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SELECTION FOR GRAIN YIELD PER PLANT UNDER HEAT STRESS IN BREAD WHEAT *(Triticum aestivum* L.)

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Abstract: Divergent phenotypic selection for grain yield per plant under heat stress in wheat (*Triticum aestivum* L.) was performed in five F_2 populations derived from crosses established between eight local landraces quite variable in heat susceptibility index under the heat stressed condition of a late sowing date. Selection was imposed on 200 F2 spaced plants for each of the five populations where the highest and the lowest five plants in grain yield were selected. Responses in grain yield per plant and the correlated response in a number of agronomic traits were measured in the F_3 descending families of the selected F_2 plants against the F_3 bulks.

Selection for higher grain yield per plant under heat stress produced significant positive responses in three populations derived from heat tolerant x heat susceptible crosses, with the responses ranging from 3.87 to 25.71% of population mean with an average of 11.59%. However, selection for lower grain yield per plant was ineffective in four of the five populations which substantiate the conclusion of other factors, possibly earliness supporting yield under heat stress. The heritability estimates of grain yield per plant under heat stress were rather low ranging from 0.03 to 0.19.

Selection for higher grain yield per plant resulted in positive correlated responses in grain weight per spike which was significant in three populations and ranged from 0.93 to 8.56% with an average of 6.67% of population mean. In the low grain yield per plant direction, the grain weight per spike was significantly reduced in two populations only with an average reduction of 9.04% of the population mean. The heritability estimates were low ranging from 0.05 to 0.51.

Positive and significant concurrent responses to selection for high grain yield were also obtained in 1000 grain weight in four of the five populations which ranged from 0.13 to 7.54% with an average of 4.47% of population mean. Meanwhile, significant reductions were obtained in 1000 grain weight in the five populations with selection for lower grain yield per plant which ranged from 3.74 to 18.31% with an average of 9.79% of population mean. The heritability estimates ranged from low (0.14) in one population to moderate to high in the other four (0.4 to 0.84).

Key words: heat stress, Bread Wheat, grain yield.

Introduction

The high temperature prevailing during maturation hinders the productivity of wheat (Stone and Nicolas,1995): Various physico-chemical processes are responsible for heat tolerance in wheat genotypes. The genetic variation with regards to such processes among wheat genotypes would be of great value in developing heat tolerance cultivars. It has already bean established that many wheat genotypes can be considered high temperature tolerant (Lawson 1986).In wheat improvement programmes, breeding for heat stress tolerance in has bean approached through the utilization of limited number of progenitor germplasms in crosses and the subsequent selection for high yield under favorable environmental conditions. Such course of action resulted in narrowing down of genetic diversity of the tolerance traits including heat stress tolerance (Holden et al., 1993). As suggested by Hede et al., (1999) wild species and landraces may harbour genes for tolerance traits which are extinct in modern cultivars. Therefore, a number of landraces collected from stressful isolated fields in Upper Egypt, with variable heat susceptibility index for grain yield were used in this study for initiating the F2 populations on which selection for heat stress tolerance was imposed. The objective of this study was: to assess response to divergent selection for heat stress grain yield per plant in wheat.

Materials and methods

Eight local landraces of bread wheat (*Triticum aestivum L.*) quite variable in heat tolerance were used as parents for the crosses from which the five F_2 populations of this study were derived.

The parental landraces were chosen from the germplasm accessions collected from farmers' fields in stressful areas in Upper Egypt in 1993 (Omara, 1994). The whole array of landraces which included 150 accessions was evaluated for drought and heat tolerance under field conditions in a project at the Dept. of Genetics, Assiut University where each landrace was characterized by a heat susceptibility index (HSI). The accession numbers and relative HSI of the eight parental landraces are given in Table 1.

In 2001-2002 season, five crosses were established among the eight parental landraces; the details of which are given in Table 2. Four of the five crosses were made between parents contrasting in their relative heat tolerance so as to ensure enough variability to be generated in the segregating generation.

