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Inheritance of stem diameter and its relationship to heat and drought tolerance in wheat (*Triticum aestivum L.*)

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Genetic control of stem diameter and other stem attributes of wheat in relation to yield components were analyzed in a 7- parent F1 diallel cross in favorable, drought and drought combined heat environments, as well as in 12 F2 populations under heat stress. Polygenes with mainly additive effects were involved in the control of stem diameter which segregated in normal distributions in the F2. The narrow-sense heritability was of comparable magnitude under favorable (0.73), drought (0.62) and drought + heat stress (0.76); whereas heritability of stem dry weight was reduced under stress. Stem diameter was positively correlated under both drought and drought + heat stresses with stem weight and stem density. Stem diameter was significantly associated with 1000 kernel weight and grain yield per spike in three environments. Such strong associations of stem diameter with single grain mass and grain yield per spike under stress indicated the important role this character play in sustaining grain filling through provision of greater capacity for assimilation in the stem before mobilizing it to grains.

Key words: Stem diameter, heat stress, drought stress, diallel analysis.

INTRODUCTION

Despite the wide adaptation of wheat (*Triticum aestivum L.*), which can be grown in many different environments ranging from temperate-irrigated to dry and high-rain-fall areas and from warm-humid to dry-cold conditions (Acevedo et al., 2002; Lillemo et al., 2005), drought and heat stresses are of common occurrence during grain filling in wheat growing areas with a mediterranean climate (Wardlaw, 2002). Drought stress causes 11 to 61% reduction in kernel mass (Cseuz et al., 2002) while heat stress causes 10 to 15% yield loss due mainly to reduced single kernel weight (Wardlaw and Wrigley, 1994). Drought and heat stresses during anthesis and grain filling caused reduction in kernel number and size, grain yield and harvest index (Blumenthal et al., 1995; Veisz et al., 2005), grain growth duration (Ishag and Mohamed, 1996; Stone and Nicholas, 1995a, b) as well as kernel weight per spike (Denecic et al., 2000). Grain growth and development in wheat depend on carbohydrates from three sources: (i) carbohydrates produced after anthesis and translocated directly to the grains, (ii) carbohydrates produced after anthesis but stored temporarily in the stem before being remobilized to the grains, and (iii) carbohydrates produced before anthesis stored mainly in the stem and remobilized to grains during grain filling (Gallager et al., 1975; Daniels et al., 1982; Kobata et al., 1992; Ehdaie et al., 2006a). Under drought and heat stresses, photosynthesis rapidly declines after anthesis which limits the contribution of current assimilates to the grain leading to reduction in kernel dry weight (Wardlaw and Willenbrink, 2000).

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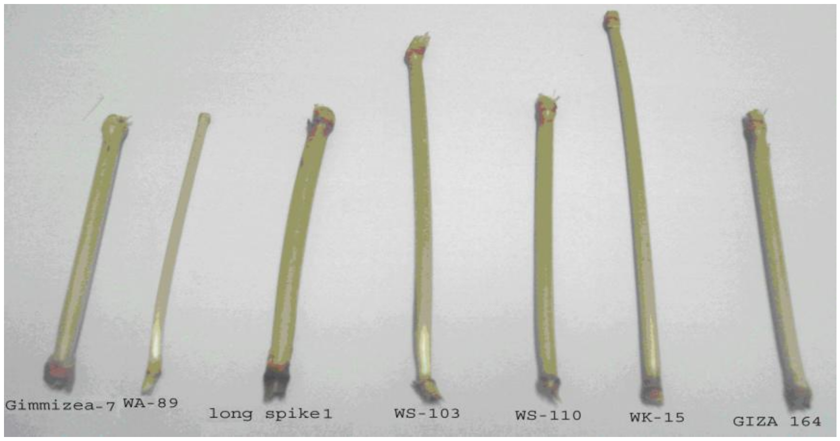

Figure 1. A photograph of the second internode for the seven parents under heat stress conditions.

The wheat canopy respires rapidly during grain filling (Gent and Kiyomoto, 1985; McCullough and Hunt, 1989). Flag leaf photosynthesis alone cannot support both respiration and grain growth under terminal stress (Rawson and Evans 1983). A substantial amount of the carbohydrates used during grain filling in wheat must come from reserves assimilated before anthesis (Gent, 1994). Stem characteristics such as internode length, internode weight, internode specific weight of the wheat plant were found to be affecting accumulation and mobilization of stem reserves with maximum specific weight appeared to be correlated with stem mobilized dry matter (Ehdaie et al., 2006b). Stem diameter and stem density might play an important role in stabilizing grain yield in stressful environments and could be used as selection criteria for enhancing drought and heat tolerance. The objectives of the present study were:

1. To analyze the genetic system controlling stem diameter and stem density in wheat under favorable, drought and heat stress conditions,
2. To find out any possible relationships between stem characters and grain filling capacity under heat and drought stresses,
3. To analyze the segregating patterns of stem diameter in a number of wheat crosses.

MATERIALS AND METHODS

Seven local genotypes of bread wheat (*T. aestivum L.)* quite variable in stem diameter and other stem attributes (Figure 1) were used in this study. The seven genotypes comprised three with large stem diameter, namely Gimmeiza-7(P_1), Long spike 1(P_3) and Giza-164 (P_7), one with medium stem diameter (WA-89, P_2) and three with small stem diameter (WS-103 (P_4), WS-110 (P_5) and WK-15 (P_6)). The seven parental genotypes were crossed in a diallel fashion in 2005 to 2006 winter season. In the following 2006 to 2007 season, seeds of the seven parents and the 21 F_1 crosses were grown in favorable, drought stress and combined drought and heat stress environments.

The favorable environment was that of the fertile clay-loam soil of the Experimental Farm of Assuit Uinversity with the 28 entries of the diallel cross (reciprocal were pooled) sown in optimal date (25th November) and irrigation applied each two weeks. For drought stress environment, seeds were sown in the same optimal date in the infertile sandy-calcareous soil of El-ghoraieb Experimental Station which is located 25 km south of Assuit where soil contains 80% sand and 19% calcium carbonates. Irrigation was applied each 12 days with a total of five irrigations throughout season (excluding the establishment irrigation). For the combined drought and heat stress environment, seeds were sown in the sandy-calcareous soil of El-ghoraieb Exp. St. one month later (25th December). So as to allow the drought-stressed plants to be exposed to the heat stress that result from the rise in temperature in late March and in April while plants are at grain filling. The recorded maximum daily temperature (Figure 2a and b) at the experimental sites during March and April of the two growing seasons (2007 and 2008) indicated that temperature fluctuated between 25° and 30°C in March 2007 and from 25° and to 35°C in March 2008 and it was risen above 40°C by the end of the month.

