

Full Length Research Paper

Genetic analysis of tolerance to heat stress in maize (*Zea mays* L.)

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Accepted 16 May, 2011

Twenty eight hybrid combinations of eight selected inbred lines ((including 3 lines sensitive (A679, K3651/1 and K3640/5), 2 lines medium (K47/2-2-1-21-2-1-1-1 and K19) and 3 lines tolerance to heat stress (K18, K166A and K166B)) with different response to heat stress were evaluated in 2008 for grain yield and some related traits in a randomized complete block design arranged into three replications in Shoushtar City (a sub-tropical region in Khuzestan Province of Iran). Hybrids were planted at two planting dates, 6th of July (coinciding heat stress with pollination time and grain filling period) and 27th of July (normal planting). Diallel analysis was done using Griffing's method 4 and model II. As a result, grain yield in heat stress condition and 1000 grain weight in both conditions showed high general combining ability to specific combining ability ratio, indicating the effects of additive contribution. But grain yield in normal condition, grain number per ear, grain row number per ear, grain number per ear row and hektolitr weight in both conditions showed low GCA/SCA, indicating contribution of non-additive effects. General combining ability of all traits was non-significant in parents except for grain row number per ear. K18×K166B of the highest yield, positive and combining significantly in both conditions for grain yield was enjoyed.

Key words: Maize, heat stress, additive and non-additive effects, combining ability, hybrid.

INTRODUCTION

Maize is the third important leading cereal crop after wheat and rice in relation to area and production in Iran. Stress can reduce maize grain yield and quality. Further rise in temperature reduces pollen viability and silk receptivity, resulting in poor seed set and low grain yield (Johnson, 2000; Aldrich et al., 1986). Heat stress reduced the yield of inbred lines maize grain up to 70% (Khodarahmpour et al., 2010). Drought stress reduced the yield of maize grain up to 80% (Makus et al., 2000). In southern part of Iran, especially in Khuzestan Province, high temperature stress is one of the most important abiotic stresses in maize growing area.

The diallel cross mating schemes have been extensively used in breeding programs for the evaluation of the genetic potential of genotypes (Miranda and Vencovsky, 1984). Combining ability describes the breeding values of parental lines to produce hybrids. Sprague and Tatum (1942) used the term general combining ability (GCA) to designate the average performance of a line in hybrid combinations, and used the term specific combining ability (SCA) to define those cases in which certain combinations do relatively better

or worse than would be expected on the basis of the average performance of the lines involved.

Rezaei et al. (2005) and Sridic et al. (2006) reported significant variance due to GCA and SCA for grain yield, plant height and row number per ear traits. There are different reports on the genetic control of different traits in maize. Some studies revealed that grain yield and yield components were controlled by additive and non-additive genes (Wolf and Poternelli, 2000; Singh et al., 2002; Wu et al., 2003; Butruille et al., 2004; Choukan and Mosavat, 2005). Some others (Melani and Carena, 2005; He et al., 2003) reported the importance of additive effects as well as non-additive effect (Pal and Prodham, 1994; Kalla et al., 2001; Renugopal et al., 2002; Unay et al., 2004). Akbar et al. (2008) reported that GCA and SCA effects were highly significant but GCA effect on 100 grain weight under high temperature condition was non-significant. The GCA/SCA variance ratio exhibited that yields were predominantly under non-additive control. The inbred line 935006 was found as the best general combiner with better mean performance for all traits followed by R2304-2 and F165-2-4. The best cross was

Table 1. Average minimum and maximum temperatures of research farm in heat stress and normal conditions in 2008.

| Months | Temperature (°C) | |
|-----------|------------------|---------|
| | Minimum | Maximum |
| July | 31 | 46 |
| August | 32 | 46 |
| September | 31 | 45 |
| October | 23 | 38 |
| November | 17 | 27 |
| December | 11 | 21 |

935006×R2304-2. Betran et al. (2003) showed that the type of gene action appeared to be different under drought than when under low nitrogen, with additive effects more important under drought and dominance effects more important under low nitrogen. Afarinesh et al. (2008) showed additive and dominance variances role in normal condition and dominance variance in drought stress condition.

Unay et al. (2004) showed that the general and specific combining ability effects were significantly different among parental lines. Choukan and Mosavat (2005) reported that MO17×B73 and MO17×K74/1 are significant and negative when combined for grain yield in normal condition.

