Journal of Plant Breeding and Crop Science Vol. 4(11). pp. 184-196, December 2012
Available online http://www.academicjournals.org/jpbcs
DOI: 10.5897/JPBCS12.047
ISSN 2006-9758 ©2012 Academic Journals

Full Length Research Paper

High temperature combined with drought affect rainfed spring wheat and barley in south-eastern Russia: Yield, relative performance and heat susceptibility index

Akbar Hossain[1]*, Jaime A. Teixeira da Silva[2], M. V. Lozovskaya[3], V. P. Zvolinsky[4] and V. I. Mukhortov[4]

[1]Wheat Research Center, BARI, Nashipur, Dinajpur-5200, Bangladesh.
[2]Faculty of Agriculture and Graduate School of Agriculture, Kagawa University, Ikenobe, Miki-cho, 761-0795, Japan.
[3]Faculty of Biological Resources, Astrakhan State University, Astrakhan, Russia.
[4]The Caspian Scientific Research Institute of Arid Agriculture, Chernoyarsky District, Astrakhan, Russia.

Accepted 6 July, 2012

Among all abiotic stresses, drought is undoubtedly the major factor, which, individually or combined with heat stress, limits crop productivity worldwide. Considering these facts, four spring barley and two spring wheat genotypes were evaluated under two stress (early and late) conditions in a southern arid region of Russia in order to identify suitable spring wheat and barley genotypes for that region and to assess the optimum sowing time for specific genotypes. High temperature followed by deficit soil moisture affected all stages from germination through to reproduction of crop when sown late, finally drastically reducing yield. On the other hand, due to low temperature, germination and stand establishment of crop sown early were highly affected, resulting in lower grain yield. Thus, high temperature (air and soil) followed by drought (deficit soil moisture) in the late-sown crop (from germination to reproductive stages) and low temperature in germination through vegetative stages of the early-sown crop are the most important constraints for crop production in this arid region. From the overall performance (yield, relative performance and stress susceptibility index), genotype 'Zernograd.770' is recommended for both early and late drought stressed areas and 'Ratnik' were sensitive to stress both at low temperatures when sown early and high temperatures followed by drought when sown late.

Key words: High temperature, drought, spring wheat, barley, Russia.

INTRODUCTION

Accounting for a fifth of humanity's food, wheat is second only to rice as a source of calories in the diets of developing country consumers, and it are first as a source of protein (Braun et al., 2010). The International Food Policy Research Institute (IFPRI) projections indicate that the world demand for wheat will rise from 552 million tons in 1993 to 775 million tons by 2020 (Rosegrant et al., 1997). At the same time, increases in climate change-induced temperature are likely to reduce wheat production in developing countries (where around 66% of all wheat is produced) by 20 TO 30% (Easterling et al., 2007; Lobell et al., 2008). The Intergovernmental Panel on Climate Change (IPCC, 2007) noticed that global climate change will have a major impact on crop production, while CIMMYT-ICARDA (2011) estimated that wheat yield losses amounting to 20 to 30% will occur between by 2050 in developing countries with an assumed temperature increase of 2 to 3°C. On a global scale, these yield losses will not be fully compensated by yield grains in high latitude regions (Canada, Russia,

*Corresponding author. E-mail: tanjimar2003@yahoo.com.

Kazakhstan, and Northern USA), estimated at 10 to 15% (OECD-FAO, 2009) since major wheat producers like France already reported yield reductions due to increasing temperatures (Charmet, 2009).

Wheat is mostly grown under rainfed conditions. In 2000, 70% of the world's wheat harvested area was under rainfed condition (Portmann et al., 2010). This rainfed crop frequently suffers from drought resulting in significant yield loss and decreased revenue with periodic drought affecting 50 and 70% of wheat-growing areas in developing and developed countries, respectively (Trethowan and Pfeiffer, 1999). In Russia, spring wheat and barley are normally cultivated in rainfed condition. In the Volga region such as the south eastern part of Russia, climate is Mediterranean type and spring is very short and, wheat and barley are typically planted in mid-April under rainfed conditions and harvested in late June. During the grain-filling period in late-sown crops, limited rainfall and high temperatures occur frequently; consequently, water stress in this period is one of the major production constraints in these environments due to low relative humidity (USDA, 2011). Martell (2011) reported that in 2010, Russian grains ripened prematurely under heat and moisture stress in southern European Russia, a key production area for wheat and barley (accounting for 26% of all wheat production in Russia); as a result, estimated yields were sharply down (30% from 2009).