As for April 2007 and 2008, temperature fluctuated around 35°C with waves that lasted for several days in which it was raised above 35°C. For each of the three environments, the experimental layout was a complete randomized block design with three replications for the favorable environment and two for each of the two stressful environments. Each of the 28 entries of the diallel crosses were represented in each block by a family of five plants with single-seed plant randomization within blocks. Rows were set 30 cm apart while plants within rows were spaced 15 cm from each other. Each row consisted of 10 plants. In 2007 to 2008 winter season, 12 F_2 population forming a 3 (fathers) x 4 (mothers) North Carolina Design II were chosen from the 21 crosses to be sown under the heat stress of a late sowing date (30th December) in the favorable environment of the University Farm in order to analyze the segregation patterns of stem characters and their association with yield attributes. The 12 F_2 populations was represented in each block by 5 rows of 1.5 m long with rows spaced 20 cm apart and plants spaced 15 cm from each other within rows. The following characters were recorded for each plant of each entry:

1. Stem diameter (mm) recorded on the middle of the second internode of the main stem at anthesis using a venire caliper,

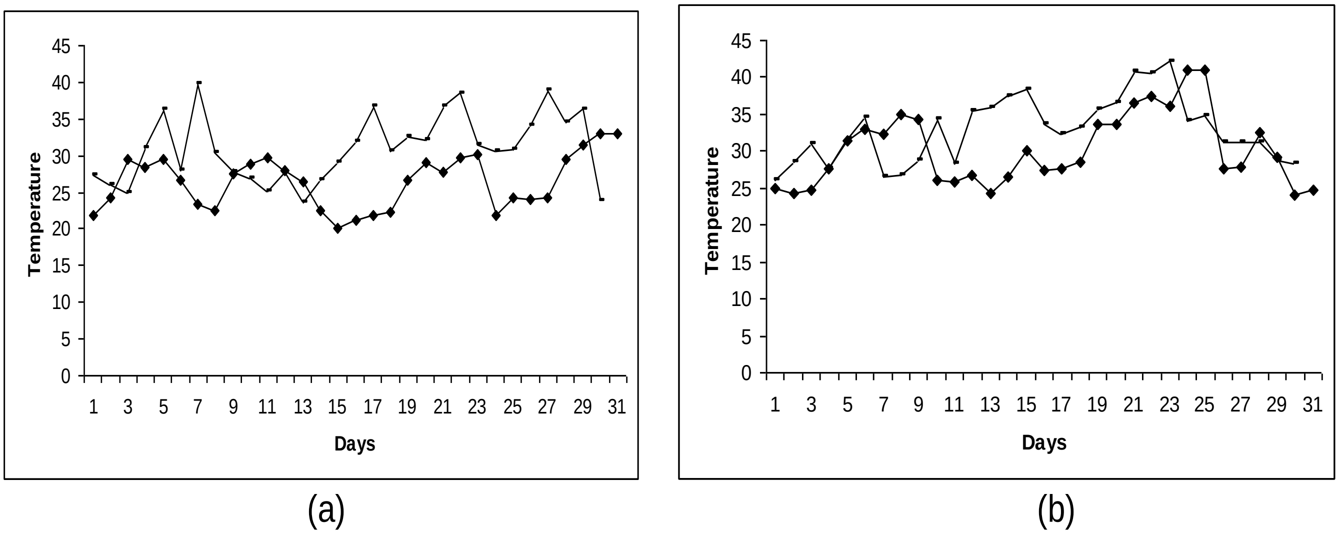

Figure 2. Maximum daily temperatures during March, April 2007(a) and March, April 2008 (b) at the experimental site **(March , April)**.

2. Stem length (cm) at anthesis: taken as the main stem length (cm) from the soil level to the lowest spikelets of the ear of main stem,
3. Stem dry weight (g): the weight of the main stem at anthesis that was oven dried at 70°C.
4. Stem density (gm/cm) was obtained by dividing the dry weight of main stem on the length of main stem (cm) at anthesis, using the formula:

$$Stem \quad density = \frac{the \quad weight \quad of \quad main \quad stem}{the \quad lenght \quad of \quad main \quad stem} x1000$$

5. Grain yield per spike (g): grain yield per plant divided by number of spikes per plant,
6. 1000- kernel weights (g).

The diallel analysis and the estimation of the genetic components were carried out using the methods developed by Hayman (1954a, b).

RESULTS

Main stem diameter

Under the favorable environment, the range means of stem diameter of the seven parents (Table 1) was quite wide extending from 4.41 to 6.26 mm for with a parental average of 5.09 mm whereas those of F_1's ranged from 4.41 to 6.02 mm with an average of 5.24 mm, marking a slight increase of F_1 averaged over parental averaged. Under drought stress (optimal sowing date in sandy soil), the range of variation was reduced with means of parents extended from 3.41 to 4.94 mm with an average of 3.84 mm and those the of F_1 crosses ranging from 3.26 to 4.85 mm with an average of 3.92 mm.

The average reduction in main stem diameter over parents and F_1's due to drought stress amounted to 25%. Under combined effects of drought and heat stresses (late sowing date in the sandy soil), greater reduction in stem diameter occurred with the parental means ranging from 3.08 to 4.43 mm with an average of 3.53 mm and the F_1 range extending from 2.83 to 4.08 mm with an average of 3.62 mm. The average reduction in main stem diameter over parents and $F_1'_s$ due to the combined drought and heat stresses amounted to 31%, marking a 6% reduction due to heat stress alone.