Table(1): Designation numbers and relative heat susceptibility index of the eight parental landraces.

Designation numbers	**HIS**	**characterization**
WA 50	1.38	Heat susceptible
45-3-4	0.36	Heat tolerant
WK 37	0.48	Heat tolerant
WK 4	1.24	Heat susceptible
WA 80	0.92	Heat tolerant
WA 90	0.87	Heat tolerant
WA 81	1.14	Heat susceptible
WS 126	1.15	Heat susceptible

Table (2): Crosses established between the eight parental landraces.

Cross No.	Cross	Description
1	45-3-4xWA50	Tolerant x susceptible
2	WK37xWA50	Tolerant x susceptible
3	WA80xWK4	Tolerant x susceptible
4	WA90xWA81	Tolerant x susceptible
5	WA81xWS126	Susceptible x susceptible

The F_1's were grown in the 2002 -2003 season in order to produce F_2 seeds. In 2003 -2004 season, seeds of the five F_2 populations were sown into the clay-loam fertile soil of Assiut University Experimental Farm in normal (17 November) and late (23 December) sowing dates so as to allow the late sown plants to be subjected to the heat stress which usually develop later in the season. The recorded temperatures during February and March 2004 (Assiut Agriculture Meteorological Station) indicated that heat waves have occurred with temperature rised above 34 °C for several days which coincided with the post flowering stages of plant development.

A total of 200 spaced plants were raised for each of the five F_2 populations at each sowing date. Plants were arranged in rows of 10 plants spaced 50 cm apart with plants within rows set 30 cm from each other. Each individual plant was tagged with a serial number referring to the population and the sowing date.

At maturity, plants were individually harvested and grain yield per plant was determined.

I- Selection procedure:

Divergent selection for heat stress tolerance was applied to the late sown 200 F_2 plants of each of the five populations. The selection criteria used was stress grain yield/plant (g).

The highest five plants in stress grain yield /plant were selected in the high direction. Meanwhile, the five plants with the lowest stress grain yield were selected in the low direction (an intensity of 2.5% in each direction). For each population, equal numbers of seeds were pooled from the 200 F_2 plants so as to form the F_3 bulks.

In 2004-2005 seasons, an experiment was conducted at the Exp. Farm of Assiut University for assessing the response to selection for stress grain yield /plant. The experiment was planted in the field in a late sowing date (22 December) which was so chosen as to expose the selected plants to heat stress resulting when temperature rises late in the growing season. The recorded temperature during February and March 2005 indicated the occurrence of waves of high temperature (above 30°C) which coincided with post flowering stages of plant development.

The selected F_3 families of the five crosses were raised along the F_3 bulks in a randomized complete block design with three replications. Each family was represented in each block by a 10 – plant row with rows spaced 50 cm apart and plants within rows set 30 cm from each other.

At maturity, grain yield per plant, number of spikes per plant, 1000 grain weight and harvest index were determined for each individual plant.

III- Heritability estimation

Heritability of each character was estimated by Parent –offspring regression (b_{po}); determined for each character by regressing the means of the F_3 selected families on the values of their corresponding progenitor F_2 plants.

Results

Base populations

I- Distribution of F_2 segregates under normal and late sowing date conditions

The distributions of F_2 segregates of the five crosses for grain yield per plant under normal and late sowing date conditions are illustrated in Fig. (1) The distributions were continuous and normal for the five populations.

Under the heat stress of the late sowing date, the distributions became narrower than those of the normal sowing date with the CV. values being uniformly reduced. Similarly, the mean grain yield per plant was consistently reduced under the heat stress of the late sowing date. Grain yield reductions due to heat stress ranged from 23.05% for pop.5 to 39.2% for pop.2 with an overall average reduction of 33.53% (Table 3).