Drought is a major environmental stress reducing crop yield around the world (Bruce et al., 2002). The combined effects of drought and high temperature on the physiology, growth, water relations, and yield are significantly higher than the individual effects (Sharma and Kaur, 2009; Grigorova et al., 2011). Research findings related to high temperature, drought and low temperature stress in barley and wheat around the world are presented in Table 1.

Water deficit (drought) and high temperature (air and soil) are important environmental factors restricting plant growth in many regions of the world, and while the two stresses often occur simultaneously (Shah and Paulsen, 2003), still relatively little is known about how their combination impacts plants (Rizhsky et al., 2004). Of additional concern is global climate change, which will presumably increase global temperature, change the distribution of precipitation, and intensify drought in arid and semi-arid areas (Wigley and Raper, 2001; Chaves et al., 2003), leading to a reduction in the productivity of grass (like wheat) (Bai et al., 2004).

Considering this fact, an experiment was conducted in the south-eastern part of Russia (where high temperature in combination with drought affect spring wheat and barley), in order to identify suitable genotypes of both cereals from existing varieties for that region, to know their relative performance, stress tolerance and susceptibility for future breeding programmes, and to be able to provide guidance on the suitable sowing time for specific genotypes.

MATERIALS AND METHODS

Plant material and location of the experimental site

Four barley and two wheat genotypes were evaluated in a research field of the Caspian Scientific Research Institute of Arid Agriculture (CSRIAA), Salt Zaymische, Chernoyarsky District, Astrakhan Region, Russia, during the period of April to July, 2011.

Astrakhan is situated in the southern part of Russia, in the south-east of the East European Plain in the middle latitudes in the northern zone of a semi-desert and covers an area of 57,600 km². The extreme northern point of the region lies on the border with the Volgograd region at 48° 52′ N (lat.). The western most point is located in Chernoyarsky district on the border with the Volgograd region at 44° 58′, where this experiment was conducted. The CSRIAA is situated in Salt Zaymische, Chernoyarsky District, Astrakhan Region, Russia.

Treatments and experimental design

The experiment was laid out in a randomized complete block design (RCBD) with 3 replications. Treatments were three sowing dates *viz.*, early sowing (ES) (sown on 8 April), optimum sowing (OS) (sown on 15 April) and late sowing (LS) (sown on 22 April) using four spring barley cultivars ('Zernograd.770', 'Sokol', 'Nutans', 'Ratnik') and two spring wheat cultivars ('Saratov.70' and 'Line 4'). These sowing dates were determined for ES, OS and LS by the CSRIAA (http://www.pniiaz.ru/) since optimum sowing time for spring wheat and barley is a very narrow window in mid-April for this region. Unit plot size was 4 × 1 m wide with 6 rows and a 20-cm inter-row distance. The experiment was conducted under rainfed condition without irrigation or fertilizers.

Harvesting and data collection

Sample plants were harvested separately. The harvested crop of each plot was bundled separately, tagged and taken to a threshing floor where bundles were thoroughly dried in bright sunshine, weighed and threshed. Yield and yield component data, namely number of spikes m^{-2} (NS), spike length (cm) (SL), number of spikelets $spike^{-1}$ (no) (NSS), number of grains $spike^{-1}$ (no) (NGS), 1000-grain weight (g) (1000-GW), harvest index (%) (HI), straw yield (g m^{-2}) (SY) and grain yield (g m^{-2}) (GY), as well as heat tolerance evaluation data on relative performance and heat susceptibility index, were calculated from grain yield.

Soil moisture (%) and total moisture content (mm) were recorded, which were presented in previously published paper (Hossain et al., 2012d). Maximum, minimum and mean air temperature and relative humidity (RH) were recorded daily during the experimental period from the information division of the CSRIAA website (http://rp5.ru/archive.php?wmo_id=34578&lang) (Figure 1). Data was analyzed using MSTAT-C (Russell, 1994). Treatment means were compared for significance by using the Least Significance Difference (LSD) test at P = 0.05.

Grain yield and 1000-grain weight was adjusted at 12% moisture by following equation (Hellevang, 1995):

$$Y(M_2) = \frac{100 - M_1}{100 - M_2} \times Y(M_1)$$

where, $Y(M_2)$ = weight of grain at expected moisture percentage (generally 12% for wheat), $Y(M_1)$ = weight of grain at present moisture percentage, M_1 = present moisture percentage, M_2 = expected moisture percentage

Harvest index was calculated according to the following formula (Donald, 1962):

Table 1. Effect of heat stress, drought and low temperature stress on wheat and barley in different countries around the world.

