	WSG
		DTA			**DTS**	
h^2_b%	95.60	96.04	97.40	97.23	98.79	98.89
GA%	6.68	5.92	8.12	6.85	8.32	9.79
		ASI			**PH**	
h^2_b%	99.56	68.99	51.13	99.98	99.98	99.96
GA%	3.50	3.41	2.28	64.98	58.72	68.95
		EH			**LR**	
h^2_b%	99.93	99.83	99.94	N/A	94.96	90.47
GA%	46.21	37.27	43.75	N/A	3.14	3.08
		BS			**EPP**	
h^2_b%	9.48	45.32	44.80	0.001	33.33	33.33
GA%	2.87	16.19	15.88	0.001	0.14	0.13
		GYPP			**GYPH**	
h^2_b%	67.84	72.33	83.62	74.33	79.25	90.38
GA%	38.28	30.39	34.56	4.28	3.39	3.79

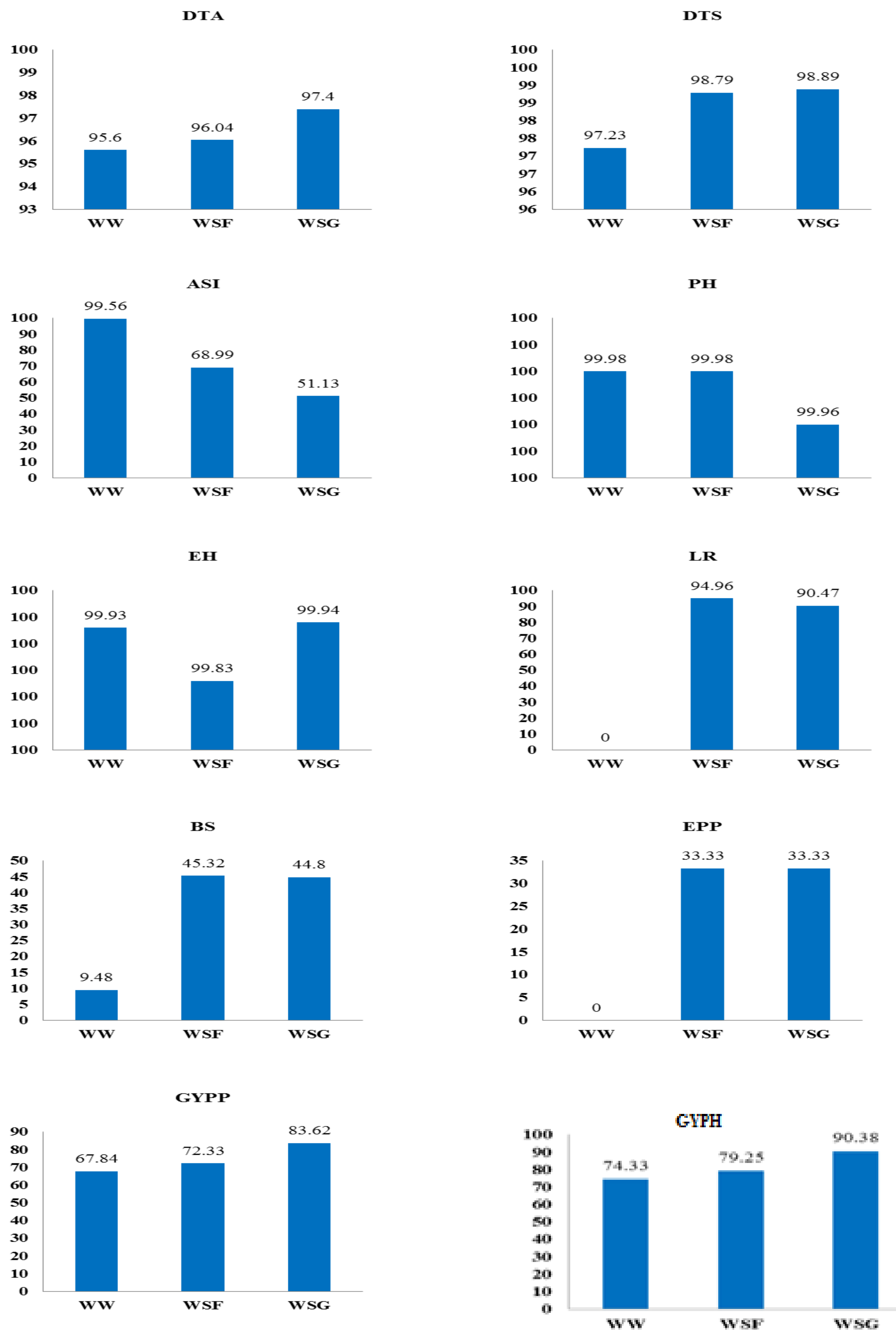

Fig. 3. Broad sense heritability (h^2_b %) for studied traits of maize top crosses under WW, WSF and WSG conditions

