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Evaluation of stem reserve mobilization in Egyptian bread wheat (*Triticum aestivum* L.) genotypes and F_1 hybrids under post-anthesis chemical desiccation stress

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Abstract

The assimilation of stem reserves by pre-anthesis is regarded as an essential source of grain filling during abiotic stresses that inhibit photosynthesis during post-anthesis. Twenty-one Egyptian wheat genotypes and F_1 hybrids were evaluated using potassium iodide (0.4% KI) induced desiccation stress 14 days after anthesis for stem reserve mobilization (SRM). For a percentage reduction in grain weight under chemical desiccation stress, the measured genotypes differed significantly ($P<0.01$). The stress tolerance index for grain weight varied from 85.88 to 97.67%. The minimum reduction was observed in Gemmiza-10 x Sids-12 (85.88 %) showing the lowest SRM while in Gemmiza 7 x Gemmiza 11 (97.67%) showing the highest utilization of SRM, the maximum reduction in grain weight was reported. A strong negative correlation ($r = 0.037$) was observed between the percentage decrease in grain weight and plant height. In conclusion, when subjected to post-anthesis chemical desiccation that prevents photosynthesis, tested genotypes differ considerably in stem reserve use. In the absence of photosynthesis, genotypes with better SRM dependent grain growth can also have relative drought tolerance. Therefore, this approach can be used to indirectly screen the genotypes of wheat for better output under conditions of terminal drought.

Keywords: **Bread wheat (*Triticum aestivum* L.), Chemical Desiccation Stress, Drought stress, Post-anthesis, Stem reserve mobilization**.

Introduction

Wheat is one of the world's main grains and a staple food for over half of the world's population. The wheat grain contains about 12% of water, 60-80% of carbohydrates (mainly starch), 8-15% of proteins, 1.5-2% of fats, 1.5-2% of minerals and about 2% of vitamins and crude fibers. Grain production and growth depends primarily on current assimilates that is directly translocated to the grains, but also plays an important role in the development and growth of carbohydrates assimilated after anthesis and temporarily deposited in the stem until mobilizing to the grains. The carbohydrate synthesized before anthesis accumulated primarily in the stem and mobilized to produce grain is the third source of carbohydrates in grains, which is very important for grain filling under stress (Ehdaie et al., 2006, Saleh et al. 2020). During grain growth and production, wheat crops frequently experience salt stress, heat stress and water deficiency, limiting productivity (Ehdaie et al., 1988; Salem et al. 2008; Mattar et al. 2009; Salem 2009; Salem and Mattar 2014; El-Absawy, 2015; Mattar et al. 2016; Nawara, et al. 2016; 2017, Mourad et al., 2019). The response of wheat genotypes, however, differs according to different water-deficit levels (Hameed et al., 2011). Grain shriveling, decrease in test weight and decrease in grain yield are the typical result of these stresses. In many developing countries, these stresses are permanent restrictions on agricultural productivity, while in developed countries, these stresses cause occasional losses in agricultural production (Ceccarelli and Grando, 1996). Usually, there is a growing pattern at the time of grain filling for wheat crop temperature while moisture levels are decreasing. In normal grain filling, readily available assimilates could be a limiting factor even under mild circumstances. The current source of assimilated carbon depends on the plant's active green surfaces that intercept light for photosynthesis. The effect of multiple stresses and natural senescence reduces the photosynthesis rate at the terminal level, while the need for the growing grain increases at this stage. Stem reserves are a critical source of grain filling in this situation, and wheat crops can rely more on stem reserves in dryland areas than on current photosynthesis for proper grain filling (Ehdaie et al., 2006). In wheat, an important physiological feature and breeding aim is to increase the ability to sustain grain filling through stem and spike reserves (Blum, 1998, Börner et al. 2010). In a theoretical model for drought tolerance, a strong capacity for stem reserve and its remobilization has been suggested as a drought adaptive trait (Reynolds et al., 1999). Several studies are confirming that the desiccation of leaves significantly decreases photosynthesis when extreme drought stress occurs at the time of grain filling, and grain filling mainly depends on mobilized stem reserves (Bidinger et al., 1977; Davidson and Birch, 1978; Hunt, 1979; Blum, 1988, Salem et al. 2007; Börner et al. 2010; Nezhad et al. 2012). Different indicators have been tested that may be useful to distinguish between drought tolerant and wheat vulnerability (Hameed et al., 2010). In the absence of active photosynthesis, the chemical desiccation process applied at the time of grain filling shows genotypic variations in varieties in the use of stem reserves (Blum et al., 1983a; 1983b; 1990). Potassium iodide (KI), a chemical contact desiccant, has been reported to be useful for disrupting photosynthesis and assessing grain filling via stem reserve mobilization (Blum et al., 1983a, 1983b; Blum and Pnuel, 1990; Hossain et al., 1990; Nicholas and Turner, 1993, Salem et al. 2007). This treatment does not replicate drought stress, but inhibiting photosynthesis produces the impact of stress. The observed outcome of treatment with KI is close to that recorded in plants under stress from water. One of the most desirable breeding targets of recent times is the enhancement of drought tolerance (Keim and Kronstad 1979; Blum 1983b). In the above view, the present investigation was carried out to i) examine genetic differences between Egyptian wheat genotypes and F_1 hybrids in the use of stem reserve by developing grains under post-anthesis drought stress using chemical desiccation and ii) determine the potential use of this technique in wheat for indirect screening for post-anthesis drought tolerance.