Country	Tested cultivars	Key research findings	Reference
Barley			
China	Four barley genotypes (‘Tadmor’, ‘Arta’, ‘Morocco9-75’ and ‘WI2291’) were used to investigate the correlation between these traits and drought tolerance	The results reflected that all of these traits were affected negatively in the four genotypes at different levels of post-anthesis drought stress, but the decrease in drought tolerant genotypes was much less than that of drought sensitive genotypes.	Li et al. (2006)
Iran	Six barley varieties ‘Karoon× Kavir’, ‘Reihani’ (drought-tolerant), ‘Torkman’, ‘C-74-9’ (intermediate), ‘Kavir × Badia’ and ‘Gorgan-4’ (2-rowed type, drought-sensitive)	It was concluded that the higher canopy temperature (25-35°C) under well irrigated conditions and higher grain yield, 1000-grain weight under water stress conditions could possibly be the proper criteria for screening the drought tolerant barley genotypes under field or laboratory conditions.	Mamnouie et al. (2006)
Jordan	Four barley cultivars (‘Rum’, ‘ACSAD176’, ‘Athroh’ and ‘Yarmouk’)	As drought stress severity increased, gross photosynthetic rate, water potential, plant height, grain filling duration, spike number per plant, grain number per spike, 1000-grain weight, straw yield, grain yield and harvest index decreased.	Samarah et al. (2009)
Lithuania	Three spring barley (‘Aura DS’, ‘Barke’ and ‘Gustav’)	It was found that ‘Gustav’ performed better in both dry and wet condition in Central Lithuania's weather conditions.	Janusauskaite et al. (2011)
Wheat			
Turkey	20 wheat cultivars (16 bread wheat, *Triticum aestivum*; four durum wheat, *Triticum durum* cultivars)	Considering drought sensitivity indices over 2 years, the bread wheat cultivars ‘Yayla-305’, ‘Gerek-79’, ‘Dagdas-94’ and ‘Bolal-2973’ were found to be more drought-tolerant than the other cultivars.	Bagci et al. (2007)
Hungary	Evaluated drought tolerant ‘Plainsman V’ and sensitive ‘Cappelle Desprez’ wheat genotypes.	It was found that heat tolerant ‘Plainsman V’ also affected under combined effect of heat stress (34/24°C) and drought and decreased percent germination and number of seminal roots.	Fabian et al. (2008)
Bulgaria	Two drought-tolerant (‘Katya’ and ‘Zlatitza’) and two drought-sensitive genotypes (‘Sadovo’ and ‘Miziya’)	The obtained results showed that the drought tolerant varieties ‘Katya’ and ‘Zlatitza’ had higher levels of these proteins, especially RBP and Clp proteases.	Demirevska et al. (2008)
USA	Spring wheat variety ‘Sinton’	It was noticed that cool air temperature (65°F) lengthened the life span and high temperature (79°F) shortened the life span.	Frank et al. (2009)
Azerbaijan	Two bread wheat (‘Giymatli-2/17’, ‘Azamatli-95’) and two durum wheat (‘Garagylchyg-2’, ‘Barakatli-95’)	It was found that drought tolerant genotypes ‘Azamatli-95’ and ‘Barakatli-95’ this decrease was less pronounced compared to genotypes ‘Garagylchyg-2’ and ‘Giymatli-2/17’, which are sensitive to drought.	Bayramov et al. (2010)
Pakistan	Four wheat genotypes viz., ‘LU-26s’, ‘Bhittai’, ‘Roshan’, ‘Taifu’	The genotypes ‘LU-26s’ was found to have best performance under drought condition, with minimum decrease in the growth parameters i.e., plant height, number of tillers and shoot dry weight.	Shirazi et al. (2010)
Ethiopia	Three landrace [‘B5-5B’, ‘S-17B’, and ‘WA-13’], 13 commercial cultivars [‘Asassa, Bekelcha’, ‘Boohai, Egersa’, ‘Foka, Gerardo’, ‘Ilani, T Kilinto’, ‘Obsa, Oda’, ‘Quamy’, ‘Tob-66’ and ‘Yeror’] and two advanced lines [‘CDSS93Y107’ and ‘CD94523’]	Water deficit significantly affected gas exchange and chlorophyll fluorescence parameters. It reduced the net photosynthesis rate, transpiration rate and stomatal conductance measured both at anthesis and grain-filling stages.	Boglae et al. (2011)