Genetic variation is the basis of genetic improvement in any crop. Crossing of diverse inbred lines provides sufficient variability for an effective selection of desirable traits. Suitable inbred lines and their specific combinations may be selected on the basis of combining ability effects with higher mean yield (Akbar et al., 2008). The success of identifying parental inbred lines that combine well together and produce productive crosses mainly depends on gene action that controls the traits to be improved. The variance of GCA/SCA ratio is useful in estimating the variability existed whether due to additive or non-additive or both types of gene action. Therefore, understanding of genetic mechanism for high temperature tolerance is necessary for the development of tolerant hybrids and synthetics to high temperature stress for sustainable agriculture.

In present study, eight inbred lines varying in degree of their temperature tolerance were crossed in half diallel model to get information on genetic control of high temperature tolerance by estimating combining ability effects for morphological traits.

MATERIALS AND METHODS

The study was conducted at Shushtar City located in Khuzestan Province, IRAN (32°2' N and 48°50' E, 150 m asl) in 2008. The soil type at this location is clay loam, pH = 7.6 with EC = 0.5 mmhos/cm.

Twenty eight hybrid combinations of eight selected inbred lines ((including 3 lines sensitive (A679, K3651/1 and K3640/5), 2 lines

medium (K47/2-2-1-21-2-1-1-1 and K19) and 3 lines tolerance to heat stress (K18, K166A and K166B)) with different response to heat stress were evaluated in 2008 for grain yield and some related traits in a randomized complete block design arranged into three replications in Shushtar City (a sub-tropical region in Khuzestan Province of Iran). This was done under two planting dates, 6th July (coinciding heat stress with pollination time and grain filling period) and 27th July (the normal planting date) to avoid high temperature during pollination and grain filling period. Each plot had 3 rows of 75 cm apart and 9 m in length, with 45 hills. Two seeds each were sown, one of which seedlings were removed at 4 leaves stage. Minimum and maximum air temperatures at pollination time were 31 and 45°C under heat stress condition (planting date, 6th July) and 23 and 38°C under normal condition (planting date, 27th July) (Table 1).

Data pertaining to grain row number per ear, grain number per ear row, grain number per ear, 1000 grain weight, hektolitr weight and grain yield traits were recorded in both conditions. Analysis of variance was performed for each individual experiment randomized complete block using SPSS computer program and mean separation performed according to Duncan's Multiple Range Test at 5% probability level. Diallel analysis based on Griffing's method 4 and model II was done using Diall 98 software.

RESULT AND DISCUSSION

Significant differences were observed among hybrids in both conditions for all studied traits (Table 2). Therefore Griffing's method 4 and model II in both conditions was used to partition the genetic effect into general combining ability (GCA) and specific combining ability (SCA).

The highest grain yield in heat stress condition belonged to hybrids K18×K166B and K18×K42/2-2-1-21-2-1-1-1 and in normal condition belonged to hybrids such as K18×K166B, K18×K42/2-2-1-21-2-1-1-1 and K166A×K3640/5. There was 70% yield reduction in stressed condition compared to normal condition (Table 3). Khodarahmpour et al. (2010) showed that heat stress reduced the yield of maize grain up to 73.5%. Makus et al. (2000) reported drought stress reduced the yield of maize grain up to 80%. Hybrids such as K18×K47/2-2-1-21-2-1-1-1, K166A×K19, K166B×K19 and K47/2-2-1-21-2-1-1-1×K19 in stress condition and many number of hybrids in normal condition showed the highest grain row number per ear (Table 3). Hybrid K18×K166B in stress condition and hybrids K3651/1×K3640/5 and A679×K166A in

Table 2. Analysis of variance and combining ability for different traits maize hybrids in diallel crosses in heat stress and normal conditions.