Materials and Methods

Plant materials: At the experimental farm of Genetic Engineering and Biotechnology Research Institute (GEBRI), Sadat City, University of Sadat City, Egypt, during the two wheat growing season. six wheat genotypes were used in this study i.e., Giza 168, Gemmiza 7, Gemmiza 9, Gemmiza 10, Gemmiza 11 and Sids 12 as local genotypes from Agriculture Research Center (ARC), Giza, Egypt and these genotypes were drawn from the genetic stock of wheat section, Field Crops Research Institute, Agriculture Research Center (ARC), Egypt. Name, origin and pedigree of the six wheat genotypes are presented in (Table 1).

Table 1. Wheat varieties, origin, and pedigree used in the study.

No.	Variety	Pedigree	Selection history	Year of release
1	Giza-168	MIL/BUC// Seri CM93046-8M-0Y-0M-2Y-0M	CM93046-8M-0Y-0M-2Y-2B	1999
2	Gemmiza-7	CMH74A.360/5x//Seri82/3/Agent CGM4611-2GM-3GM-1GM-0GM.	CGM 4611-2GM-3GM-1GM-0GM	2000
3	Gemmiza-9	ALD”S”/HUAC”S”//CMH74A.630/5X.	CGM 4583-5GM-1GM-0GM	2000
4	Gemmiza-10	MAYA74"S"/ON//II60.147/3/BB/GLL/4/CHAT"S" /5/CROW"S"	---	2004
5	Gemmiza-11	BUC’’S’’/ Kvz’’S’’// 7c/ Seri 82 /3/Giza 168/ Sakha 61 GM7892-2GM-1GM- 0 GM.	---	2011
6	Sids-12	BUC// 7c/ Ald/5/ Maya 74/ On/ 1160.147/3/ BB/ G11/4/ Chat’’S’’ /6/ Maya/ vu1 // Cmh 74A.630/4* sx, SD7096- 4SD- 1SD-0SD.	SD7096-4SD-1SD-1SD-0SD	2008

Field experiments: All possible crosses among the six parents excluding reciprocal were generated through a diallel mating scheme in wheat-growing season 2012/2013. The seeds of the six parents and all possible 15 crosses were sown in the next season 2013/2014 in rows. The experiments were arranged in a randomized complete block design (RCBD), with three replicates for each stress condition. All of the agricultural practices recommended were followed up to the harvest.