Table(3): Means of grain yield per plant (g) of the five F_2 populations under normal and late sowing date conditions with the means of the plants selected in the higher and lower directions under heat stress together with the selection differential.

Population No	Population Mean		Mean of the selected F_2 plants		Selection differential	
	Normal	Stress	High	Low	High	Low
1	40.89	26.79	60.12	7.12	33.33	19.67
2	44.34	26.94	54.66	4.24	27.72	22.70
3	44.50	29.30	65.04	6.70	35.74	22.60
4	46.87	29.57	57.46	9.30	27.89	20.27
5	39.53	30.42	75.86	5.74	45.44	24.68

The selection differentials in the high direction ranged from 27.72 g (pop.2) to 45.44 g (pop.5) with an overall average of 34.02 g. In the low direction, the selection differentials were consistently smaller than those of the high direction ranging from 19.67 g (pop.1) to 24.68 (pop.5) with an average of 21.98 g (Table 4).

II- Phenotypic correlations in the F_2 populations

Grain yield per plant was positively and significantly correlated with both grain weight per spike and 1000 kernel weight under both normal and late sowing date conditions (Table 4) in the five populations analyzed. The associations between grain yield per plant of the F_2 segregates with harvest index was weaker under normal sowing date conditions than under late sowing date conditions where it was uniformly significant in the five populations. The association between grain yield per plant and flowering time was uniformly negative under the late sowing date

Table(4): Phenotypic correlations between grain yield per plant and other agronomic traits in the F_2 plants under normal and late sowing date conditions.

Normal sowing date					
Traits	Grain yield per plant				
	Pop.1	Pop.2	Pop.3	Pop.4	Pop. 5
Grain weight/spike	0.449**	0.637**	0.716**	0.597**	0.663**
1000 grain weight	0.277**	0.368**	0.468**	0.241*	0.537**
Harvest index (%)	0.156	0.174	0.021	0.264**	0.253*
Flowering time	0.044	0.013	-0.056	-0.124	0.081
Late sowing date					
Traits	Grain yield per plant				
	Pop.1	Pop.2	Pop.3	Pop.4	Pop. 5
Grain weight/spike	0.331**	0.516**	0.485**	0.439**	0.489**
1000 grain weight	0.248*	0.256**	0.370**	0.323**	0.242*
Harvest index (%)	0.233*	0.500**	0.211*	0.335**	0.222*
Flowering time	-0.128	-0.385**	-0.396**	-0.262**	-0.203*

* $P < 0.05$ ** $P < 0.01$

conditions indicating the role of earliness in escaping the heat stress that developed later in the season.

III - Response to selection for Grain yield per plant:

Positive responses to selection for grain yield per plant were obtained in both the high and low directions in the five populations (Table 5). Significant responses to selection for high grain yield per plant were obtained in three populations, namely pop.1, pop.2 and pop.3 but was non-significant in the other two populations. The %response ranged from 3.87 (pop.4) to 25.71% (pop. 1) with an average of 11.59% of the population mean. Meanwhile, % response to selection in the low direction for decreased grain yield per plant was significant in one population only, namely pop.2. The %response ranged from 0.037 (pop.5) to 18.40% (pop.2) with an average of 6.48% of the population mean.

The heritability estimates obtained by the parent-offspring regression (b_{po}) were quite similarly low and ranged from 0.03 to 0.19 for the five populations.

The analysis of variance revealed significant differences between the F_3 families selected for high (H) and those selected for low (L) grain yield per plant in four of the five populations. The differences between the average of the F_3 families selected for high and those selected for low grain yield per plant were 6.95, 8.15, 3.24, 2.99, and 2.32g for pop.1, pop.2, pop.3, pop.4, and pop.5, respectively with an overall average difference of 4.73g. The %response was greater in the high direction in three populations namely, pop.1, pop.3 and pop.5. but greater in the low direction for pop.2 and pop.4.