| Source of variance | df | Grain yield (kg/ha) | | Grain number per ear | | Grain row number per ear | | Grain number per ear row | | 1000 grain weight (g) | | Hektolitr weight (g/L) | |
|---------------------------|----|---------------------|-----------|----------------------|----------|--------------------------|--------|--------------------------|--------|-----------------------|---------|------------------------|--------|
| | | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal |
| Block | 2 | 535426* | 2317944* | 34218* | 244832** | 181** | 14* | 97.90* | 1236** | 5718ns | 4946ns | 2052ns | 5998ns |
| Hybrid | 27 | 1092651** | 1316319** | 66388** | 135981** | 87** | 9.57** | 377.30** | 651** | 10357** | 10738** | 3395** | 5170* |
| Error | 54 | 145969 | 584733 | 1785 | 120742 | 20 | 6 | 27.33 | 584 | 2784 | 3669 | 582 | 2608 |
| GCA | 7 | 1190980** | 1535789* | 15597** | 40532ns | 16* | 4* | 96** | 213ns | 21539** | 21021** | 4935** | 7485* |
| SCA | 20 | 287450ns | 1239505* | 18264** | 29039ns | 22** | 2ns | 99.85** | 152ns | 6437** | 7139* | 2856** | 4362ns |
| Error (combining ability) | 54 | 193825 | 584733 | 3755 | 31110 | 5 | 1 | 16.3 | 121 | 2785 | 3669 | 852 | 2605 |
| GCA/SCA | | 4.14 | 0.12 | 0.85 | 1.4 | 0.73 | 2 | 0.96 | 1.4 | 3.35 | 2.94 | 1.73 | 1.72 |
| Baker ratio ¹ | | 0.89 | 0.71 | 0.63 | 0.74 | 0.59 | 0.8 | 0.66 | 0.74 | 0.87 | 0.85 | 0.78 | 0.77 |

¹-2δ²GCA/(δ²SCA+2δ²GCA). ²- ns, * and **:nonsignificant, significant at 5% and 1% probability levels, respectively.

Table 3. Mean comparison of different traits in maize hybrids in heat stress and normal conditions.

| Name of hybrids | Grain yield (kg/ha) | | Grain number per ear | | Grain row number per ear | | Grain number per ear row | | 1000 grain weight (g) | | Hektolitr weight (g/L) | |
|------------------------------|---------------------|-----------|----------------------|----------|--------------------------|-----------|--------------------------|----------|-----------------------|---------|------------------------|--------|
| | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal |
| K18×K3651/1 | 196h | 2900bcde | 47defg | 413cdefg | 7fgh | 14abcdefg | 4defg | 29bcdef | 273fgh | 329cde | 738abcde | 762a |
| K18×A679 | 411gh | 3066bcde | 55cdefg | 474cdef | 10bcdef | 14abcdefg | 5cdefg | 34bc | 292efgh | 317cdef | 727cde | 685ab |
| K18×K166A | 815defgh | 3220abcde | 64bcdef | 471cdef | 10bcdef | 15ab | 6cdefg | 31cdef | 362abcdef | 470a | 694ef | 691ab |
| K18×K166B | 3266a | 5046a | 263a | 456cdef | 12abcd | 14abcdefg | 21a | 33bcd | 389abcde | 399abcd | 753abcd | 706ab |
| K18×K3640/5 | 828defgh | 3134bcde | 65bcdef | 453cdef | 9efg | 15ab | 6cdefg | 31bcdef | 407abc | 345cd | 712def | 705ab |
| K18×K47/2-2-1-21-2-1-1-1 | 2799ab | 3566abc | 233a | 459cdef | 13a | 15ab | 16b | 30bcdef | 362abcdef | 329cde | 742abcde | 680ab |
| K18×K19 | 1074defgh | 1500ef | 131bc | 368defgh | 12abcde | 12g | 10c | 28bcdefg | 413a | 352bcd | 711def | 667ab |
| K3651/1×A679 | 250h | 3434abcd | 46defg | 337fgh | 9efg | 14abcdefg | 4defg | 23fg | 325abcdef | 331cde | 732bcde | 723a |
| K3651/1×K166A | 596efgh | 2320cdef | 83bcdef | 348efgh | 11abcde | 14abcdefg | 6cdefg | 24efg | 325abcdef | 321cdef | 732bcde | 716ab |
| K3651/1×K166B | 1229cdefg | 2800bcdef | 109bcde | 478cde | 12abcde | 14abcdefg | 8cde | 34bc | 309bcdefg | 293def | 780abc | 731a |
| K3651/1×K3640/5 | 833defgh | 3720abc | 115bcde | 739a | 9efg | 15ab | 8cde | 49a | 259fgh | 281def | 786ab | 738a |
| K3651/1×K47/2-2-1-21-2-1-1-1 | 321gh | 3366abcde | 37efg | 496bcd | 7gh | 15ab | 4efg | 35b | 276fgh | 280def | 744abcde | 767a |
| K3651/1×K19 | 335gh | 3334abcde | 14g | 416cdefg | 5h | 15ab | 2g | 26bcdefg | 304cdefgh | 292def | 717def | 699ab |
| A679×K166A | 468fgh | 2780bcdef | 83bcdef | 612b | 10bcdef | 14abcdefg | 7cdefg | 45a | 341abcdef | 341cde | 664f | 702ab |
| A679×K166B | 120 h | 1054f | 18g | 401cdefg | 6gh | 15ab | 2g | 25defg | 212h | 207f | 688ef | 719ab |
| A679×K3640/5 | 491fgh | 3300abcde | 29fg | 304gh | 5h | 14abcdefg | 3fg | 20g | 226gh | 343cd | 794a | 709ab |
| A679×K47/2-2-1-21-2-1-1-1 | 791defgh | 3161abcde | 39efg | 337fgh | 10bcdef | 14abcdefg | 3fg | 23fg | 266gh | 221ef | 731bcde | 691ab |
| A679×K19 | 161h | 1534def | 29fg | 531bc | 7fgh | 15ab | 3fg | 34bc | 267fgh | 347cd | 689ef | 683ab |
| K166A×K166B | 1231cdefg | 3479abc | 124bcd | 465cdef | 11abcde | 14abcdefg | 15b | 34bc | 402abcd | 418abc | 777abc | 755a |