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}} \times 100$$

To compare the yield performance of a genotype, relative performance (RP%) for yield was calculated as described by Asana and Williams (1965) and was expressed as a percentage:

$$\text{RP (\%)} = \frac{\text{Stress performance}}{\text{Optimum performance}} \times 100$$

The stress susceptibility index (SSI) was used as a measure of stress tolerance in terms of minimization of the reduction in yield caused by unfavorable versus favorable environments. SSI was calculated for each genotype according to the formula of Fisher and Maurer (1978):

$$\text{SSI} = \frac{1 - \frac{Y}{Y_P}}{1 - \frac{X}{X_P}}$$

X_P

Where: Y = mean grain yield of a genotype under a stress environment; Y_p = mean yield of the same genotype under a stress-free environment; X = mean Y of all genotypes; X_p = mean Y_p of all genotypes

In this experiment, stress means high temperature combined with drought. If SSI < 0.5, the crop is highly stress tolerant, if SSI > 0.5 < l.0, it is moderately stress tolerant, and if SSI > 1.0, it is susceptible to stress.

RESULTS AND DISCUSSION

There are several definitions of drought which include precipitation, evapotranspiration, potential evapotranspiration, temperature, humidity and other factors individually or in combination (Renu and Suresh, 1998). High temperature combined with drought affects the phenology and growth (data not presented), and finally yield and other parameters of rainfed spring wheat and barley in southern Russia, which were studied in the field. In this paper, we demonstrated the effect of high temperature (soil, air) and drought (deficit soil moisture) conditions under different sowing regimes on yield and yield-related components of wheat and barley. On the other hand, to evaluate the sensitivity or tolerance of genotypes to stress, we also studied relative performance and assessed SSI.

Soil moisture (%) and total moisture content (mm) in experimental soil

Soil moisture is the most important parameter for the growth and development of plants, especially in dry land farming where rainfall is very low, irrigation is limited and evapotranspiration and temperature are high. When temperatures increases, relative humidity in the air decreases and the demand of water and other growth resources for the plant increases from the soil. This is due to higher rates of metabolism, development and evapotranspiration (Rawson, 1988). However, if soil moisture is not available, plants cannot take up essential nutrients and water and they try to survive without production. In our present research, soil moisture (%) and total moisture content (mm) in the soil were recorded before sowing and also at different sowing stages, which were presented in our another published paper from the same experiment (Hossain et al., 2012d). Pre-sowing soil moisture was higher than all other sowing stages. There was also a relationship between increasing temperature and relative humidity: when temperature increased, soil moisture and relative humidity decreased, which would ultimately affect the plants (Hossain et al., 2012d; Figure 1), especially the late sowing crop. Xu and Zhou (2006) conducted a field experiment and stated that severe water stress (23 to 32% of field capacity) exacerbated the adverse effects of high temperature (32°C), and that their combination reduced the plant productivity and distribution range of *Leymus chinensis* (perennial grass) in the future. Hassan (2006) noticed that water deficit affected leaf expansion and photosynthesis of wheat, with ultimately an effect on final yield.

Climatic condition during the growing season

Weather parameters such as maximum and minimum air and soil temperature, rainfall and relative humidity are the most important climatic factors for the growth and development of plants, especially in dryland cultivation. In this research, as observed in Figure 1, ES had very low temperatures (occasionally minus °C) at germination and seedling stages which can delay germination, stand establishment, tillering, ultimately effect biomass and grain yield. Zabihi-e-Mahmoodabad et al. (2011) in Iran tested three spring wheat cultivars under three low temperature conditions (2, 3 and 5°C) and observed that the lowest temperature (2°C) affected germination and root growth, and finally growth and development. On the other hand, all genotypes showed better performance in the high temperature treatment (5°C). In our present research, in LS, high temperatures (soil, air) combined with deficit soil moisture (drought) from germination through to reproductive stages highly affected germination, biomass and yield due to a shortened life span (Hossain et al., 2012d; Figure 1). Hossain et al. (2011) and Hossain et al. (2012a, b, c) noticed the same results in different wheat genotypes. They stated, due to high air temperature (25 to 30°C) in LS at the reproduction stage, the tested wheat genotypes matured 20 to 23 days earlier in LS than in OS.