Drought test: The planting of materials was carried out according to the method defined (Blum 1983a,b; Salem 2004; Salem et al. 2007) in two plots, one as control (without the spray) and another as treated sprayed with potassium iodide spray (KI, 0.4 % w/v) including ears. The treatments were hand-sprayed 14 days after anthesis using a hand-held boom sprayer ensuring full wetting of leaves and panicles at a rate of 280 ml/m^2 (Figure 1). The rows have been spaced 30 cm apart so that the lower sections of the canopy also receive the right amount of spray.

Figure 1: Chemical desiccation drought test. a) Wheat spike with exerted anthers, b) Spray treatment with potassium iodide spray (KI, 0.4 % w/v) in the field and c) Potassium iodide spray.

Agronomic data: At maturity, plants were selected at random for subsequent measurements as follows i.e., plant height (cm) and 1000-grain weight (g) for each treated and untreated genotypes and F$_1$. The data were recorded on an individual plant basis for parents and F$_1$ generation. Finally, due to chemical desiccation, the magnitude of stem reserve was calculated as a percentage reduction in grain weight by comparing the mean grain weight of desiccated and control genotypes (Salem 2004, Salem et al. 2007).

Statistical analysis: All the information was subjected to MSTAT-C statistical analysis. In order to compare the mean values, correlation analysis was carried out to analyze correlations between characters.

Results and Discussion

By analysis of variance for a percent reduction in grain weight due to chemical desiccation, highly significant differences (*P <0.01*) were revealed (Table 2). The differences in plant height between the genotypes were also important. Regan et al. (1993) have previously documented substantial variations in the response of genotypes to the treatment of desiccation. For the improvement of yield, genetic variability among genotypes for tested traits can be helpful.

Table 2. Mean square estimates of ordinary analysis for all traits studied under control and post-anthesis drought stress.

S.O.V.	d.f	Plant height (cm)	1000-grain weight			1000-grain weight STI %
			Normal	Stress	Comb.	
Replications	2	8.11	0.02	0.15	0.08	115.62**
Genotypes (G)	20	186.80**	0.90**	1.87**	1.47**	28.89**
Error	40	6.13	0.03	0.025	0.029	6.98

* and ** significant at the P < 0 .05 and the P < 0.01 levels of probability, respectively

To simulate drought stress in the field, chemical desiccants are recorded to enable the selection of drought stress tolerance postanthesis (Haley and Fast, 1993; Salem 2004, Salem et al. 2007). Grain filling depends mainly on the source of carbon resulting from the current assimilation resulting from the viable green surfaces that intercept light after the stage of anthesis. The chemical desiccant spray (0.4% KI) in our experiment resulted in leaf desiccation of the tested genotypes within 3-4 days of treatment. The induced desiccation, as an outcome of different stresses, resulted in complete yellowing of leaves similar to natural senescence. In the absence of photosynthesis, the stem reserve mobilization capacity of the plant is calculated as a variance in 1000-grain weight because at the time of treatment all yield components other than grain weight were already determined (Blum et al., 1983a; 1983b; 1991; Salem 2004, Salem et al. 2007). The differential response of six Egyptian wheat genotypes and 15 F$_1$ to the imposed stress condition was shown by the percent reduction of grain weight by chemical desiccation. With an average of 94.33% (Table 3), the mean values for percent reduction in grain weight ranged from 85.88 to 97.67%. The highest decrease was observed in Gemmiza 10 x Sids-12 (85.88%), followed by Giza 168 x Gemmiza 10 (87.27%), while the minimum decrease in grain weight was observed in Gemmiza 7 x Gemmiza 11 (97.67%), followed by 96.84% in Gemmiza 9 (Table 3). The reduction rate in the tested wheat germplasm ranged from 2 to 15%, which is comparable to previous findings (Blum et al. 1983a; 1983b; Salem 2004; Salem et al. 2007; Börner et al. 2010). Significant associations have been identified in previous studies between the rate of decrease in grain weight by chemical desiccation and the rate of drought stress reduction (Blum et al., 1983b; Nicholas & Turner, 1993; Salem 2004; Salem et al. 2007).