Apparently, the reduction in stem diameter due to drought stress was greater (25%) than that due to heat stress (6%). The diallel analysis of variance of stem diameter revealed highly significant additive and non-additive mean squares in the three environments with ambidirectional dominance. Significant array differences in the (Wr + Vr) values were found indicating non-additive variation between arrays whereas the array differences in the (Wr – Vr) values were non-significant indicating absence of non-allelic gene interaction. The slope of the covariance/variance (Wr/Vr) regression line was significantly deviating from zero but not from unity for the three environment (b = 0.65 ± 0.245, b = 0.827 ± 0.178 and b = 0.815 ± 0.238 for favorable, drought stress and combined drought and heat stresses environments, respectively). The Wr/Vr regression lines (Figure 3) cut the Wr axis in a positive position near the origin in the three different environments indicating partial dominance. The additive (D) genetic variance was greater than the dominance (H_1) in the three different environments (Table 5) with the degree of dominance $(H_1/D)^{1/2}$ being less than unity confirming that dominance was partial. The narrow sense heritability of stem diameter was almost comparable

Table 1. The means of stem diameter (mm) of the 7-parents and their F_1 hybrids in favorable environment, F (upper values), drought stress environment, D (middle values) and drought + heat stresses environments, D&H (lower values).

Parents		P_1	P_2	P_3	P_4	P_5	P_6	P_7	Array mean
	F.	6.26	5.74	6.02	5.45	5.52	4.91	5.1	5.69
P_1	D	4.94	4.14	4.17	4.1	4.85	4.06	4.76	4.47
	D&H	4.43	4.06	3.88	3.85	4.00	3.7	4.03	3.99
	F.		4.84	5.33	4.95	4.94	4.41	5.22	4.99
P_2	D		3.45	4.85	3.82	3.90	3.25	3.90	3.98
	D&H		3.19	4.08	3.09	3.05	3.10	3.23	3.30
	F.			5.87	5.53	5.02	4.97	5.69	5.41
P_3	D			4.81	4.13	3.97	4.35	4.43	4.34
	D&H			4.00	3.61	3.13	3.33	3.88	3.59
	F.				4.49	5.05	5.02	5.19	4.94
P_4	D				3.40	3.50	3.88	3.78	3.64
	D&H				3.08	2.96	3.20	3.39	3.16
	F.					4.64	4.90	5.12	4.88
P_5	D					3.41	3.56	3.97	3.65
	D&H					3.15	2.83	3.19	3.06
	F.						4.41	4.81	4.60
P_6	D						3.88	3.93	3.91
	D&H						3.77	3.42	3.60
	F.							5.17	5.16
P_7	D							3.57	3.57
	D&H							3.097	3.09

under favorable (0.73), drought stress (0.62) and combined drought and heat stresses (0.76).

Stem density

The range of variation in stem density among the seven parents was quite wide in the favorable environment extending from 17.08 to 35 mg/cm with a parental average of 24.28 mg/cm. Meanwhile, the means of stem density of the F_1's ranged from 19.4 to 32.6 mg/cm with an average of 24.58 mg/cm (Table 2). Under drought stress, stem density as averaged over parents and F_1's was reduced by 18.6% which is less than that observed in stem diameter. The average reduction in main stem density under combined drought and heat stresses amounted to 29.3% indicating a 10.7% reduction due to heat stress alone.

Here again, the impact of drought stress on stem density was much stronger than that of heat stress. The diallel analysis of variance of stem density revealed highly significant additive and non-additive mean squares in the three environments with ambidirectional dominance. The slope of the Wr/Vr regression line did not deviated significantly from unity for the favorable and combined drought and heat stress environments (Figure 4). For drought stress environment, a downward curvature of the Wr/Vr relationship indicated a duplicated type of non-allelic gene interaction. The partitioning of genetic variation (Table 5) revealed that the additive component (D) was greater than the dominance component (H_1) in the favorable and combined drought and heat stresses environments with the narrow sense heritability being comparably of moderate magnitude in the two environments (0.70 and 0.66, respectively).

1000 Kernel weight (g)

The average of 1000 kernel weight of the 28 genotypes of the 7-parent diallel cross was reduced from 44.96 g in the favorable environments to 41.09 g under drought stress indicating 8.7% reduction due to drought whereas the reduction under combined drought and heat stresses amounted to 17.5% marking 8.8% reduction due to heat stress alone (Table 3). The diallel analysis revealed highly significant additive and non-additive mean squares with dominance being directional towards greater 1000 kernel weight in the three different environments. The slope of the Wr/Vr regression line was significantly