Yield and yield components

Cereals are mainly grown for grain yield. In wheat and barley, GY is the function of the number of plants ha^{-1}, the number of fertile tillers $plant^{-1}$, NGS, and individual grain weight. Factors that affect one of these components directly or indirectly will affect GY. Stress, like high temperature, singly or in combination with drought adversely affects all these components resulting in a

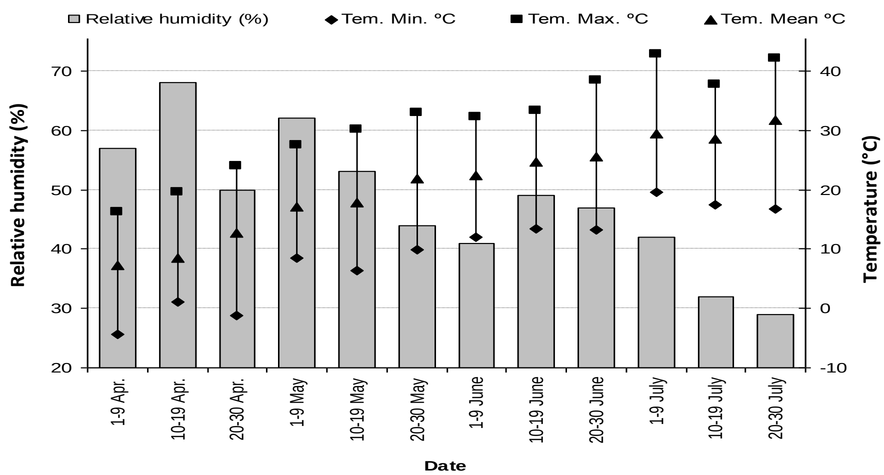

Figure 1. Maximum, minimum and mean air temperature and relative humidity during the experimental period from the information division of the CSRIAA.

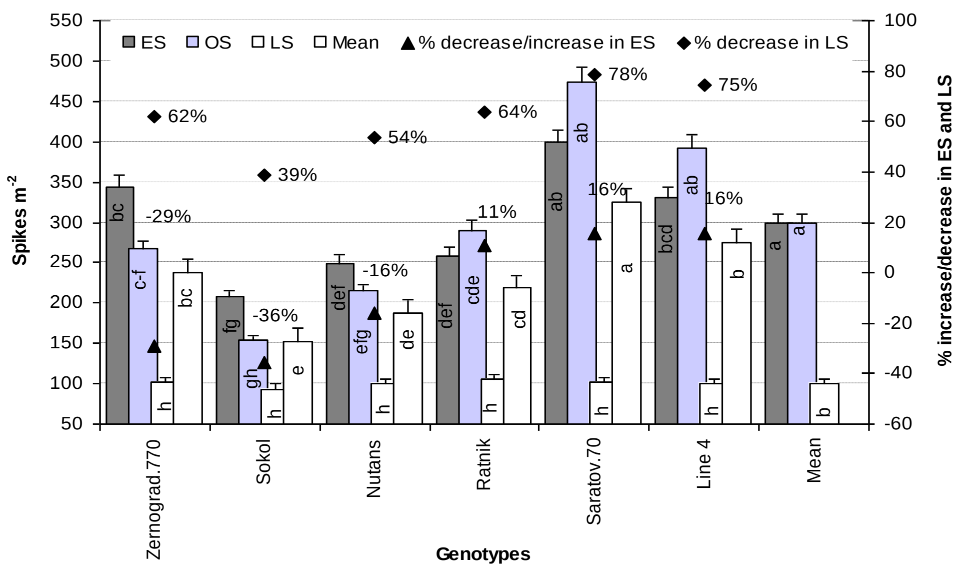

Figure 2. Number of spikes m^{-2} of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P ≤ 0.05 (LSD test). The percentage decrease or increase was calculated relative to OS. Negative percentage values indicate an increase.

marked decline in GY. Tawfelis (2006) found significant variation in yield and yield-related components among wheat genotypes under OS and LS. Reproductive processes are markedly affected by high temperatures in most plants, which ultimately affect fertilization and post-fertilization processes leading to reduced crop yield (Wahid et al., 2007).