The correlated responses to selection for grain yield per plant.

3.1- Grain weight per spike:

The correlated responses to selection for grain yield per plant in grain weight per spike when selection was practiced for higher grain yield per plant were positive and significant in three populations (Table 6) and ranged from 0.93% (pop.4) to 8.56% (pop.2) with an average of 6.67% of the population mean.

Meanwhile, the correlated responses to selection in the grain yield per spike, when selection was practiced for lower grain yield per plant were positive in four of the five populations and reached significance in two populations (pop.2 and pop.4). The correlated response obtained with selection for lower grain yield per plant in grain weight per spike ranged from a reduction of 1.52% (pop.3) to 25.59% (pop.2) with an average of 9.04% of the population mean.

The heritability estimates obtained by the parent-offspring

Table(5): Response to selection for grain yield per plant in the high and low directions as well as parent-offspring regressions (b_{po})

Pop No.	Pop 1		Pop 2		Pop 3		Pop4		Pop 5	
	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response
F_3 Bulk	24.54		27.33		25.62		27.1		27.2	
High	30.85	25.713**	30.45	11.416*	27.79	8.469*	28.15	3.874	29.51	8.492
Low	23.9	2.607	22.3	18.404**	24.55	4.176	25.16	7.158	27.19	0.0367
Heritability (b_{po})	0.122 ± 0.053*		0.186 ± 0.121		0.060 ± 0.087		0.056 ± 0.07		0.029 ± 0.048	

* $P < 0.05$ ** $P < 0.01$

Table(6): Correlated responses to selection in grain weight per spike as well as realized heritability estimates and parent-offspring regression (b_{po}).

Pop No.	Pop 1		Pop 2		Pop 3		Pop4		Pop 5	
	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response
F_3 Bulk	2.043		2.02		1.706		2.15		1.973	
High	2.213	8.321*	2.193	8.564*	1.83	7.268	2.13	0.93	2.136	8.261*
Low	2.003	1.957	1.503	25.594**	1.68	1.524	1.86	13.488**	2.026	2.686
heritability (b_{po})	0.27 ± 0.094**		0.51 ± 0.151**		0.16 ± 0.108		0.15 ± 0.091		0.05 ± 0.103	

* $P < 0.05$ ** $P < 0.01$

regression (b_{po}) were low and ranged from 0.05 to 0.51.

The analyses of variance revealed significant differences between the averages of the F_3 families selected for higher and those selected for lower grain yield per plant in grain weight per spike in three populations, namely pop.1, pop.2 and pop.4.

3.2- 1000 grain weight:

The correlated responses to selection for grain yield in 1000 grain weight were positive and significant in four of the five populations (Table 7) and ranged from 0.13% (pop.4) to 7.54% (pop.2) with an average of 4.471% of the population mean.

Meanwhile, the correlated responses in 1000 grain weight, when selection was practiced for lower grain yield per plant were positive and significant in the five populations and ranged from 3.74% (pop.1) to 18.31% (pop.2) with an average of 9.79% of the population mean.

Meanwhile, heritability estimates obtained by the parent-offspring regression (b_{po}) were high in pop.2 (0.84) but of moderate magnitude for pop.1 (0.32), pop.3 (0.45), pop.4 (0.60) and pop.5 (0.45).

The differences in average 1000 grain weight between the families selected for high and those selected for low grain yield per plant were consistent in four of the five populations namely, pop.1, pop.3, pop.4 and pop.5 and amounted to3.37, 5.07, 6.07 and 7.01 g in the four populations, respectively.

Discussion

The impact of heat stress of the late sowing date on grain yield per plant was rather strong since the reductions ranged from 23.05 to 39.2% with an average of 33.5%. Similar reductions of 40 to 50% were reported by Blum *et al.* (2001) in recombinant inbred lines of wheat grown under heat stress.