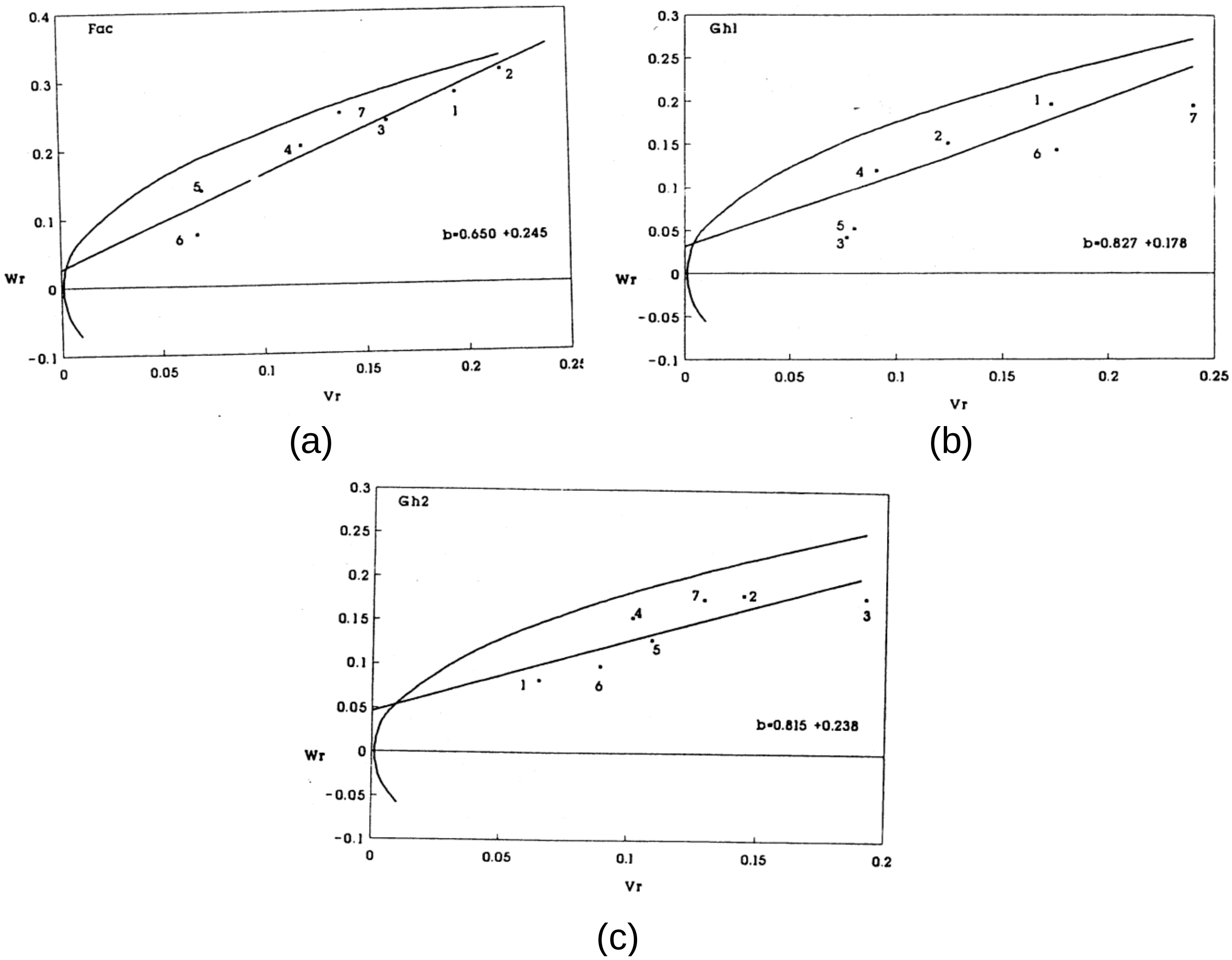

Figure 3. The Wr/Vr graphs of main stem diameter in favorable environment (a), drought stress environment (b) and the combined drought and heat stresses environment (c).

deviating from zero but not from unity for the three environments (Figure 5) indicating adequacy of the additive-dominance model. The additive component of genetic variation (D) was smaller in magnitude than the dominance component (H_1) for the favorable and the combined drought and heat environments while the reverse was true under drought stress (Table 5). The narrow sense heritability values were 0.38, 0.47 and 0.46 for the favorable, drought and combined drought and heat environments, respectively.

Grain yield per spike

Grain yield per spike (g) as averaged over parents and their F_1'$_s$ was reduced from 2.54 (g) in the favorable environments to 2.06 g under drought indicating 18.8% reduction (Table 4). Under combined drought and heat stresses the average grain yield per spike was reduced further to 1.69 g marking 35.8% reduction relative to that of the favorable environment which indicated 17% yield reduction due to heat stress alone. The slope of the Wr/Vr regression line did not deviate significantly from zero for the three environments (Figure 6) with the array differences in the (Wr – Vr) values being significant, indicating that non-allelic gene interaction was operating. However, the sharp discontinuity in the distribution of the points representing the seven parents along the regression line with parent No. 3 (Long spike) occupying a position at the far end of the line and the pointsrepresenting the other parents clustering at the other and near the origin suggested that a major gene might differentiate the two groups of parental genotypes.

The analyses of the components of variation in grain yield per spike are presented in Table 5. The dominance (H1) genetic component was greater than the additive (D) component in both favorable drought stress environments but situation was reversed in the combined drought and

Table 2. The means of stem density of the 7-parents and their F_1 hybrids in in F, D and D&H environments.

Parents		P_1	P_2	P_3	P_4	P_5	P_6	P_7	Array mean
P1	F	29.02	26.73	28.09	26.76	26.16	20.82	32.54	27.16
	D	25.74	20.67	23.42	20.37	18.86	18.08	22.04	21.31
	D&H	23.42	20.03	21.70	19.92	16.60	14.92	20.83	19.63
P2	F		21.19	28.23	25.78	20.94	19.54	22.09	22.96
	D		16.82	23.14	21.05	18.65	14.71	20.59	19.16
	D&H		15.21	20.08	19.34	15.38	13.34	19.14	17.08
P3	F			35.00	29.91	22.36	24.41	30.14	28.36
	D			25.98	26.25	20.01	22.31	23.70	23.65
	D&H			25.55	20.75	15.29	15.79	18.57	19.19
P4	F				20.60	23.42	20.72	24.89	22.41
	D				17.29	18.46	17.31	19.13	18.04
	D&H				13.94	14.33	15.60	18.11	15.49
P5	F					21.33	19.38	20.52	20.41
	D					18.23	14.67	17.63	16.85
	D&H					14.96	12.21	13.63	13.59
P6	F						17.08	22.78	19.93
	D						15.49	16.6	16.05
	D&H						14.60	14.03	14.32
P7	F							25.71	25.71
	D							21.45	21.45
	D&H							19.15	19.15

heat stresses environment. The positive values of (F) in the three different environments suggest that more dominance alleles are presented in the parent than recessive alleles. Evidently the $(H1/D)^{1/2}$ values were 1.90, 1.85 and 1.31 for the favorable, drought stress and the combined drought and heat stresses environments, respectively, indicating over dominace. The narrow sense heritability of grain yield per spike was higher (0.49) in the combination of drought and heat stresses environment than under both favorable (0.23) and drought stress (0.19) environments. Highly significant additive and non-additive mean squares were revealed by the analysis of variance with dominance being ambidirectional.

Associations between stem attributes and yield components

Stem diameter was positively associated with 1000 kernel weight and with grain yield per spike in the three different environments (Table 6) while stem density was positively correlated with 1000 kernel weight under favorable conditions only and with grain yield per spike under drought stress. Stem diameter displaced positive association with stem density under drought and combined drought and heat stresses. The association between 1000 kernel weight and grain yield per spike was positive and highly significant in the three different environments.

Segregation for stem diameter under heat stress

The distributions of the F2 individuals of the 12 crosses for stem diameter (Figure 7) were continuous and normal character, indicating the polygenic nature of the system controlling this character. Segregates with extremely large stem diameter (> 6.5 mm) obtained with crosses having Parent 3, 1 and 7. However, although Patent 2 and 6 have small stem diameter, some of their F2 individual showed large stem diameter under heat stress. Transgressive variation was apparent in most of the 12 crosses indicating that the genes controlling this trait were highly dispersed among the parental genotypes.

