

## SELECTION FOR CELL MEMBRANE THERMOSTABILITY IN BREAD WHEAT (*Triticum aestivum* L.)

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**Abstract:** Divergent phenotypic selection was performed for cell membrane thermostability (CMS) in wheat (*Triticum aestivum* L.) in five F<sub>2</sub> populations derived from crosses established between eight local landraces quite variable in heat susceptibility index. CMS was assayed in the flag leaves of field-hardened segregating plants at anthesis. Selection was imposed on 200 F<sub>2</sub> spaced plants for each of the five populations where the highest and the lowest five plants in CMS were selected. Responses in CMS and a number of agronomic traits were measured in the F<sub>3</sub> descending families of the selected F<sub>2</sub> plants against the F<sub>3</sub> bulks.

Significant responses to selection for CMS were obtained in both directions in the five populations which averaged 19.52% in the high and 11.9 % in the low CMS direction. The realized heritability estimates for CMS which were similar to the calculated parent-offspring regressions ranged from low (0.09 and 0.22) to intermediate (0.34, 0.53 and 0.57). Selection for high CMS produced concurrent positive responses in grain weight per spike in the five populations which averaged 15.72% whereas selection for low CMS reduced grain weight per spike in only two

populations with an average reduction of 5.2%. The realized heritability estimates for grain weight per spike ranged from low (0.39) to moderately high (0.70). Significant correlated responses to selection for CMS were obtained in 1000 grain weight in the five populations which averaged 8.25% of population mean in the high direction indicating an improved grain filling capacity. With selection for low CMS, the 1000 grain weight was reduced by 6.09% on average indicating impaired capacity for grain filling. The realized heritability for 1000 grain weight ranged from 0.57 to 0.88.

Significant concurrent responses to selection for high CMS were obtained in grain yield per plant only in two of the five populations. Meanwhile, selection for low CMS was not effective in reducing grain yield per plant in four of the five populations. Such limited effect of CMS on grain yield per plant could be attributed to the confounding effect of earliness as an escaping mechanism or heat avoidance which might support yield of the unselected base populations as well as the low CMS selections. The realized heritability estimates of grain yield per plant under heat stress were low ranging from 0.09 to 0.43.

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**Key words:** selection, cell membrane, thermostability, *Triticum aestivum* L.

## Introduction

Heat stress is a major constraint to the productivity of wheat (*Triticum aestivum* L) in most of the cereal growing areas especially the warmer regions of the world (Fischer, 1986). Although most of the world crops are exposed to heat stress during some stage of their life cycle (Stone, 2001), the problem is becoming increasingly serious nowadays due to the "greenhouse" phenomenon resulting from the excessive emission of CO<sub>2</sub> from industry into the air. Exposure of wheat plants to higher than optimal temperature causes considerable reduction of yield and decreases quality of the grains (Fischer and Byerlee, 1991). The continual heat stress reduced the duration of development phases leading to fewer organs, smaller organs, reduced light perception over the shortened life cycle and perturbation of the processes related to carbon assimilation (Stone, 2001). Meanwhile, terminal heat stress, which is more common in temperate and hot environments, impacts the capacity for grain filling and reduces grain quality. Apparently, where heat stress occurs, it is essential that wheat cultivars possess a certain degree of heat tolerance in order to withstand the stress period.

Cell membrane thermostability (CMS) is a technique developed for measuring heat tolerance of crop plants (Martineau *et al.*, 1979a and

Sullivan and Ross, 1979). The CMS technique is based on the observation that leaf tissue injury caused by high temperature increases membrane permeability and electrolytes diffuse out of the cell into the solution. Relative heat damage is assessed by measuring the amount of electrolyte leakage from injured cells by the electrical conductivity of the solution. The effectiveness of CMS assay in detecting genetic variability in heat tolerance was demonstrated in various crops such as soybean (Martineau *et al.*, 1979a,b), sorghum (Sullivan and Ross, 1979), and wheat (Blum and Ebercon 1981; Reynolds *et al.* 1994; Saadalla *et al.*, 1990a,b and Fokar *et al.*, 1998a, b).