Number of spikes m^{-2}

NS is one of the major components for wheat GY. In our experiment, we found that the NS in wheat genotypes was higher than in barley genotypes both in ES and OS. Among these, 'Saratov.70' in ES and OS produced the highest NS, closely followed by 'line4' in OS. Genotype 'Gernograd.770' and 'Ratnik' produced the highest NS in all sowing conditions (Figure 2), reflecting possible genotype effects. In LS, all genotypes produced statistically similar and fewer NS (Figure 2). In ES, NS of 'Zernograd.770' (29%), 'Sokol (36%)' and 'Nutans' (16%) was higher than in OS, implying that these genotypes were not affected by low temperature. On the other hand, due to high temperature (air and soil) and deficit soil

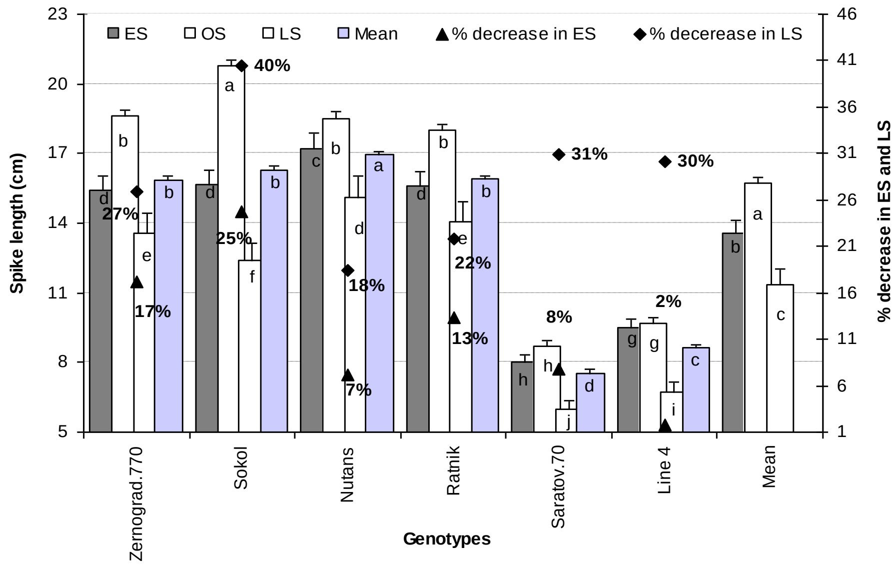

Figure 3. Spike length (cm) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P ≤ 0.05 (LSD test).

moisture (drought) in LS, NS of all genotypes decreased (39 to 78%). Among them, 'Saratov.70' (78% decrease) was more affected than 'Sokol' (39% decrease) (Hossain et al., 2012d; Figures 1 and 2). Saleem (2003) reported that during the stem elongation stage, moisture stress reduced GY due to fewer NS per unit area and fewer NGS. Sattar et al. (2010) noticed that the pattern of tillering was affected by the sowing date due to a change in temperature and contribution of tillers to GY; it was maximum during the optimum planted crop and decreased with delayed planting due to stress.

Spike length

Ali et al. (2008) reported that GY plant^{-1} showed a highly significant positive correlation with number of productive tillers plant^{-1}, NSS, NGS and SL. They also stated that SL depends on the inherent character (genetic makeup) of the genotype, which changes in different environmental conditions. The assumption is also similar to our present research: 'Sokol' produced the longest spikes in OS, but in ES and LS it was 'Nutans'. In stress conditions (ES and LS), all genotypes had shorter spikes (decreased by 2 to 25% in ES and by 18 to 40% in LS), which ultimately reduced the final yield (Figure 3). It was due to low air and soil temperature from germination to vegetative stages of the ES crop and high temperature (air, soil) and drought from germination to reproductive stages of the LS crop affected SL (Hossain et al., 2012d; Figures 1 and 3). Hossain et al. (2011, 2012a, b, c) found the same result, but in different wheat genotypes ('Sourav', 'Gourab', 'Shatabdi', 'Sufi', 'Bijoy', 'Prodip', 'BARI Gom-25' and 'BARI Gom-26'), and stated that low temperature in the vegetative stage of LS wheat, reduced stand establishment and tillering ability, which ultimately affects yield and yield-related components. On the other hand, high temperature in the reproductive stage forced life span to decrease which also ultimately affected yield and yield-related components.

Number of spikelets spike^{-1}

The reproductive stage is considered to be the most temperature sensitive period in wheat and barley. The main sensitive trait to drought stress at this stage is NSS (Sangtarash, 2010). Deficit soil moisture (drought) in the reproductive stage, forced premature death in more distal and basal florets; as a result, grain number decreased drastically (Oosterhuis and Cartwright, 1983). In our present study, all genotypes showed more NSS in OS due to a more favourable environment than ES and LS (Hossain et al., 2012d; Figure 1). Among these, 'Zernograd.770', 'Sokol' and 'Nutans' produced the maximum and statistically similar NSS. In LS, all genotypes were highly affected and produced fewer NSS (decreased 32 to 70%). Among them, 'Sokol' (70% decrease) was more affected than 'Saratov.70' (32%). In LS, high temperature followed by deficit soil moisture (drought) affected all stages, which ultimately reflected NSS (Hossain et al., 2012d; Figures 1 and 4). Wollenweber et al. (2003) also reported that the GS2 stage (double ridge to anthesis) was the most susceptible to high temperature since this is the period when NSS are determined.