Associations between stem attributes and yield components in F_2 segregates under heat stress

Stem diameter displayed significant positive correlation with 1000 kernel weight under heat stress in the 12 F_2 examined (Table 7) and with grain yield per spike in nine

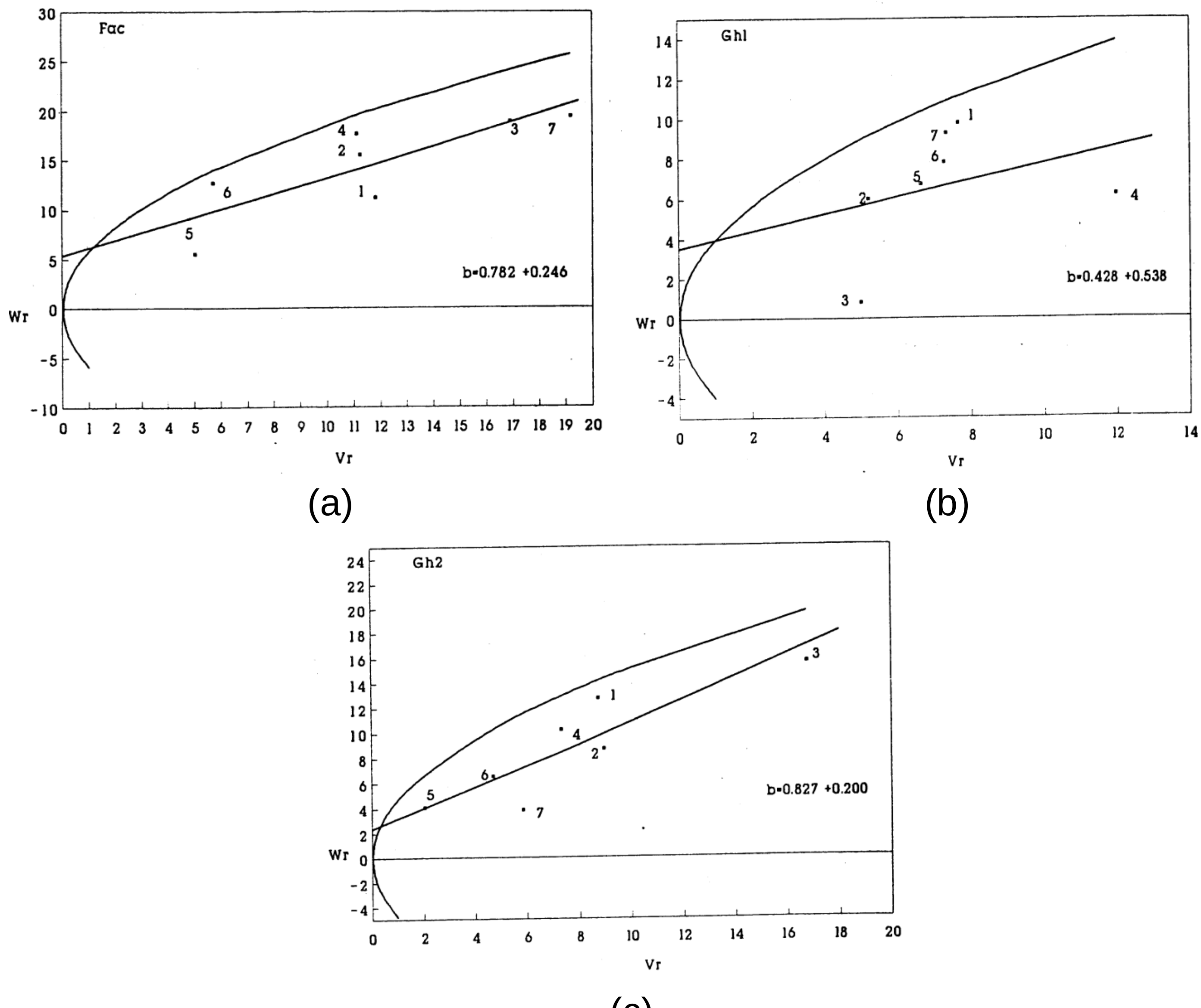

Figure 4. The Wr/Vr graphs of main stem density in favorable environment (a) drought stress, environment (b) and the combined drought and heat stresses environment (c).

populations. Meanwhile, stem density showed significant positive association with 1000 kernel weight in only five populations and with grain yield per spike in only six populations.

DISCUSSION

Stem diameter of the wheat plant proved to be a quantitatively inherited trait, the variation in which was controlled by polygenes with mainly additive effects that segregates out in the F_2 generation displaying continuously normal distributions. The distribution of F2 for SD indicated to that SD is normally distributed under heat stress for all the 12 population (Figure 7). In most populations, the values of SD of F2 individuals were extremely exceeded the mean values of their parents, indicating that there was no parent contained all dominant alleles or all recessive alleles at all. Despite the considerable reductions in mean stem diameter under drought (25%) and combined drought and heat stresses (31%), the narrow sense heritability estimates were moderately high (0.62 and 0.76 in the two environments, respectively) indicating that the relative size of the additive to the non-additive variance was not affected.

In the favorable drought, combined drought and heat

Table 3. The means of 1000 kennel weight of the 7-parents and their F_1 hybrids in in F, D and D&H environments.

Parents		P_1	P_2	P_3	P_4	P_5	P_6	P_7	Array mean
	F.	44.82	50.94	48	48.78	49.44	52.97	48.60	49.08
P_1	D	41.01	44.78	42.00	42.00	44.32	45.11	43.12	43.19
	D&H	38.07	44.00	40.13	37.33	43.7	41.4	41.74	40.56
	F.		36.50	51.76	47.40	43.00	43.22	42.04	43.99
P_2	D		34.62	42.85	41.45	40.94	41.68	41.05	40.43
	D&H		33.19	36.11	34.98	33.20	38.76	39.20	35.91
	F.			45.81	43.96	40.91	47.24	52.27	46.04
P_3	D			43.71	41.30	39.27	45.32	45.13	43.36
	D&H			40.39	32.90	32.11	34.78	40.42	36.23
	F.				33.93	42.27	45.34	46.50	42.01
P_4	D				32. 32	36.30	41.86	41.29	39.82
	D&H				24.61	30.67	38.78	39.42	33.37
	F.					35.62	42.20	46.18	41.33
P_5	D					32.90	40.05	42.44	38.46
	D&H					31.00	34.29	40.32	35.20
	F.						41.97	46.47	44.22
P_6	D						40.15	43.02	41.58
	D&H						39.24	39.46	39.35
	F.							44.36	44.36
P_7	D							41.55	41.55
	D&H							38.03	38.03

Table 4. The means of grain yield per spike of the 7-parents and their F_1 hybrids in F, D and D&H environments.