In view of previous studies, the genotypes tested were divided into three groups with large (< 30% decrease in grain weight), medium (31-41 % decrease in grain weight) and low (< 41 % decrease in grain weight) stem reserve utilization during post-anthesis drought stress and any association with reported drought tolerance or susceptibility was analyzed (Table 3).

Table 3. Plant height, 1000-grain weights and description of wheat genotypes.

No.	Variety/Accession	Origin	Year of release	Plant height (cm)	1000-grain weight (spray)	1000-grain weight (control)	1000-grain weight (STI %)
1	Giza-168	Egypt	1999	88.85	48.79	47.08	96.50
2	Gemmiza-7	Egypt	2000	88.21	53.54	50.77	94.83
3	Gemmiza-9	Egypt	2000	63.61	49.74	48.17	96.84
4	Gemmiza-10	Egypt	2004	86.68	55.63	51.94	93.37
5	Gemmiza-11	Egypt	2011	83.30	47.40	45.99	97.03
6	Sids-12	Egypt	2008	101.99	51.98	47.76	91.88
7	Giza-168 x Gemmiza-7	Egypt	2013	81.90	53.58	51.48	96.08
8	Giza-168 x Gemmiza-9	Egypt	2013	90.94	47.23	45.93	97.25
9	Giza-168 x Gemmiza-10	Egypt	2013	93.48	52.41	45.74	87.27
10	Giza-168 x Gemmiza-11	Egypt	2013	101.90	57.84	53.04	91.70
11	Giza-168 x Sids-12	Egypt	2013	93.05	59.43	57.08	96.05
12	Gemmiza-7 x Gemmiza-9	Egypt	2013	93.26	52.43	50.27	95.88
13	Gemmiza-7 x Gemmiza-10	Egypt	2013	82.70	54.39	51.77	95.18
14	Gemmiza-7 x Gemmiza-11	Egypt	2013	96.85	45.89	44.82	97.67
15	Gemmiza-7 x Sids-12	Egypt	2013	93.23	53.93	51.18	94.90
16	Gemmiza-9 x Gemmiza-10	Egypt	2013	83.32	54.43	50.17	92.17
17	Gemmiza-9 x Gemmiza-11	Egypt	2013	98.65	50.16	47.74	95.18
18	Gemmiza-9 x Sids-12	Egypt	2013	80.10	55.14	52.07	94.43
18	Gemmiza-10 x Gemmiza-11	Egypt	2013	78.45	58.23	56.07	96.29
20	Gemmiza-9 x Sids-12	Egypt	2013	84.29	45.69	39.24	85.88
21	Gemmiza-11 x Sids-12	Egypt	2013	89.31	53.53	50.66	94.64
Mean		----	----	88.29	52.45	49.47	94.37
L.S.D. 5 %		----	----	1.33	3.36	3.18	4.36
L.S.D. 1 %		----	----	1.75	4.50	4.20	5.83

Compared to those with low use (drought susceptible), the genotypes with high use of stem reserves were considered relatively drought tolerant. Theoretically, when the supply of photosynthesis is reduced, genotypes that accumulate a large amount of water-soluble carbohydrates (WSC) in the stem may be able to relocate more carbohydrates to the grain than genotypes with lower stem carbohydrate concentrations. The Gemmiza 7 x Gemmiza 11 and Gemmiza 9 fall in the first group having a minimum percent reduction in grain weight exhibiting high utilization of stem reserves under stressed conditions (Figure 2). Under conditions of drought, these genotypes also perform well. Wheat genotypes with low decreases in grain weight after KI treatment also showed stable grain weight under drought stress in previous reports (Nicolas and Turner, 1993, Salem 2004; Salem et al. 2007). Such high grain weight reductions have also been reported (Mohammadi et al., 2009). In drought conditions, genotypes with low stem reserve use may not perform well, as stem reserve use is an efficient yield sustaining mechanism under drought stress (Hossain et al., 1990; Pheloung & Siddique, 1991; Gavuzzi et al., 1997; Yang et al., 2002; Asseng & Van Herwaarden, 2003; Plaut et al., 2004; Salem 2004; Salem et al. 2007).