Table 3. Contd.

| | | | | | | | | | | | | |
|------------------------------|----------|-----------|---------|-----------|---------|-----------|--------|----------|-----------|---------|----------|-------|
| K166A×K3640/5 | 945defgh | 4366ab | 103bcde | 421cdefg | 10bcdef | 15ab | 6cdefg | 28bcdefg | 278fgh | 327cde | 744abcde | 559c |
| K166A×K47/2-2-1-21-2-1-1-1 | 771defgh | 4020abc | 63bcdef | 361defgh | 9efg | 15ab | 5cdefg | 25defg | 412ab | 294def | 689ef | 691ab |
| K166A×K19 | 1375cdef | 3896abc | 134bc | 401cdefg | 13a | 13efg | 10c | 30cdef | 358abcdef | 462ab | 740abcde | 731a |
| K166B×K3640/5 | 1508cde | 3366abcde | 109bcde | 342efgh | 12abcde | 14abcdefg | 8cde | 23fg | 401abcd | 357abcd | 731bcde | 721a |
| K166B×K47/2-2-1-21-2-1-1-1 | 1544cd | 3500abc | 89bcdef | 393cdefgh | 12abcde | 14abcdefg | 7cdefg | 27cdefg | 338abcdef | 388abcd | 718def | 696ab |
| K166B×K19 | 2096bc | 3100bcde | 137b | 465cdef | 13a | 14abcdefg | 10c | 33bcd | 393abcde | 391abcd | 727cde | 712ab |
| K3640/5×K47/2-2-1-21-2-1-1-1 | 803defgh | 3178abcde | 47defg | 263h | 10bcdef | 13efg | 4defg | 20g | 300defgh | 323cdef | 790a | 618bc |
| K3640/5×K19 | 793defgh | 3141bcde | 21g | 478cde | 7fgh | 15ab | 3efg | 32bcd | 270fgh | 292def | 700def | 711ab |
| K47/2-2-1-21-2-1-1-1×K19 | 625defgh | 2509bcdef | 242a | 398cdefg | 13a | 13efg | 19ab | 30bcdef | 323abcdef | 306cdef | 700def | 671ab |
| Average ² | 953 | 3135 | 90 | 421 | 10 | 14 | 7 | 20 | 323 | 334 | 730 | 701 |

²Means with similar letter(s) in each trait is not significantly different at 5% probability level according to Duncan's multiple range test.

normal condition showed the highest grain number per row (Table 3). Hybrids K18×K166B, K18×K47/2-2-1-21-2-1-1-1 and K47/2-2-1-21-2-1-1-1×K19 in stress condition and hybrid K3651/1×K3640/5 in normal condition showed the highest grain number per ear. In heat stress condition, hybrid K18×K19 and in normal condition hybrid K18×K166A had the highest 1000 grain weight. Hybrids A679×K3640/5 and K3640/5×K47/2-2-1-21-2-1-1-1 in stress condition and many hybrids for example K18×K3651/1 in normal condition had the highest hektolitr weight (Table 3).