Parents		P_1	P_2	P_3	P_4	P_5	P_6	P_7	Array mean
	F.	2.79	2.67	2.54	2.84	2.55	3.38	2.69	2.78
P_1	D	2.31	2.05	2.35	2.19	1.88	2.58	2.43	2.25
	D&H	2.01	1.88	2.01	1.85	1.80	1.68	2.09	1.90
	F.		1.60	2.39	2.93	2.05	2.29	2.99	2.38
P_2	D		1.40	2.06	2.63	1.96	1.89	2.39	2.05
	D&H		1.31	1.71	1.70	1.25	1.53	2.05	1.59
	F.			3.40	1.35	2.96	2.54	3.45	2.74
P_3	D			3.10	0.85	2.28	2.05	2.99	2.25
	D&H			2.66	0.49	1.55	1.68	1.98	1.67
	F.				1.94	2.66	2.32	2.55	2.37
P_4	D				1.57	1.96	1.58	2.07	1.79
	D&H				0.96	1.17	1.37	1.7	1.30
	F.					2.08	2.13	2.92	2.38
P_5	D					1.47	1.74	2.07	1.76
	D&H					1.24	1.39	1.65	1.43
	F.						1.90	2.71	2.31
P_6	D						1.65	1.93	1.79
	D&H						1.36	1.14	1.25
	F.							2.66	2.66
P_7	D							2.19	2.19
	D&H							1.98	1.98

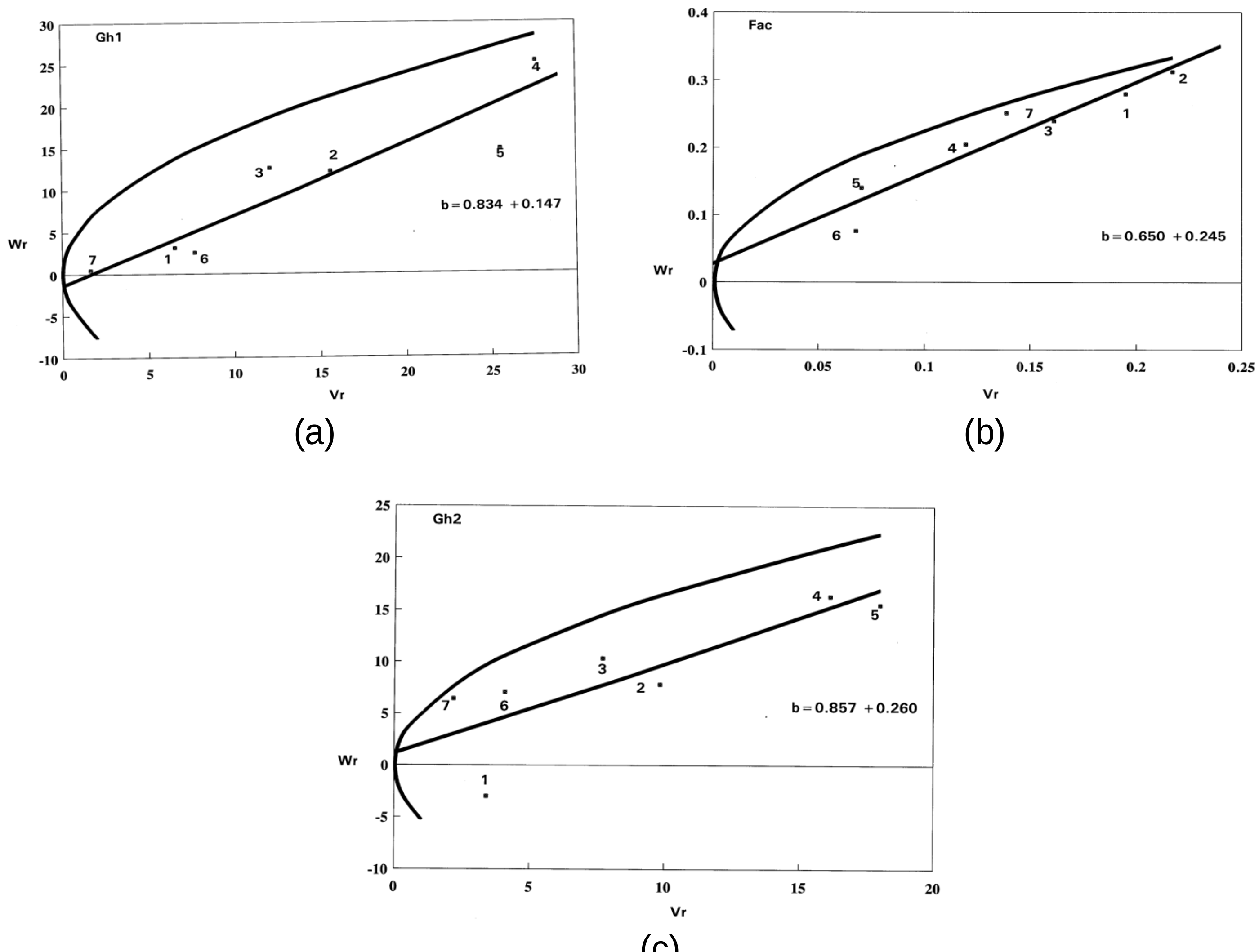

Figure 5. The Wr/Vr graphs of 1000 kernel weight in favorable environment (a) drought stress, environment (b) and the combined drought and heat stresses environment (c).

stresses environments, stem diameter was positively correlated with 1000 kernel weight (r = 0.56, 0.53 and 0.56, P < 0.01, in the three different environments, respectively) as well as with grain yield per spike (r = 0.40, 0.40 and 0.50, respectively, P < 0.05). On the other hand, stem density displayed positive association with 1000 kernel weight only under favorable environment (r = 0.49, P < 0.01) and with grain yield per spike only under drought (r = 0.43, P < 0.01) despite the strong correlation between stem density and stem diameter under stress (r= 0.69 under drought and r = 0.81 under combined drought and heat stresses, P < 0.01).

Moreover, while stem diameter displayed significantly positive association under heat stress with 1000 kernel weight in the 12 F_2 populations and with grain yield per spike in nine of the 12 F_2 populations analyzed. Stem density showed positive association with 1000 kernel weight in only five F_2 populations and with grain yield per spike in only six of the 12 F_2 populations. Such strong associations of stem diameter with 1000 kernel weight and grain yield per spike under stress demonstrated clearly an important role of this character in sustaining grain filling and supporting grain growth, possibly through providing greater stem capacity for storing assimilates that are formed before anthesis be remobilized to grains after anthesis. Since a substantial amount of the carbohydrates used during grain filling in wheat must come from reserves assimilated before anthesis (Gent, 1994), larger stem diameter and stem density would be advantageous under stress for grain filling.