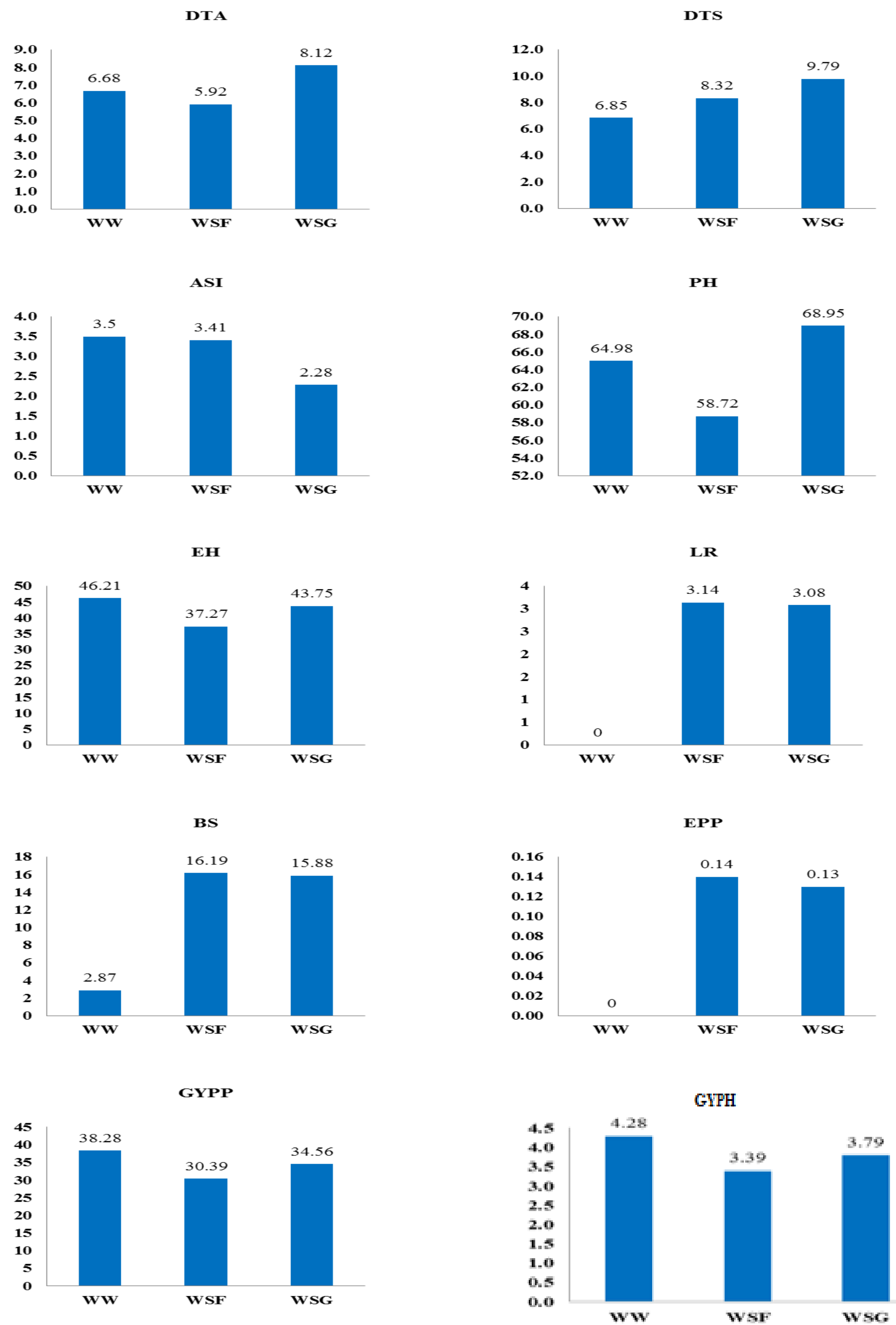

Fig. 4. Genetic advance (GA%) from selection for studied traits of maize top crosses under WW, WSF and WSG conditions

The estimates of h^2_b were of low magnitude (< 46.0%) in EPP and BS traits under all environments, indicating that the genetic variance was the smallest component of phenotypic variances, and that environment had great effect on the performance of these two traits. Low heritability estimates for these two traits, could be attributed to the very small magnitude of genotypic variance as reported by Al-Naggar et al. [17,23].

It is also obvious from the results that h^2_b estimates were the lowest under full irrigation as compared to those under drought stress at flowering and/or grain filling stages for 6 out of 10 studied traits (DTA, DTS, BS, EPP, GYPP and GYPH), *i.e*. showing higher h^2_b under water stressed as compared to non-stressed environments (Fig. 3).

On the contrary, the h^2_b estimates were the lowest under WSF and WSG as compared to well-watered for the two traits ASI and LR (Fig. 3). The magnitude of h^2_b estimates under all environments under study for PH and EH was approximately the same.

Similar to these results for DTA, DTS, BS, EPP, GYPP and GYPH traits, other researchers found that heritability was increased in stressful environments [17,18,23-33]. However, some researchers reported a decrease in heritability under stressed environments [34-42]. This is similar to what was found for the ASI and LR traits in this study.