General combining ability variance for all traits except grain number per ear row and grain number per ear in normal condition was significant (Table 2). Grain yield trait in heat stress condition and grain row number per ear, grain number per ear row, grain number per ear and hektolitr weight traits in normal condition showed non-significant specific combining ability variance. Other traits showed significant specific combining ability (Table 2).

Akbar et al. (2008) reported that GCA and SCA effects were found as highly significant but non-significant to GCA effect for 100 grain weight under high temperature condition. Rezaei et al.

(2005) and Sridic et al. (2006) reported significant variance due to GCA and SCA for grain yield, plant height and row number per ear traits. Unay et al., (2004) reported general and specific combining ability effects were significantly different among parental lines.

Grain yield in heat stress condition and 1000 grain weight in both conditions showed high GCA/SCA ratio, indicating importance of additive than non-additive effects (Table 2). But grain yield in normal condition, grain number per ear, grain row number per ear, grain number per ear row and hektolitr weight in both conditions showed low GCA/SCA, showing the importance of non-additive effects, compared to additive gene effects (Table 2). Also Baker's ratio for these traits indicates genetic control of these traits by additive effect and non-additive genes, but with more portion of non-additive genes effect (Table 2). Unay et al. (2004) and Kalla et al. (2001) reported grain yield was under the non-additive gene effect. Akbar et al. (2008) reported that the GCA/SCA variance ratio exhibited that all traits were predominantly under non-additive control in high temperature and normal conditions.

General combining ability except grain row

number per ear trait, in other traits in two conditions in neither of parents was nonsignificant (Table 4). Therefore in two conditions for breeding these traits can of breeding methods base hybridization used. Line K3651/1 in stress condition and lines K166B and K47/2-2-1-21-2-1-1-1 in normal condition showed negative effect and significant and line K3640/5 positive effect and significant for grain row number per ear trait (Table 4).

Hybrid K18×K166B was significant and positive, combining in two conditions for grain yield; and hybrid K18×K47/2-2-1-21-2-1-1-1 was significant and positive, combining in stress condition for grain row number per ear; hybrids K166A×K47/2-2-1-21-2-1-1-1 and K18×K19 in stress condition and hybrid K3651/1×K166B in normal condition were significant and positive, combining for grain number per ear row; hybrid K18×K19 in two condition for grain number per ear trait was significant and positive; hybrid A679×K166B and K166A×K3640/5 for 1000 grain weight and hektolitr weight traits respectively were significant and negative, combining in normal condition (Table 5). Rezaei et al. (2005) reported general combining ability effects were significant for most

Table 4. Parent's general combining using Griffing's method 4 in heat stress and normal conditions.

| Inbred line | Grain yield (kg/ha) | | Grain number per ear | | Grain row number per ear | | Grain number per ear row | | 1000 grain weight (g) | | Hektolitr weight (g/L) | |
|-----------------------|---------------------|----------|----------------------|--------|--------------------------|--------|--------------------------|--------|-----------------------|----------|------------------------|----------|
| | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal |
| K18 | 259.97ns | 64.7ns | 4ns | 71ns | -1ns | 0ns | -0.21ns | 4ns | 37.91ns | 33.73ns | -5.85ns | -2.29ns |
| K3651/1 | -303.29ns | -9.97ns | -49ns | -43ns | -2* | 0ns | -3.6ns | -4ns | -33.36ns | -35.26ns | 19.56ns | 37.67ns |
| A679 | -341.98ns | 483ns | -13ns | -21ns | 1ns | 0ns | -1.58ns | -3ns | -56.95ns | -38.91ns | -14.65ns | 0.53ns |
| K166A | -19.87ns | 284ns | -4ns | 32ns | 0ns | 0ns | 0.59ns | 1ns | 34.5ns | 48.91ns | -12.09ns | -10.77ns |
| K166B | 419.89ns | 53.14ns | 31ns | 50ns | 1ns | -1* | 1.81ns | 4ns | 28.7ns | 19.02ns | 10.15ns | 21.50ns |
| K3640/5 | -82.43ns | 310.08ns | -28ns | -33ns | 1* | 1* | -2.13ns | -2ns | -21.68ns | -11.81ns | 24.13ns | -24.8ns |
| K47/2-2-1-21-2-1-1-1 | 54.46ns | 180.47ns | 32ns | -62ns | 0ns | -1* | 3.03ns | -4ns | 1.07ns | -32.98ns | 0.12ns | -16.09ns |
| K19 | 13.24ns | -39.36ns | 28ns | 5ns | 1ns | 0ns | 2.09ns | 2ns | 37.91ns | 33.73ns | -21.37ns | -5.74ns |
| SE (GCA) ³ | 257.23 | 53.14 | 29.44 | 47.45 | 0.95 | 0.5 | 2.31 | 3.44 | 33.36 | 35.26 | 16.56 | 20.39 |

³ns, * and **:nonsignificant, significant at 5% and 1% probability levels, respectively.