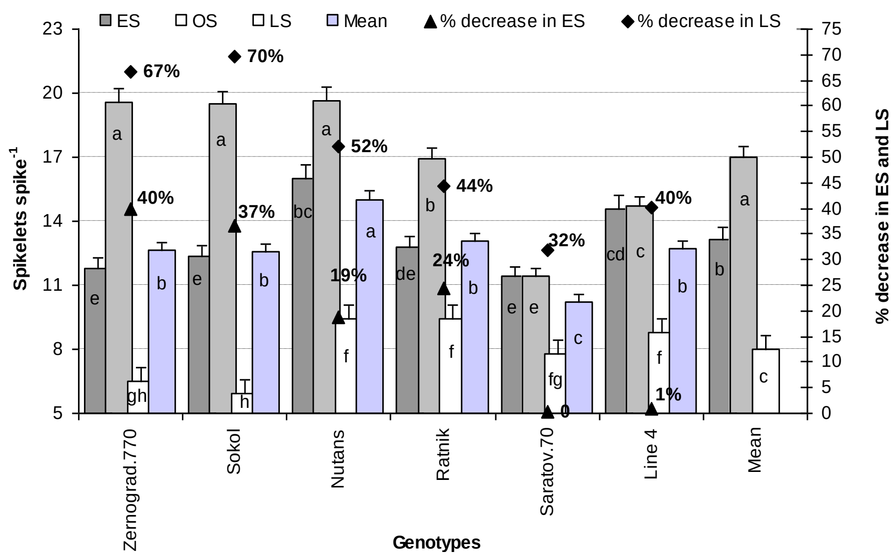

Figure 4. Number of spikelets spike^{-1} (no.) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions**.** Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ (LSD test).

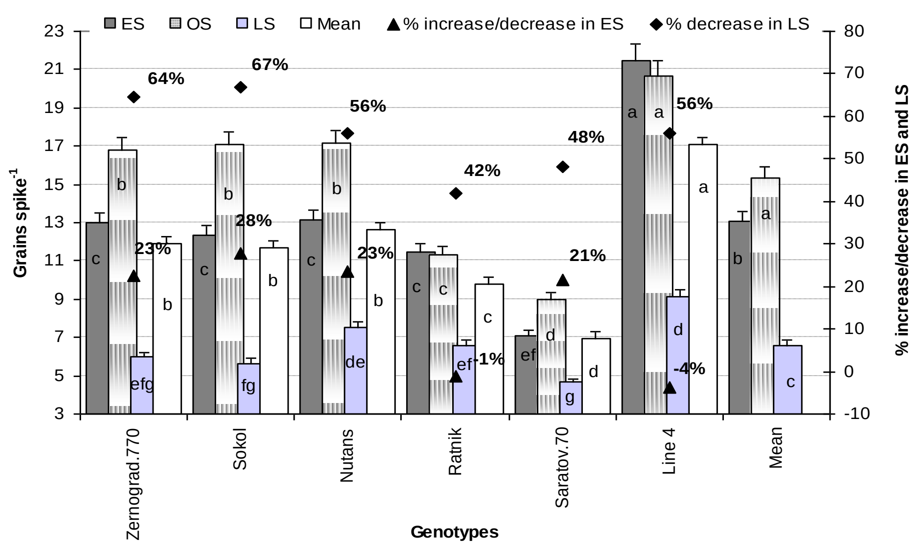

Figure 5. Number of grains spike^{-1} (no.) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ (LSD test).

Number of grains spike^{-1}

High temperature and drought (water deficit) during the flowering stage decreases grain set in almost all field crops due to lower fertilization caused by pollen sterility and/or ovule abortion. Similarly, a higher decline in grain number is observed when drought occurs at or immediately after anthesis in wheat (Sangtarash, 2010). In our research, all genotypes produced fewer but statistically similar NGS (42 to 67% decrease) in LS (Hossain et al., 2012d; Figures 1 and 5). Among these, ‘Sokol’ (67% decrease) was more affected than ‘Ratnik’ (42%) (Figure 5). Guttieri et al. (2001) and Gupta et al. (2001) stated that water stress at stages before anthesis can reduce number of ear heads ear^{-1} and number of kernels ear^{-1} while water stress imposed during later stages might additionally cause a reduction in number of kernels/ears and kernel weight. Blum (2007) noted that water deficit