The significant positive responses obtained in this study to selection for higher grain yield per plant under heat stress was confined to there populations derived from crossing heat tolerant x heat susceptible parental landraces. Progress has also been reported with selection for grain yield under stress using barley dry land landraces (Ceccarelli *et al.*, 1998). Such responses were attributed to in harbor physiological factors for stress adaptation present in the dry land landraces (Blum *et al.*, 2001 and Ceccarelli *et al.*, 1991). The lack of response in pop. 5 which was derived from cross between heat susceptible parents lends further support to the conclusion.

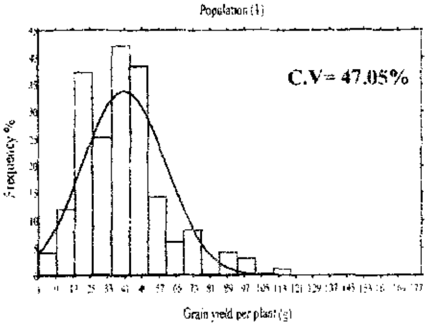
The apparent low realized heritability estimates obtained for grain yield under heat stress (ranged from 0.03 to 0.13) and the reductions of genetic variation have been reported by Ceccarelli (1989) and Blum *et al.* (2001).

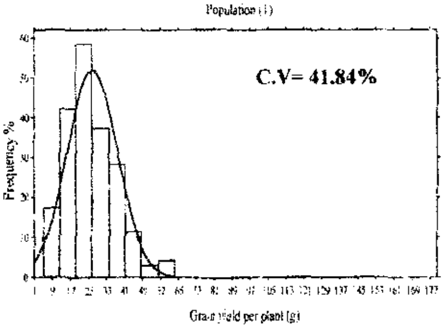
Table(7): Correlated responses to selection for grain yield per plant in 1000 Grain weight in the high and low directions as well as parent-offspring regression (b_{po}).

Pop No.	Pop 1		Pop 2		Pop 3		Pop4		Pop 5	
	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response	Mean	% Response
F_3 Bulk	49.45		42.7		42.95		46.15		50.97	
High	50.97	3.07*	45.92	7.54**	44.99	4.749**	46.21	0.13	54.47	6.866**
Low	47.6	3.74*	34.88	18.313**	39.92	7.054**	40.14	13.022**	47.46	6.886**
heritability (b_{po})	0.32 ± 0.121**		0.84 ± 0.133**		0.45 ± 0.082**		0.60 ± 0.213**		0.45 ± 0.168*	

* $P < 0.05$ ** $P < 0.01$

a b


Population (1)
C.V= 47.05%
Frequency %
Grain yield per plant (g)
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145 153 161 169 177


Population (1)
C.V= 41.84%
Frequency %
Grain yield per plant (g)
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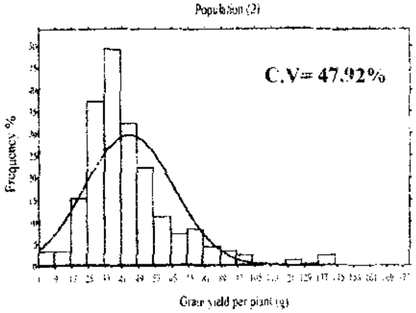
Population (2)
C.V= 47.92%
Frequency %
Grain yield per plant (g)
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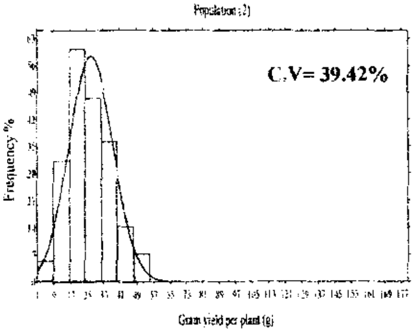
a