Despite the substantial genetic variability for CMS found among wheat genotypes (Blum and Ebercon, 1981; Saadalla *et al.*, 1990a,b; Fokar *et al.*, 1998a,b and Ibrahim *et al.*, 2001a,b) limited efforts have been made for enhancing heat stress tolerance through selecting for CMS. The utilization of a limited number of progenitor germplasms in breeding for a high yield potential under favorable environmental conditions has resulted in the narrowing down of the genetic diversity of the stress 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 F<sub>2</sub> populations on which selection for heat stress tolerance was imposed. The objectives of this study were:

- To assess response to divergent selection for CMS and for heat stress grain yield per plant in wheat plants at anthesis.
- To measure the correlated responses to selection for CMS in yield and some of its components under heat stress.

### **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 F<sub>2</sub> 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 was evaluated for drought and heat tolerance under field conditions in a project at the Dept. of Genetics, Assiut University and 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.

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

<b>Designation numbers</b>	<b>HSI</b>	<b>characterization</b>
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

\* Extracted with permission from ATUT W-6 project final report, ARC, Egypt.

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.

The F<sub>1</sub>'s were grown in 2002 - 2003 in order to produce F<sub>2</sub> seeds. In 2003 -2004 season, seeds of the five F<sub>2</sub> 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<sub>2</sub> 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 flowering, fully expanded flag leaf of the main culm of each plant was excised and placed in a capped vial containing distilled water and was transferred to the laboratory for cell membrane thermostability assay. Vials were kept in the refrigerator overnight.

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

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

Cross No.	Cross	Description
1	45-3-4 x WA50	Tolerant x susceptible
2	WK37 x WA50	Tolerant x susceptible
3	WA80 x WK4	Tolerant x susceptible
4	WA90 x WA81	Tolerant x susceptible
5	WA81 x WS126	Susceptible x susceptible

### I- Selection procedure:

Divergent selection for heat stress tolerance was applied to the late sown 200 F<sub>2</sub> plants of each of the five populations. The selection criteria used was CMS.

The highest five plants in CMS score as well as the five plants with the lowest CMS score were selected for the high and low directions, respectively. For each population, equal numbers of seeds were pooled from the 200 F<sub>2</sub> plants so as to form the F<sub>3</sub> bulks.

In 2004-2005 season, an experiment was conducted at the Exp. Farm of Assiut University for measuring the response to selection for CMS. 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<sub>3</sub> families of the five crosses were raised along the F<sub>3</sub> 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.

Each individual plant was tagged and marked with a number referring to the cross and block. Fully expanded flag leaf of the main culm was excised from each individual plant and each was placed in a capped vial containing distilled water and marked with plant number and vials were transferred to the laboratory and kept at 6°C over night until CMS measurement.

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

### II- Cell membrane thermostability assay:

The CMS assay was performed according to the method described by Fokar *et al.* (1998a). CMS was calculated as the reciprocal of cell membrane injury after Blum and Ebercon (1981) as:

$$\text{CMS (\%)} = \frac{\left(1 - \frac{T_1}{T_2}\right)}{\left(1 - \frac{C_1}{C_2}\right)} \times 100$$

Where: T and C refer to treatment and control, respectively and 1 and 2 refer to initial and final conductance readings, respectively.

### III- Heritability estimation

Heritability of each character was estimated by two methods

1- Realized heritability calculated as:

$$h^2 = \frac{[\overline{H}_S - \overline{L}_S]}{[\overline{H}_B - \overline{L}_B]}$$

Where:  $\bar{H}_S$  and  $\bar{L}_S$  are the averages of the  $F_3$  families selected for a trait in the high and low directions, respectively while  $\bar{H}_B$  and  $\bar{L}_B$  are the averages of the  $F_2$  plants selected for that trait in the two directions (Ibrahim and Quick, 2001).

2- Parent – offspring regression ( $b_{po}$ ); was 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**

**1- Cell membrane thermostability:**

Means of CMS of the five  $F_2$  populations under normal and late

sowing date conditions, with the means of the plants selected for higher and lower CMS under heat stress, and the selection differentials are given in Table 3. The selection differentials in the high CMS direction were of comparable magnitude for the five populations. However, in the low CMS direction the selection differential varied among the five populations being considerably reduced in four of which as compared with those of the high direction.