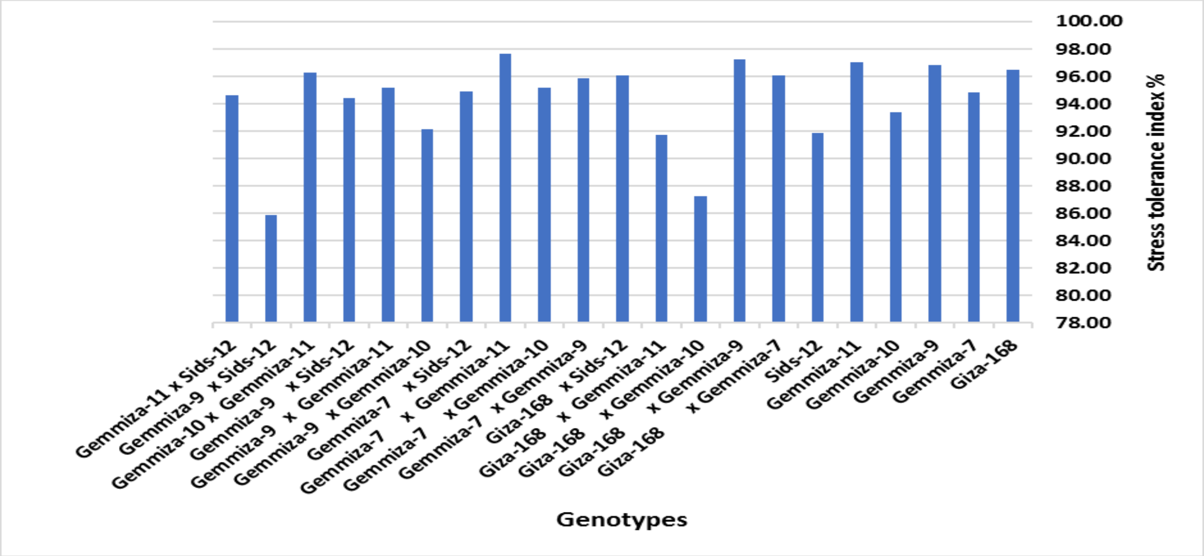

Fig. 2. Variation in stem reserve mobilization by different wheat genotypes under post-anthesis drought stress.

It appears that plant height in bread wheat is an essential component of grain yield. The storage ability is increased by longer stems and a greater specific weight (Blum et al., 1994). The correlation coefficient between plant height and 1000-grain weight stress tolerance index was elucidated in our data, *r = 0.037* (P < 0.01) Figure 3.

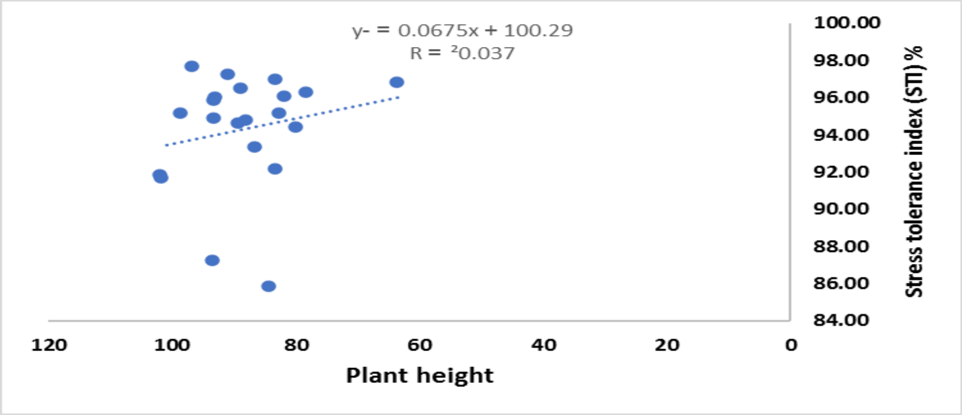

Fig. 3. Correlation between plant height and 100-grain weight STI under post anthesis drought stress. y = -0.0675x + 100.29, R^2= 0.0373