Population (2)
C.V= 39.42%
Frequency %
Grain yield per plant (g)
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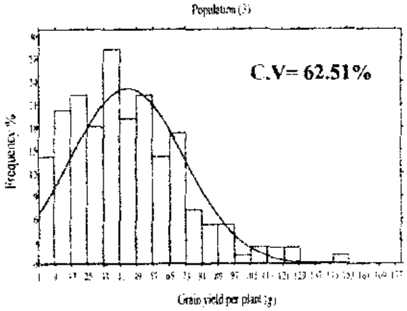
b


Population (3)
C.V= 62.51%
Frequency %
Grain yield per plant (g)
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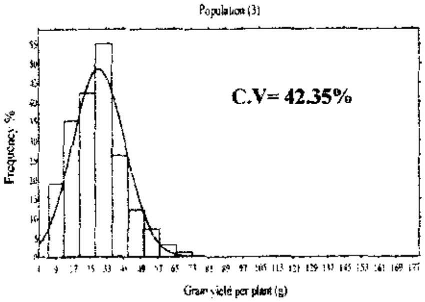
a


Population (3)
C.V= 42.35%
Frequency %
Grain yield per plant (g)
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b

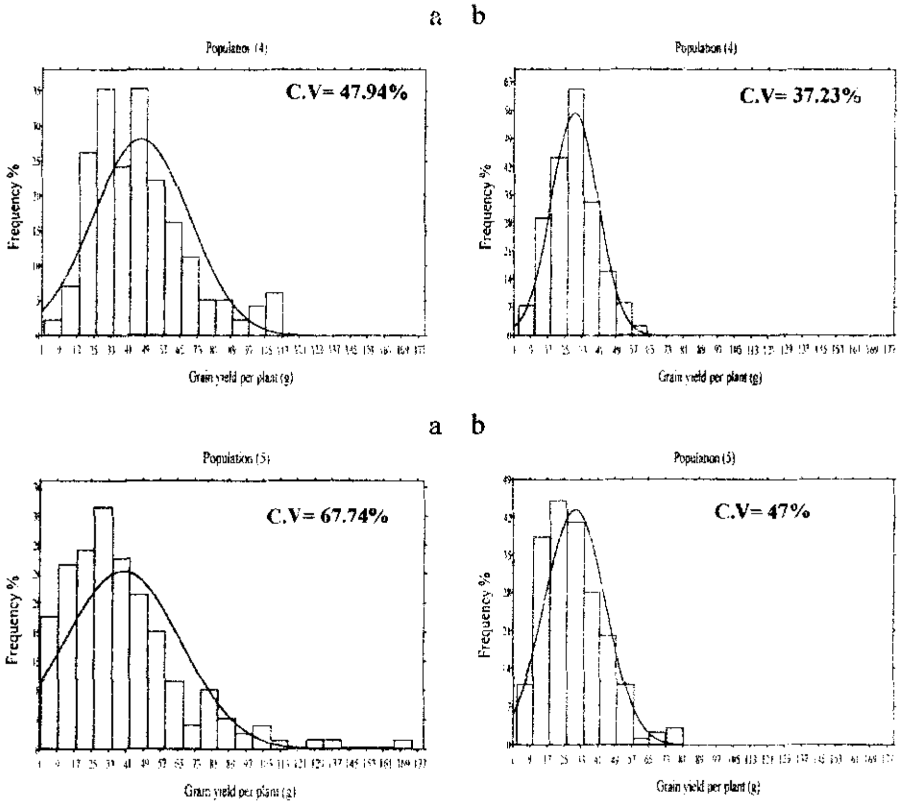

Fig.(1): Distributions of F_2 segregates for grain yield per plant (g) under (a) normal (1st sowing date) and (b) heat stress (2nd sowing date) conditions.

Such reductions would hinder progress from selection unless some specific factors for stress resistance is expressed in the populations which sustained yield (Blum *et al.*, 2001). Evidently the dry land landraces used in this study, being the product of natural and artificial selection must harbor certain genes for stress tolerance which might account for the responses obtained.