**II- Phenotypic correlations in the  $F_2$  populations CMS and agronomic traits:**

Under normal sowing date conditions, CMS values were significantly associated with grain

**Table(3):** Means of CMS of the five  $F_2$  populations under normal and late sowing date conditions with the means of the plants selected for higher and lower CMS under heat stress and the selection differential.

Population No	Population Mean		Mean of the selected $F_2$ plants		Selection differential	
	Normal	Stress	High	Low	High	Low
1	16.80	46.80	83.22	8.68	36.42	38.12
2	40.80	31.60	66.76	14.70	35.16	16.90
3	33.17	16.21	47.68	5.14	31.47	11.07
4	57.13	42.27	78.60	15.92	36.33	26.35
5	23.38	22.19	57.58	9.66	35.39	12.53

weight per spike in only two of the five populations (Table 4). However, under the heat stress of the late sowing date, the correlations were positive and significant in the five populations. Similarly, there were significant positive correlations between CMS values and 1000 kernel weight in only two populations under normal sowing date conditions but in three of the five populations under the heat stress of the late sowing date. Such associations indicated that segregates with higher CMS values tended to yield more and heavier

grains under heat stress. This is also substantiated by the positive associations found between CMS values and harvest index in four of the five populations under the heat stress of the late sowing date as opposed to only two populations under normal conditions.

Finally, the CMS values were negatively associated with flowering time under both normal and late sowing date conditions with the correlations being significant in three of the five populations under heat stress indicating the role of earliness in heat avoidance.

**Table(4):** Phenotypic correlations between CMS and some agronomic traits in the F<sub>2</sub> plants under normal and late sowing date conditions.

Normal sowing date					
Traits	CMS				
	Pop.1	Pop.2	Pop.3	Pop.4	Pop. 5
Grain weight/spike	0.184	0.258**	0.028	0.196*	0.163
1000 grain weight	0.147	0.304**	0.101	0.218*	0.100
Harvest index (%)	0.055	0.223*	0.045	0.194*	0.007
Flowering time	-0.106	-0.191*	-0.082	-0.173	-0.202*
Late sowing date					
Traits	CMS				
	Pop.1	Pop.2	Pop.3	Pop.4	Pop. 5
Grain weight/spike	0.194*	0.218*	0.233*	0.197*	0.194*
1000 grain weight	0.273**	0.242*	0.041	0.341**	0.086
Harvest index (%)	0.238**	0.232*	0.156	0.191*	0.206*
Flowering time	-0.315**	-0.257**	-0.112	-0.259*	-0.123

\* P < 0.05    \*\* P < 0.01

### **III- Response to selection for CMS:**

Positive and significant responses to selection for CMS were obtained in both the high and low directions in the five populations (Table 5). The %response to selection for high CMS ranged from 4.08% (pop.4) to 39.40% (pop.3) with an average of 19.52% of the population mean. Meanwhile, % response to selection in the low direction for decreased CMS ranged from 4.04% (pop.4) to 14.55% (pop.3) with an average of 11.92 % of the population mean.

The analysis of variance revealed highly significant differences between the F<sub>3</sub> families selected for high (H) and those selected for low (L) CMS with the differences being 16.4, 17.9, 24.2, 5.5, and 25.2% for pop.1, pop.2, pop.3, pop.4, and pop.5, respectively. The %response in the high and low directions were symmetrical in two populations, namely pop.2 and pop.4. However, asymmetrical responses were obtained in the other three populations being greater in the high directions in two populations (pop.3 and pop.5) but greater in the low direction for pop.1.

The realized heritability estimates were quite low for pop.4 (0.09) and pop.1 (0.22) but of moderate magnitude for pop.2 (0.34), pop.3 (0.57) and pop.5 (0.53).

Meanwhile, heritability estimates obtained by the parent-offspring regression ( $b_{po}$ ) were similar to the realized heritability estimates for the five populations. The obtained %response to selection was closely related to the heritability estimate as calculated by the parent-offspring regression.

### **IV- The correlated responses to selection for cell membrane thermostability (CMS).**

#### **1- Grain weight per spike:**

The correlated responses to selection in the grain weight per spike, when selection was practiced for higher cell membrane thermostability, were positive and significant in the five populations (Table 6). The positive concurrent response obtained with selection for high CMS in the grain weight per spike ranged from 8.79% (pop.2) to 23.48% (pop.1) with an average of 15.72% of the population mean. Meanwhile, the correlated responses to selection in grain yield per spike when selection was practiced for lower CMS were positive in the five populations and reached significance in pop.2 and pop.3. The correlated responses obtained with selection for low CMS in grain yield per spike ranged from a reduction of 1.44% (pop.1) to 8.06% (pop.2) with an average reduction of 5.20% of the population mean.