Under stress conditions, the genotypes having tall stature showed less reduction in grain weight. However, the relatively short genotypes were susceptible to a high decrease in grain weight, indicating a poor contribution of stem reserves to stressed plants. In this regard, Borrell et al. (1993) and Salem (2015) stated that a 21% decrease in stem length can result in a 35 and 39% decrease in storage reserves, depending on the presence of wheat's dwarfing genes *Rht8*, *Rht-B1b* and *Rht-D1b* respectively. Our findings are also in line with the results of Mohammadi et al. (2009), who reported a major association in chemically induced stress conditions between plant height and stem reserve. During the 1960s and 1970s, the high-yielding technologies developed in Mexico helped revolutionize cereal production and culminated in what is known as the green revolution. A new plant form, the semi-dwarf varieties with short stature, which were tolerant to lodging under higher levels of fertilizers and irrigation, was shaped by the use of dwarfing genes. As described above, the decreased storage capacity of the stem was the product of dwarfing genes in wheat (Borrell et al., 1993). It seems rational to conclude that semi-dwarf wheat has lower stem reserve usage and tolerance to drought after the green revolution. In this regard, it is important to note that wheat genotype Gemmiza 7 x Gemmiza 11 (97.67%), followed by 96.84% in Gemmiza 9 in the current study belongs to the comparatively taller pre-green revolution period. A major goal in the current scenario is a decrease in irrigation water with every passing day of breeding for drought tolerance. In our view, changing the preference for breeding from. In our view, it can help to improve the drought tolerance of this crop by changing the breeding preference from semi-dwarf to medium stature plant type in wheat.

Conclusion

It can be assumed that when subjected to post-anthesis stress relative to transient photosynthesis, stem reserve mobilization supports grain development in cereal crops. The implementation of post-anthesis chemical desiccation stress tests provides a probable basis for the selection of genotypes that are relatively drought tolerant. To grow wheat varieties that are more suited to stressed conditions, genetic variation for the use of stem reserves may be used for further development. Based on the continuous change in the climate, we need to alter our breeding preferences.

References

Ahmad R, Q Saleem, A Nazir and HS Kazim (2003) Yield potential and stability of nine wheat varieties under water stress conditions. Intl J Agric Biol 5: 7-9.

Asseng S and AFV Herwaarden (2003) Analysis of the benefits to wheat yield from assimilates stored prior to grain filling in a range of environments. Plant Soil 256: 217-229.

Bidinger F, RB Musgrave and RA Fischer (1977) Contribution of stored preanthesis assimilates to grain yield in wheat and barley. Nature 270: 431-433.

Blum A (1988) Plant breeding for stress environments. CRC Press: Boca Raton, FL

Blum A (1998) Improving wheat grain filling under stress by stem reserve mobilization. Euphy 100: 77-83.

Blum A and Y Pnuel (1990) Physiological attributes associated with drought resistance of wheat cultivars in a Mediterranean environment. Aus J Agric Res 41: 799-810.

Blum A, B Sinmena, J Mayer, G Golan and L Shplier (1994) Stem reserve mobilization supports wheat grain filling under heat stress. Aust J Plant Physiol 21: 771-781.

Blum A, G Shplier, G Golan, J Mayer and B Sinmena (1991) Mass selection of wheat for grain filling without transient photosynthesis. Euphy 54: 111-116.