Table 5. Parent's specific combining using Griffing's method 4 in heat stress and normal conditions.

| Name of hybrids | Grain yield (kg/ha) | | Grain number per ear | | Grain row number per ear | | Grain number per ear row | | 1000 grain weight (gr) | | Hektolitr weight (g/L) | |
|-------------------------------|---------------------|------------|----------------------|--------|--------------------------|--------|--------------------------|--------|------------------------|----------|------------------------|----------|
| | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal | Stress | Normal |
| K18×K3651/1 | -330ns | -243.08ns | -5ns | -124ns | 1ns | -1ns | 1.33ns | -8ns | -56.07ns | -3.99ns | -5.72ns | 25.29ns |
| K18×A679 | -218ns | 362.8ns | -4ns | -135ns | 1ns | 0ns | -0.23ns | -9ns | -13.75ns | -12.27ns | 16.89ns | -14.27ns |
| K18×K166A | -213ns | -281.52ns | 14ns | -57ns | 2ns | -1ns | -0.73ns | -3ns | -34.41ns | 53.44ns | -18.27ns | 2.84ns |
| K18×K166B | 827** | 1411.14* | -16ns | 119ns | -2ns | 0ns | -1.29ns | 10ns | -1.64ns | 12.5ns | 18.23ns | -14.84ns |
| K18×K3640/5 | -356ns | -367.48ns | -35ns | 25ns | -1ns | 0ns | -1.67ns | 2ns | 66.21ns | -10.87ns | -36.99ns | 30.88ns |
| K18×K47/2-2-1-21-2-1-1-1 | 429ns | 99.81ns | -188ns | -26ns | 5** | 2ns | 8.84ns | -5ns | -1.70ns | -5.7ns | 17.65ns | -13.18ns |
| K18×K19 | -139ns | -981.7ns | 164* | 200* | 4ns | 0ns | 11.44* | 12ns | 41.38ns | -33.11ns | 8.21ns | -26.72ns |
| K3651/1×A679 | 364ns | 730.8ns | 68ns | 52ns | 1ns | 0ns | 4.16ns | 4ns | 90.71ns | 71.12ns | -2.99ns | -16.70ns |
| K3651/1×K166A | 124ns | -927.9ns | 20ns | -62ns | 1ns | 0ns | 0.66ns | -3ns | -0.45ns | -26.93ns | -5.54ns | -12.63ns |
| K3651/1×K166B | -171.25ns | -311.52ns | 5ns | 172ns | 0ns | 0ns | 0.77ns | 15* | -11/07ns | -24.41ns | 20.25ns | -29.77ns |
| K3651/1×K3640/5 | 81.98ns | 176.53ns | -2ns | 44ns | -2ns | 0ns | 0.05ns | 1ns | -10.46ns | -6.25ns | 12.07ns | 23.81ns |
| K3651/1× K47/2-2-1-21-2-1-1-1 | -49.38ns | 14.48ns | -50ns | -24ns | -3ns | 1ns | -4.45ns | -2ns | -15.86ns | 14.36ns | -6.42ns | 43.99ns |
| K3651/1×K19 | -19.96ns | 559.64ns | -36ns | -59ns | 1ns | 0ns | -2.51ns | -6ns | 3.20ns | -23.89ns | -11.64ns | -33.99ns |
| A679×K166A | 110.65ns | -86.3ns | -50ns | 87ns | -3ns | 1ns | -4.03ns | 4ns | 38.64ns | -3.35ns | -40ns | 10.97ns |
| A679×K166B | -469.9ns | -1235.63ns | -6ns | -120ns | 0ns | 0ns | 0.08ns | -10ns | -84.25ns | -107.56* | -38.27ns | -4.43ns |
| A679×K3640/5 | 164.56ns | 313.09ns | 33ns | 14ns | 2ns | -1ns | 2.69ns | 1ns | -19.47ns | 59.57ns | 54.65ns | 31.82ns |