According to Ehdaie et al. (2006b), internode length, internode weight and internode specific weight of the stem of the wheat plant affected the accumulation and mobilization of stem reserves with maximum specific

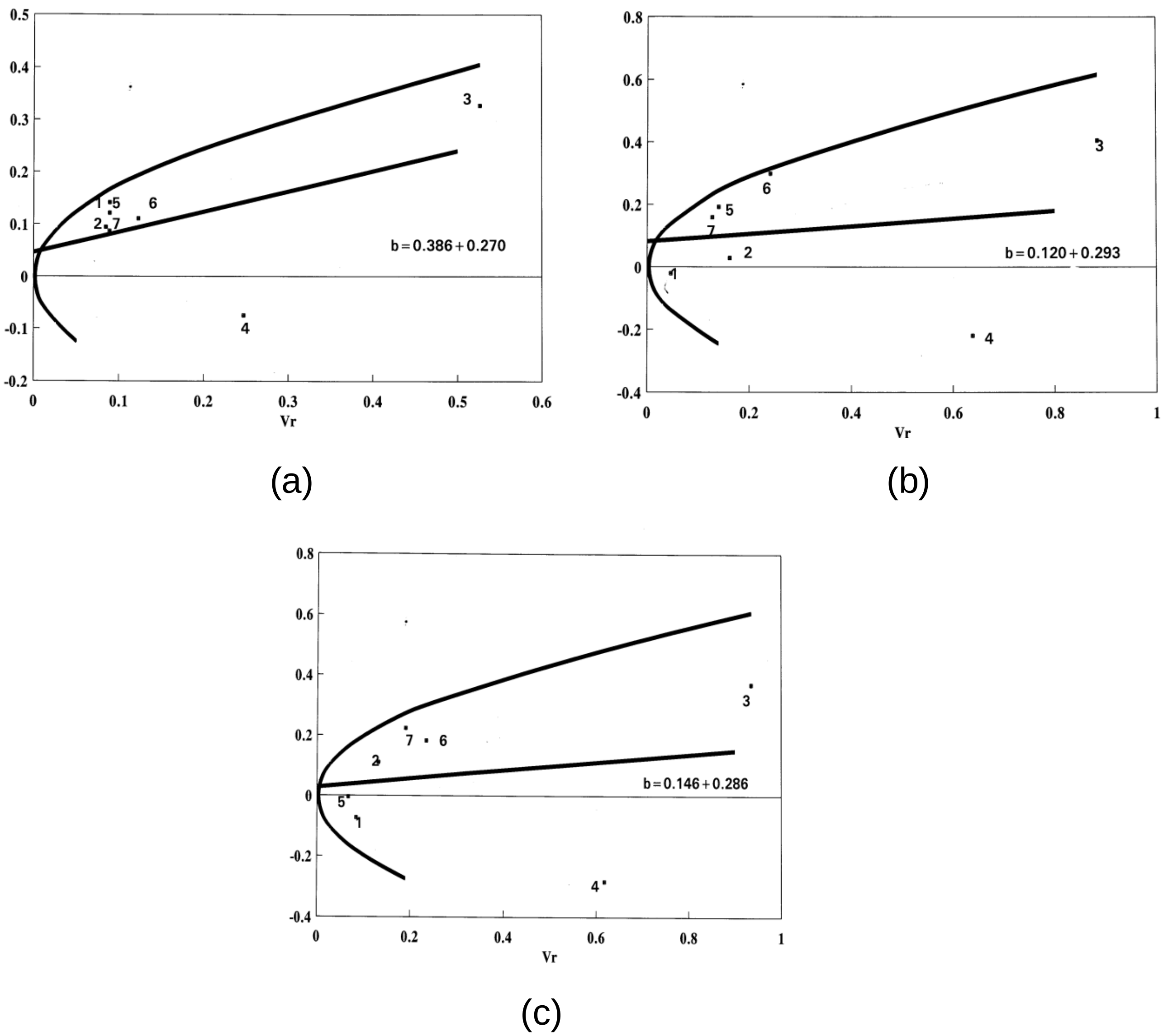

Figure 6. The Wr/Vr graphs of grain yield per spike in favorable environment (a) drought stress, environment (b) and the drought and heat stresses environment (c).

Table 4. The means of grain yield per spike of the 7-parents and their F_1 hybrids in F, D and D&H environments.

Parents		P_1	P_2	P_3	P_4	P_5	P_6	P_7	Array mean
	F.	2.79	2.67	2.54	2.84	2.55	3.38	2.69	2.78
P_1	D	2.31	2.05	2.35	2.19	1.88	2.58	2.43	2.25
	D&H	2.01	1.88	2.01	1.85	1.80	1.68	2.09	1.90
	F.		1.60	2.39	2.93	2.05	2.29	2.99	2.38
P_2	D		1.40	2.06	2.63	1.96	1.89	2.39	2.05
	D&H		1.31	1.71	1.70	1.25	1.53	2.05	1.59
	F.			3.40	1.35	2.96	2.54	3.45	2.74
P_3	D			3.10	0.85	2.28	2.05	2.99	2.25
	D&H			2.66	0.49	1.55	1.68	1.98	1.67

Table 4. Contd.

	F.	1.94	2.66	2.32	2.55	2.37
P_4	D	1.57	1.96	1.58	2.07	1.79
	D&H	0.96	1.17	1.37	1.7	1.30
	F.		2.08	2.13	2.92	2.38
P_5	D		1.47	1.74	2.07	1.76
	D&H		1.24	1.39	1.65	1.43
	F.			1.90	2.71	2.31
P_6	D			1.65	1.93	1.79
	D&H			1.36	1.14	1.25
	F.				2.66	2.66
P_7	D				2.19	2.19
	D&H				1.98	1.98

Table 5. Components of genetic variation of stem characters and yield components under F, D and D&H environments.