Blum A, H Poyarkova, G Golan and J Mayer (1983a) Chemical desiccation of wheat plants as a simulator of post-anthesis stress. I. Effects on translocation and kernel growth. Field Crops Res 6: 51-58.

Blum A, J Mayer and G Golan (1983b) Chemical desiccation of wheat plants as a simulator of post-anthesis stress. II. Relations to drought stress. Field Crops Res 6: 149-155.

Börner A, S Landjeva, KFM Salem and U Lohwasser (2010) Plant genetic resources-a prerequisite for drought tolerance breeding in cereals. Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, pp 11-13.

Borrell A, LD Incoll and MJ Dalling (1993) The influence of the *Rht1* and *Rht2* alleles on the deposition and use of stem reserve in wheat. Ann Bot 71: 317-326.

Ceccarelli S and S Grando (1996) Drought as a challenge for the plant breeder. Plant Growth Regul. 20: 149-155.

Davidson JL and JW Birch (1978) Responses of a standard Australian and Mexican wheat to temperature and water stress. Aust J Agric Res 29: 1091-1106.

Ehdaie B, GA Alloush, MA Madore and JGWaines (2006) Genotypic variation for stem reserves and mobilization in wheat: I. Post anthesis changes in internode dry matter. Crop Sci 46: 735-746.

Ehdaie B, JG Waines and AE Hall (1988) Differential responses of landrace and improved spring bread wheat genotypes to stress environments. Crop Sci 28: 838-842.

El-Absawy EA, AA Nowar, KFM Salem FA Feky and E Edward (2015) Estimation of genetic diversity among some bread wheat (*Triticum aestivum* L.) genotypes using molecular markers and agronomic traits. Minufiya J Agric Res 40: 223–233 .

Gavuzzi P, F Rizza, M Palumbo, RG Campanile, GL Ricciardi and B Borghi (1997) Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canad J Plant Sci 77: 523-531.

Haley SD and JS Quick (1993) Early-Generation selection for chemical desiccation tolerance in winter wheat. Crops Sci 33: 1217-1223.

Hameed A, M Goher and N Iqbal (2010) Evaluation of seedling survivability and growth response as selection criteria for breeding drought tolerance in wheat. Cereal Res Comm 38(2): 193-203.

Hameed A, N Bibi, J Akhter and N Iqbal (2011) Differential changes in antioxidants, proteases, and lipid peroxidation in flag leaves of wheat genotypes under different levels of water deficit conditions. Plant Physiol Biochem 49: 178-185.

Hossain ABS, RG Sears, TS Cox and GM Paulsen (1990) Desiccation tolerance and its relationship to assimilate partitioning in winter wheat. Crop Sci 30: 622-627.

Hunt LA (1979) Stem weight changes during grain filling in wheat from diverse sources. Proceeding of 5th International Wheat

Genetics Symposium, New Delhi, India, pp. 923-927.

Keim DL and WE Kronstad (1979) Drought resistance and dry land adaptation in winter wheat. Crop Sci 19: 574-576.

Mattar MZ, OA Eissa and KFM Salem (2009) Genotypic variability in some wheat genotypes (*Triticum aestivum* L.) exposed to salinity at germination stage. Egyptian J Exper Biol (Bot) 5: 143-148.

Mattar MZ, KFM Salem and AB El-Abd (2016) Identification of candidate microsatellite markers associated with agronomic traits in rice (*Oryza sativa* L.). Egypt J Bot 56(1): 67-80.

Mohammadi M, RA Karimizadeh and MR Naghavi (2009) Selection of bread wheat genotypes against heat and drought tolerance on the base of chlorophyll content and stem reserves. J Agric Soci Sci 5: 119-122.

Mourad AMI, DZ Alomari, AM Alqudah, A Sallam and KFM Salem (2019) Recent advances in wheat (*Triticum* spp.) breeding. In: Al-Khayri J, Jain S, Johnson D (eds) Advances in plant breeding strategies: Cereals. Springer, Cham. doi.org/10.1007/978-3-030-23108-8_15

Nawara HM, MZ Mattar, KFM Salem and OA Eissa (2017) Diallel study on some *in vitro* callus traits of bread wheat (*Triticum aestivum* L.) under salt stress. Int J Agric Environ Res 3(1): 1988-2006.