The absence of significant responses to selection for lower grain yield per plant under heat stress in four of the five populations used in this study could be attributed to other factors, probably earliness, supporting yield under heat stress through escaping. The fact that grain yield per plant was significantly correlated with earliness only under heat stress substantiate that conclusion. Similar correlation was found between grain yield and earliness in barley under drought stress (Ceccarelli *et al.*, 1991).

The concurrent positive responses in both grain weight per spike (averaged 6.67%) and in 1000-grain weight (averaged 4.47%) were smaller than the response in the selection character (11.6%) as expected apparently, the significant positive associations per plant under heat stress may account for such correlated responses.

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الانتخاب لمحصول الحبوب تحت الإجهاد الحراري في قمح الخبز

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أجري الانتخاب ثنائي الإتجاه لمحصول الحبوب للنبات في قمح الخبز (*Triticum aestivum* L.) تحت الإجهاد الحراري بالحقل لموعد الزراعة المتأخر في ثمانية سلالات أرضية محلية تتفاوت في المعامل الحراري. مورس الانتخاب على ٢٠٠ نبات إنعزالي بكل عشيرة في كل من الإتجاهين الطرد ي والعكسين حيث انتخبت اعلى وأقل خمس نباتات في محصول الحبوب للنبات (شدة انتخاب ٢,٥%) بكل عشيرة. تم تقدير الإستجابة للانتخاب والإستجابات المتلازمة لعدد من الخصائص المحصولية المتعلقة بالتحمل الحراري في عائلات الجيل الثالث الناتجة عن نباتات الجيل الثاني المنتخبة بالمقارنة مع الجيل الثالث غير المنتخب لكل اتجاه انتخابي تحت الإجهاد الحراري بالحقل لموعد زراعة متأخر.

تتلخص النتائج المتحصل عليها في التالي:

١- معنوية في ثلاث من العشائر الخمس وتراوحت الاستجابة بين ٣,٨٧ إلى ٢٥,٧١% بمتوسط ١١,٥٩%. أما الانتخاب العكسي لمحصول الحبوب المنخفض فلم يكن مؤثراً في أربع من العشائر الخمس مما يؤيد أن عوامل أخرى يحتمل أن من بينها التبكير في الإزهار تساند محصول الحبوب تحت الإجهاد الحراري. درجة التوريث المتحققة لمحصول الحبوب للنبات كانت شديدة الانخفاض (٠,٠٣ إلى ٠,١٩).

٢- أدى الانتخاب للمحصول العالي للحبوب بالنبات تحت الإجهاد الحراري إلى استجابة متلازمة موجبة في وزن الحبوب بالسنبلة كانت معنوية في ثلاث عشائر وتراوحت في العشائر الخمس بين ٠,٩٣ إلـــى ٨,٥٦% بمتوسط ٦,٦٧%. أما الانتخاب في الاتجاه العكسي فقد أدى إلى انخفاضات فـــي وزن الحـــبوب بالســنبلة كانت معنوية في عشيرتين بمتوسط انخفاض ٩,٠٤% في العشائر الخمس. تراوحت درجة التوريث المتحققة بين ٠,[illegible]٨ إلى ٠,٤٤%.

٣- كانـــت الاســتجابة المتلازمة للانتخاب للمحصول العالي للحبوب بالنبات في وزن الألف حبة موجبة ومعنوية في أربع عشائر وتراوحت بين ٠,١٣ إلى ٧,٥٤% بمتوسط ٤,٤٧%. في الاتجاه العكسي، انخفض وزن الألف حبة بما يتروا ح بين ٣,٧٤ إلى ١٨,٣١% بمتوسط انخفاض ٩,٧٩%. كانــت درجة التوريث المتحققة منخفضة في عشيرة واحدة (٠,١٤) ومتوسطة إلى عالية في باقي العشائر (٠,٤١ إلى ٠,٨٨).