The realized heritability estimates were rather low for pop.4 (0.39) and quite high for pop.1 (0.70) but of similar moderate magnitude in pop.2 (0.55), pop.3 (0.59), and pop.5 (0.55). However, heritability estimates obtained by the parent-offspring regression ( $b_{po}$ ) were lower than the realized heritability estimates in three of the five populations, namely pop.1, pop.2, and pop.3 while the estimates by the two methods were similar in pop.4 and pop.5.

The analyses of variance revealed significant differences between the averages of the  $F_3$  families selected for higher and those selected for lower CMS in grain weight per spike in the five populations.

### **2- 1000 grain weight:**

The correlated responses to selection for CMS in 1000 grain weight (g) when selection was practiced for increasing CMS were positive and significant in the five populations (Table 7). The correlated responses obtained with selection for high CMS ranged from 5.80% (pop.1) to 12.17% (pop.3) with an average of 8.25% of the population mean. Meanwhile, the correlated responses to selection in 1000 grain weight, when selection was practiced for decreased CMS were positive and reached significance in four populations namely, pop.1, pop.2, pop.3 and pop.4. The positive responses obtained with selection for low CMS ranged from 4.65% (pop.5)

to 9.07% (pop.2) with an average of 6.89% of the population mean.

The realized heritability estimates for 1000-grain weight were quite high in four populations namely pop.1 (0.85), pop.2 (0.88), pop.4 (0.86) and pop.5 (0.78) but of moderate magnitude in pop.3 (0.57). Meanwhile, heritability estimates obtained by the parent-offspring regression ( $b_{po}$ ) were similar to the realized heritability estimates in two populations, namely pop.2 and pop.5 but were smaller in magnitude in the other three populations. The differences between the high and low CMS selections in 1000 grain weight were significant in the five populations being 6.87, 6.5, 2.97, 6.11 and 6.94 gm in pop.1, pop.2, pop.3, pop.4, and pop.5 respectively.

### **3- Grain yield per plant:**

The correlated responses to selection for CMS in grain yield per plant when selection was practiced for increased CMS were positive in the five populations and reached significance in pop.3 and pop.4 (Table 8). The positive correlated responses obtained with selection for high CMS ranged from 4.15 (pop.2) to 13.83 (pop.3) with an average of 10.22% of the population mean. Meanwhile, the selection for decreased CMS was ineffective in reducing grain yield per plant for all populations. Negative correlated response was obtained in pop. 3 where selection for high and low



CMS produced the same means for grain yield per plant.

The realized heritability values of grain yield per plant were generally low in the five populations: pop.1 (0.29), pop.2 (0.14), pop.3 (0.09), pop.4 (0.25) and pop.5 (0.43). Similarly, low heritability estimates were obtained by the parent-offspring regression (Table 8).

### **Discussion**

The positive and significant responses to divergent selection for CMS which were uniformly obtained in the five populations used in this study indicated the presence of abundant additive genetic variation among  $F_2$  segregates allowing such responses to occur. Additive gene effects were reported to be mainly controlling cell membrane thermostability in wheat (Sharma and Tandon, 1998b; Xu-Ruqiang *et al.*, 1998; Saadalla, 1997; Fokar *et al.*, 1998a and Ibrahim and Quick, 2001b).

The obtained average % response to selection for greater CMS (19.52%) was of similar magnitude to the calculated expected gains from selection for CMS among segregates in soybean which were reported by Martineau *et al.* (1979b) to be from 16 to 18 %.

The asymmetrical responses to the divergent selection for CMS with the responses in the high direction being greater (19.52% on average) than that obtained in the low direction

(averaged 11.9 %) are attributable to the selection differentials that were greater in the high (averaged 34.95) than in the low direction (averaged 21.0).