Table 5. Contd.

| | | | | | | | | | | | | |
|------------------------------|-----------|-----------|-------|-------|------|------|---------|------|----------|----------|----------|-----------|
| A679×K47/2-2-1-21-2-1-1-1 | 113.98ns | 323.03ns | 22ns | 106ns | 2ns | 0ns | 1.19ns | 9ns | -2.18ns | -41.49ns | 14.75ns | 5.73ns |
| A679×K19 | -65.35ns | -407.8ns | -64ns | -4ns | -4ns | -1ns | -3.86ns | 0ns | -9.70ns | 33.99ns | -5.02ns | -13.12ns |
| K166A×K166B | -213.3ns | 62.63ns | -68ns | -41ns | -2ns | 0ns | -4.09ns | -2ns | 14.12ns | 15.82ns | 48.56ns | 43.14ns |
| K166A×K3640/5 | -5.64ns | 399.42ns | -1ns | 38ns | 1ns | 0ns | -0.47ns | 1ns | -59.46ns | -44.68ns | 1.86ns | -107.17** |
| K166A×K47/2-2-1-21-2-1-1-1 | -57.62ns | 242.7ns | 139ns | 52ns | 2ns | 0ns | 13.03* | 5ns | 52.12ns | -56.08ns | -29.70ns | 16.23ns |
| K166A×K19 | 254.67ns | 715.2ns | -54ns | -17ns | -2ns | 0ns | -4.36ns | -3ns | -10.56ns | 61.78ns | 43.09ns | 46.62ns |
| K166B×K3640/5 | 101.44ns | -169.25ns | 133ns | 9ns | 3ns | 1ns | 8.64ns | -3ns | 69.24ns | 15.34ns | -33.84ns | 22.82ns |
| K166B×K47/2-2-1-21-2-1-1-1 | -222.29ns | 58.03ns | -27ns | -53ns | 0ns | -1ns | -2.2ns | -3ns | -16.57ns | 67.38ns | -22.54ns | -11.94ns |
| K166B×K19 | 148.57ns | 309.87ns | -21ns | -87ns | 1ns | 0ns | -1.92ns | -7ns | -30.18ns | 20.93ns | 7.62ns | -4.99ns |
| K3640/5×K47/2-2-1-21-2-1-1-1 | -10.36ns | -447.58ns | -53ns | -76ns | 1ns | -1ns | -4.59ns | -5ns | -3.69ns | 34.07ns | 35.38ns | -42.59ns |
| K3640/5×K19 | 23.86ns | 92.25ns | -76ns | -54ns | -3ns | 1ns | -4.64ns | 2ns | -42.37ns | -47.17ns | -33.13ns | 40.43ns |
| K47/2-2-1-21-2-1-1-1×K19 | -202.93ns | -290.47ns | 87ns | 21ns | 3ns | -1ns | 5.86ns | 1ns | -12.12ns | -12.53ns | -9.12ns | -8.23ns |
| SE (SCA) ⁴ | 309.54 | 642.78 | 78.03 | 98.38 | 2.69 | 0.76 | 5.68 | 7.11 | 46.32 | 48.78 | 30.86 | 38.13 |

⁴ns, * and **: nonsignificant, significant at 5% and 1% probability levels, respectively.

parents in all the studied traits. Unay et al. (2004) reported two parents W552 and DNB statistically significant and positive GCA effects. Akbar et al. (2008) reported that the inbred line 935006 was found as the best general combiner with better mean performance for all traits under both temperatures followed by R2304-2 and F165-2-4. The best cross was 935006×R2304-2. Choukan and Mosavat (2005) reported MO17×B73 and MO17×K74/1 as significant and negative combining for grain yield.

Based on the results of this study, only line K3640/5 for grain row number per ear in normal condition was significant and showed positive effect. Hybrid K18×K166B of the highest yield, positive and significantly combining in two conditions for grain yield was enjoyed. Grain yield in heat stress condition and 1000 grain weight in both conditions are controlled by additive type of gene action and other traits are controlled by non-additive type of gene action. Therefore, for improvement of grain yield in normal condition, grain

number per ear, grain row number per ear, grain number per ear row and hektolitr weight traits in both conditions heterosis should be used and for 1000 grain weight in two conditions and grain yield in heat stress using the two methods of hybrid production and selection can be effective. But hybrid production and use of heterosis are priority.

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