Component	SD			SDN		Grain yield per spike			1000 kernel weight		
	F	D	D+H	F	D+H	F	D	D+H	F	D	D+H
D	0.52	0.30	0.27	19.79	33.73	0.20	0.29	0.34	24.48	22.29	22.53
H1	0.21	0.14	0.18	10.49	14.58	0.26	1.00	1.24	50.144	15.08	40.12
H2	0.16	0.06	0.16	5.93	11.30	0.18	0.91	1.00	45.14	15.53	29.93
(H1/D)1/2	0.63	0.68	0.82	0.72	0.66	1.31	1.85	1.90	1.43	0.83	1.34
h2	0.73	0.76	0.62	0.66	0.70	0.47	0.19	0.23	0.38	0.47	0.46

Table 6. Phenotypic correlation between stem attributes and yield components in favorable (F) drought stress (D) and combined drought and heat stresses (D&H).

Character	Environment	Stem density	1000 kernel weight	Grain yield per spike
Stem diameter	F.	0.30	0.56**	0.40*
	D	0.69**	0.53**	0.40*
	D&H	0.81**	0.56**	0.50**
Stem density	F.		0.49**	0.36
	D		0.35	0.43*
	D&H		0.28	0.35
1000 kernel weight	F.			0.61**
	D			0.51**
	D&H			0.58**

*P < 0.05; ** P < 0.0.

weight being correlated with stem mobilized dry matter. Selection for larger stem diameter seems to be feasible and practical since it is easily scorable in large populations with a reasonably high heritability under stress. Such courses of action would enhance grain filling as well as grain yield under drought and heat stress.

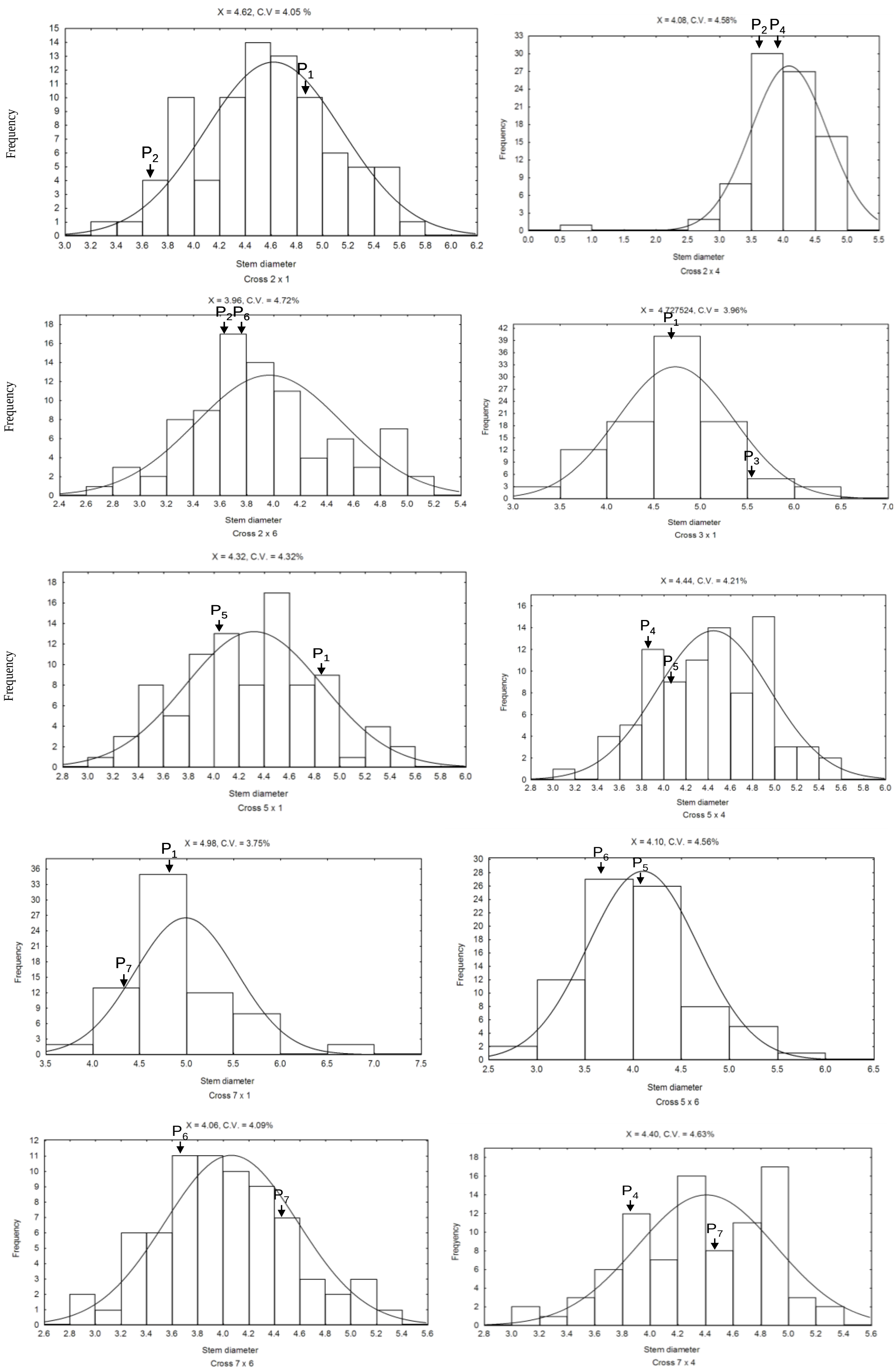

Figure 7. Distribution of F_2 segregates for stem diameter of main stem under heat stress condition.

Table 7. Phenotypic correlation between stem attributes (stem diameter and stem density) and yield components (1000 kernel weight and grain yield per spike) in F_2 segregates under heat stress.

Cross	Stem diameter		Stem density	
	1000 kernel weight	**Grain yield per spike**	**1000 kernel weight**	Grain yield per spike
2 x 1	0.35**	0.05	0.03	0.21*
2 x 4	0.39**	0.36**	0.32**	0.27*
2 x6	0.45**	0.25*	0.47**	-0.12
3 x 1	0.62**	0.31**	0.16	0.04
3 x4	0.29*	0.28*	0.23	-0.07
3 x 6	0.39**	0.30**	0.42**	0.35**
5 x 1	0.33**	0.01	0.12	-0.04
5 x 4	0.43**	0.25*	0.17	0.17
5 x 6	0.29**	0.22*	0.11	0.31**
7 x 1	0.29*	0.14	0.04	0.60**
7 x4	0.41**	0.20*	0.32**	0.14
7 x6	0.57**	0.42**	0.41**	0.24*

*P < 0.05; ** P < 0.0.

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