The heritability of CMS either realized or estimated by the parent-offspring regression ( $b_{F_2F_3}$ ) ranged from low (0.09 and 0.22) to moderate (0.34, 0.53 and 0.57). Similar low to intermediate realized heritabilities of CMS were reported in wheat (Ibrahim and Quick, 2001a) which ranged from 0.27-0.47 and for slow leaf electrolyte-leakage under heat stress in cowpea (Hall, 2004). Moreover, similarly low parent-offspring regressions for CMS were reported by Ibrahim and Quick (2001a) with  $b_{p_0}$  ranging from 0.32 to 0.38. However, moderately high narrow-sense heritability of 0.68 was reported for CMS in wheat seedlings by Saadalla (1997).

The obtained positive concurrent responses in grain weight per spike with selection for higher CMS was greater (averaged 15.72 %) than that obtained in 1000 grain weight (8.25 % on average) indicating that grain number per spike have also increased in addition to the increased capacity for grain filling. The correlated responses to selection for lower CMS were less pronounced in grain weight per spike (5.2 %, average reduction) than in 1000 grain weight (6.89 % an average reduction) which is another indication of the impaired capacity for

grain filling of such selections under heat stress.

Evidently, a strong negative association has been reported between CMS and reduction in grain weight per spike under heat stress (Foker *et al.*, 1998b). Significant negative association was also reported between kernel weight heat susceptibility index and CMS (Shipler and Blum, 1991) indicating that thermotolerance was related to grain filling capacity under heat stress. Grain volume weight and Kernel weight were found to be greater for the heat tolerant genotypes than the intermediate or heat-sensitive ones in wheat based on CMS (Saadalla *et al.*, 1990b).

As pointed out by Foker *et al.* (1998b), while a potential source of carbon must be available as transportable stem resources, this carbon cannot be synthesized into starch at high temperature unless thermotolerance is involved.

Unlike the remarkable correlated responses to selection for CMS in grain weight per spike and 1000 grain weight, the concurrent responses in grain yield per plant was rather limited being positive and significant in two populations only and non-significant in three. Moreover, selection for lower CMS was not effective on grain yield per plant in four of the five populations tested.

According to Blum *et al.* (2001), the associations between CMS and grain yield under heat stress were

reasonably strong and significant but not perfect. They also stated that other factors besides CMS may support yield under heat stress, most probably heat avoidance. They also concluded that CMS alone cannot be used as the exclusive selection criterion for heat tolerance. The results of the present study support this conclusion since flowering time was uniformly negatively associated with CMS under heat stress in the F<sub>2</sub> segregates indicating that earliness and the ensuing escape from the heat stress that usually develop later in the growing season might have supported the non-selected base plants as well as the plants selected for low CMS, thus suppressing the correlated response to selection.

In conclusion, selection for higher CMS is quite feasible and practical among the *in situ* hardened plants of the segregating generations grown in the field under hot temperature. The resultant selections will display improved grain weight per spike as well as greater single grain mass under heat stress. For greater grain yield under heat stress, selection for high CMS should be augmented with heat avoidance through earliness.

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## الانتخاب للنبات الحراري للغشاء الخلوي في قمح الخبز (*Triticum aestivum* L.)

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أجري الانتخاب ثنائي الإتجاه لخاصية الثبات الحراري للغشاء الخلوي في قمح الخبز (*Triticum aestivum* L.) تحت الإجهاد الحراري بالحقل لموعد الزراعة المتأخر في خمس عشائر إنعزالية في الجيل الثاني نتجت عن تهجينات بين سلالات أرضية محلية تتفاوت في المعامل الحراري واشتملت على أربع تهجينات بين سلالات مقاومة حرارياً X سلالات حساسة وتهجين واحد بين سلالتين حساستين ثم تقدير الثبات الحراري للغشاء الخلوي في أوراق العلم المقساة في الحقل عند مرحلة إنتشار اللقاح. مورس الانتخاب على 200 نبات إنعزالي بكل عشيرة في كل من الإتجاهين الطردى والعكسي حيث انتخبت أعلى وأقل خمس نباتات في الثبات الحراري للغشاء الخلوي (شدة انتخاب 2.5%) 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:

- 1- نتجت استجابات موجبة معنوية للانتخاب للثبات الحراري للغشاء الخلوي في الاتجاهين الطردي والعكسي في العشائر الخمسة. تراوحت الاستجابة في الاتجاه الطردي بين 4.08 إلى 39.4% بمتوسط 19.52%. كانت الاستجابة في الاتجاه العكسي أقل من الاتجاه الطردي حيث تراوحت بين 4.04 إلى 14.55% بمتوسط 11.9% ويعزى عدم التناظر في الاستجابة للانتخاب بين الاتجاهين الطردي والعكسي إلى أن الفارق الانتخابي في الاتجاه الطردي كان أكبر من ذلك الخاص بالاتجاه العكسي.
- 2- كانت تقديرات درجة التوريث المتحققة للثبات الحراري للغشاء الخلوي مطابقة تماماً للتقديرات بانحدار النسل على الأباء وتراوحت في العشائر الخمسة بين شديدة الإنخفاض (0.09 و 0.22) إلى متوسطة (0.34 ، 0.53 ، 0.57).
- 3- نتجت عن الانتخاب الطردي للثبات الحراري للغشاء الخلوي استجابات متلازمة معنوية موجبة في وزن الحبوب للسنبلة في العشائر الخمسة وتراوحت بين 8.89 إلى 23.48% بمتوسط قدرة 15.72% من متوسط العشريّة مما يشير إلى أن عدد الحبوب بالسنبلة ووزن الحبة المفردة قد زادا.
- 4- نتجت عن الانتخاب العكسي للثبات الحراري للغشاء الخلوي انخفاضات في وزن الحبوب للسنبلة كانت معنوية في عشيرتين فقط من العشائر الخمس وتراوحت الانخفاضات بين 1.44 إلى 8.06% بمتوسط قدره 5.2% وكانت الفروق بين العائلات المنتخبة للتحمل الحراري العالي للغشاء الخلوي وتلك المنتخبة للتحمل المنخفض في وزن الحبوب للسنبلة معنوية في العشائر الخمس.
- 5- درجة التوريث المنخفضة لوزن الحبوب بالسنبلة تراوحت بين منخفضة (0.39) إلى عالية (0.70) وكانت معاملات انحدار النسل على الأباء أقل من درجة التوريث المتحققة في ثلاث عشائر.
- 6- نتجت استجابات موجبة معنوية للانتخاب الطردي للثبات الحراري للغشاء الخلوي في وزن الألف حبة في العشائر الخمس وتراوحت بين 5.8 إلى 12.17% بمتوسط 8.25% مما يشير إلى تحسن القدرة على ملئ الحبوب في السلالات المنتخبة. أما الانتخاب للتحمل الحراري المنخفض للغشاء فقد أنتج انخفاضاً في وزن الألف حبة تراوح بين 4.65 إلى 9.07% بمتوسط قدره 6.09% مما يشير إلى تأثر القدرة على ملئ الحبوب سلبياً.
- 7- كانت درجة التوريث المتحققة لوزن الألف حبة عالية حيث كانت 0.57 إلى 0.88 مما يشير إلى أنها موروثية بدرجة كبيرة وكانت الفروق في وزن الألف حبة بين السلالات المنتخبة للتحمل العالي للغشاء الخلوي لإجهاد الحرارة والمنتخبة للتحمل المنخفض معنوية في العشائر الخمسة.
- 8- أدى الانتخاب للتحمل الحراري العالي للغشاء الخلوي إلى حدوث استجابة متلازمة موجبة معنوية في محصول الحبوب للنباتات في عشيرتين فقط من العشائر الخمس كما لم يؤثر الانتخاب للتحمل الحراري المنخفض معنوياً على محصول الحبوب للنباتات تحت الإجهاد الحراري في أربع عشائر من العشائر الخمسة. مثل هذا الأثر المحدود للتحمل الحراري للغشاء الخلوي على محصول الحبوب للنباتات قد يرجع إلى الأثر المتداخل للتبكير في الإزهار الذي ربما أدى إلى هروب النباتات وتجنبها ارتفاع درجة الحرارة الذي يحدث عادة قرب نهاية الموسم مما وفر دعماً لمحصول الحبوب في النباتات غير المنتخبة أو المنتخبة للتحمل المنخفض. كانت درجة التوريث المتحققة لمحصول الحبوب تحت الإجهاد الحراري شديدة الانخفاض حيث تراوحت بين 0.09 إلى 0.43.