Nawara HM, Mattar MZ, KFM Salem and OA Eissa (2016) Estimating heterosis and combining ability for agronomic and tissue culture traits using diallel cross on bread wheat (*Triticum aestivum* L.). Egypt J Bot, In 6th International Con:11-12.

Nezhad KZ, WE Weber, MS Röder, S Sharma, U Lohwasser, RC Meyer and A Börner (2012) QTL analysis for thousand-grain weight under terminal drought stress in bread wheat (*Triticum aestivum* L.). Euphy 186(1): 127-138.

Nicolas ME and NC Turner (1993) Use of chemical desiccant and senescing agents to select wheat lines maintaining grain size during postanthesis drought. Field Crops Res 31: 155-171.

Pheloung PC and KHM Siddique (1991) Contribution of stem reserves to grain yield in wheat cultivars. Aust J Plant Physiol 18: 53-64.

Plaut Z, BJ Butow, CS Blumenthal and CW Wrigley (2004) Transport of dry matter into developing wheat kernels and its contribution to grain yield under post-anthesis water deficit and elevated temperature. Field Crops Res 86: 185-198.

Regan KL, BR Whan and NC Turner (1993) Evaluation of chemical desiccation as a selection technique for drought resistance in dryland wheat breeding program. Aust J Agric Res 44(8): 1683-1691.

Reynolds MP, B Skovamand, R Trethowan and W Pfeiffer (1999) Evaluating a conceptual model for drought tolerance. In: JM Ribaut (ed) Using molecular markers to improve drought tolerance, CIMMYT, Mexico.

Saleh MM, WA Ali, MH Alwan, ZA Suliman, R Kenaan, H Daiub and KFM Salem (2020) Multi-environmental evaluation of wheat tetraploid genotypes for agronomic traits under rainfed conditions in Syria. J Aridland Agric 6:1-5.

Salem KFM (2015) Allelic state at the microsatellite locus *Xgwm261* marking the dwarfing gene *Rht8* in Egyptian bread wheat (*Triticum aestivum* L.) genotypes released from 1947 to 2004. Genetika 47(2): 741-750.

Salem KFM and MZ Mattar (2014) Identification of microsatellite alleles for salt tolerance at seedling stage in wheat (*Triticum aestivum* L.). Life Sci J 11(12s): 1064-1073.

Salem KFM (2004) The inheritance and molecular mapping of genes for post-anthesis drought tolerance (PADT) in wheat. Doctoral dissertation, Ph. D. Dissertation, Martin Luther University, Halle-Wittenberg, Germany.

Salem KFM (2009) Relationship between genetic diversity based on SSRs markers with heterosis and combining ability in diallel cross of bread wheat (*Triticum aestivum* L.). Minufiya J Agric Res 6(34): 2159-2178.

Salem KFM, AM El-Zanaty and RM Esmail (2008) Assessing wheat (*Triticum aestivum* L.) genetic diversity using morphological characters and microsatellite markers. World J Agric Sci 4(5): 538-544.

Salem KFM, MS Röder and A Börner (2015) Assessing genetic diversity of Egyptian hexaploid wheat (*Triticum aestivum* L.) using microsatellite markers. Genet Resour Crop Evol 62(3): 377-385.

Salem KFM, MS Röder and A Börner (2007) Identification and mapping quantitative trait loci for stem reserve mobilisation in wheat (*Triticum aestivum* L.). Cereal Res Comm 35: 1367–1374 doi.org/10.1556/CRC.35.2007.3.1

Yang J, RG Sears, BS Gil and GM Paulsen (2002) Genotypic differences in utilization of assimilate sources during maturation of wheat under chronic heat and heat shock stresses. Euphy 125: 179-188.