The magnitude of expected genetic advance (GA) from direct selection was higher under water stressed environment at flowering and grain filling than under well-watered for DTA, DTS, PH, BS, and EPP, *i.e.* there was a tendency of increase in GA by increasing water stressed (Fig. 4).

In contrast, the expected GA from direct selection was lower under drought at flowering and grain filling than under well-watered environment for ASI, EH, GYPP and GYPH (Fig. 4).

These results indicated that predicted selection gain would be higher if selection was practiced under water-stress environments for lower values of DTA, DTS, PH and BS; and under well watered environment for higher grain yield plant^{-1}, higher grain yield ha^{-1}, short ASI and lower EH.

It is worthy to mention that direct selection under the water-stressed environments would ensure the preservation of alleles of drought tolerance [16,23,43-47], while direct selection under full irrigation regime would take advantage of the high heritability; especially for grain yield [28,29,48-50].

3.3 Trait Interrelationships

Estimates of genetic correlation coefficients between GYPH and other studied traits under the three studied environments (WW, WSF and WSG) were calculated across all top crosses and presented in Table 5.

Grain yield/ha of top crosses had perfect and positive genetic associations (≥ 0.93**) with grain yield/plant, under the three environments. Estimates of genetic correlation coefficients between GYPH and other studied traits are very close in magnitude and sign to those between GYPP and the same other traits.

Table 5. Genetic correlation coefficients between GYPH or GYPP and other studied traits across 245 top crosses under WW, WSF and WSG environments

Trait	WW	WSF	WSG	WW	WSF	WSG
	Grain yield ha^{-1} (GYPH)			Grain yield plant^{-1} (GYPP)		
DTA	-0.28*	-0.32**	-0.27*	-0.20*	-0.27*	-0.22
DTS	-0.25*	-0.40**	-0.29*	-0.19*	-0.33**	-0.25*
ASI	-0.16*	-0.37**	-0.17*	-0.18*	-0.30*	-0.19*
BS	-0.43**	-0.56**	-0.57**	-0.40**	-0.62**	-0.58**
PH	0.17*	0.18*	0.21*	0.12	0.14*	0.17*
EH	0.14*	0.08	0.18*	0.06	-0.01	0.14*
LR	-	-0.22**	-0.16*	-	-0.22*	-0.20*
EPP	0.47**	0.55**	0.57**	0.52**	0.62**	0.58**
GYPP	0.93**	0.93**	0.95**			
GYPH				0.93**	0.93**	0.95**

WW = well watering, WSF= water stressed at flowering, WSG= water stressed at grain filling,
**and ** indicate that r_g estimate exceeds once and twice its standard error, respectively*

Grain yield ha^{-1} or $plant^{-1}$ of crosses showed a significant (*P*=.01) and positive genetic correlation with ears/plant, under all stressed and non-stressed environments.

On the contrary, GYPH or GYPP of top crosses showed significant (*P*=.01 or *P*=.05) and negative genetic correlations with DTA, DTS, ASI, BS and LR in all environments (Table 5). These traits could be considered as selection criteria for drought tolerance in maize. This conclusion is in accordance with other investigators [3,15,19,33, 51-53]. This indicates that earlier anthesis and silking, shorter interval between anthesis and silking, less barren stalks and non-rolling of leaves were suitable characteristics for obtaining high grain yield either under water stressed at flowering, water stressed at grain filling or well watered environments.

Significant correlations under drought stress were found between maize grain yield and each of number of barren plants [54,55], ASI and ears per plant [14,16] leaf rolling, and number of kernels $plant^{-1}$ [51,53,56-58].

Significant and positive r_g values detected between GYPH or GYPP of top crosses and plant height (Table 5) under WSG and WSF environments indicated that taller plants of top crosses are of high grain yield, under drought conditions. This conclusion is in agreement with others [59,60], who reported that taller genotypes are higher yielding than shorter genotypes under both WW and water stressed environments.

4. CONCLUSIONS

Results of this study indicated that predicted selection gain **(**GA) would be higher if selection was practiced under water-stressed environments (WSF and/or WSG) for lower values of DTA, DTS, PH and BS and under well-watered environment for higher grain yield $plant^{-1}$, higher grain yield ha^{-1}, short ASI and lower EH. Direct selection under the water-stressed environments would ensure the preservation of alleles for drought tolerance. In contrast, the expected GA from direct selection was higher under well-watered environment than under water stress at flowering and grain filling for ASI, EH, GYPP and GYPH. Selection under full irrigation regime would take advantage of the high heritability; especially for grain yield. Correlation analysis indicated that earlier anthesis and silking, shorter interval between anthesis and silking, fewer barren stalks and non-rolling of leaves were suitable characteristics for obtaining high grain yield either under water stressed at flowering, water stressed at grain filling or well-watered environments. Moreover, taller plants of top crosses were of high grain yield, under water stress conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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