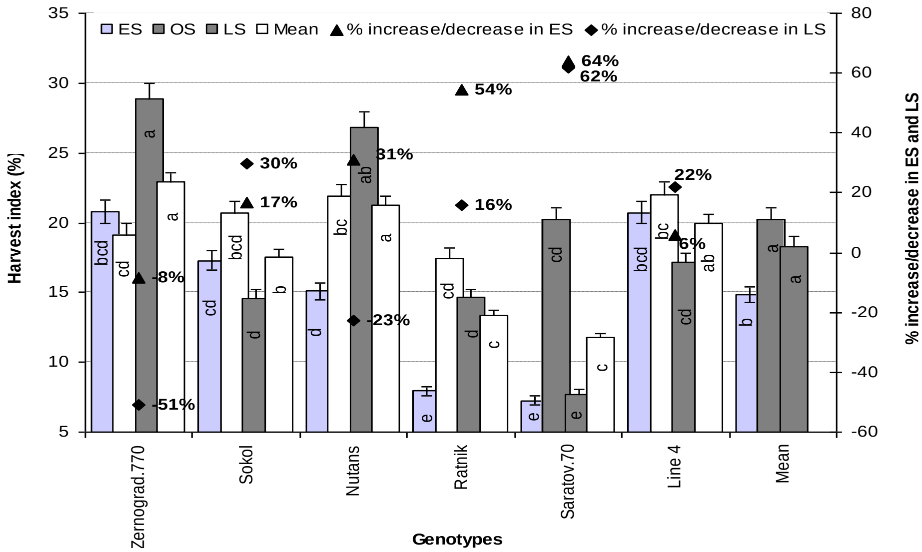

Figure 6. Harvest index of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ (LSD test).

at the flowering stage can lead to male sterility, finally reducing NGS. On the other hand, in ES, 'Ratnik' (1% increase) and 'Line4' (4% increase) were not affected by low temperature stress (Figure 5).

Harvest index

HI is defined as the grain as a percentage of total plant biomass. Genetic improvement of GY in wheat is closely associated with increases in HI, but not with increases in total biomass (Slafer and Andrade, 1991). In our present research, highest HI was found in 'Zernograd.770' (8% increase in ES and 51% increase in LS) in all sowing conditions, which was statistically similar to 'Nutans' in LS. If sowing time is considered, a higher HI was observed in OS and LS (Figure 6). A two-year field experiment showed that the combined effects of high air temperature (day/night 34/22°C) and drought (withholding water) were greater than additive effects of high air temperature or drought alone for leaf chlorophyll content, NGS and HI of two spring wheat cultivars ('Pavon-76' and 'Seri-82') (Prasad et al., 2011).

1000-grain weight

This is the most important parameter for final yield. However, under stress, 1000-GW decreased due to a decrease in individual grain weight. In OS, all genotypes produced higher individual grain weight due to favourable environmental conditions at that time (Hossain et al., 2012d; Figure 1). Compared to OS, lower grain weight was observed in LS (11 to 43% decrease) and ES (3 to 36% decreases). High temperature (soil, air) and deficit soil moisture (drought) stress in LS and low temperature stress in ES reduced individual grain weight, which ultimately affected 1000-GW (Hossain et al., 2012d; Figures 1 and 7). Among the genotypes, 'Line4' (3 to 11% decrease) was less affected while 'Zernograd.770' (36 to 43%) was highly affected by both low temperature in ES and by high temperature (air and soil) and drought stress in LS (Figure 7). Plaut et al. (2004) also reported that the 1000-GW and weight of kernels per spike were more severely decreased by water deficit than by heat in two wheat varieties but less in 'Batavia' than in 'Suneca'. Significant differences in genotype and irrigation and also their interaction were observed for GY under post-anthesis drought stress (Shafazadeh et al., 2004).

Straw yield

In our experiment, all genotypes produced statistically higher SY in OS but less in LS (44 to 72% decrease) followed by ES (11 to 29% decrease) (Figure 8). Compared with all genotypes, 'Line4' was less affected (0 to 32% decrease) than 'Sokol' (37 to 70% decrease) both in ES and in LS (Hossain et al., 2012d; Figures 1and 8). Nicolas et al. (1984) also found a greater decrease in biomass under high temperature and drought stress in early and late stages of grain development. In spring wheat ('cv. Len'), the interactive effect of high tempe-rature and drought on grain dry weight was not additive

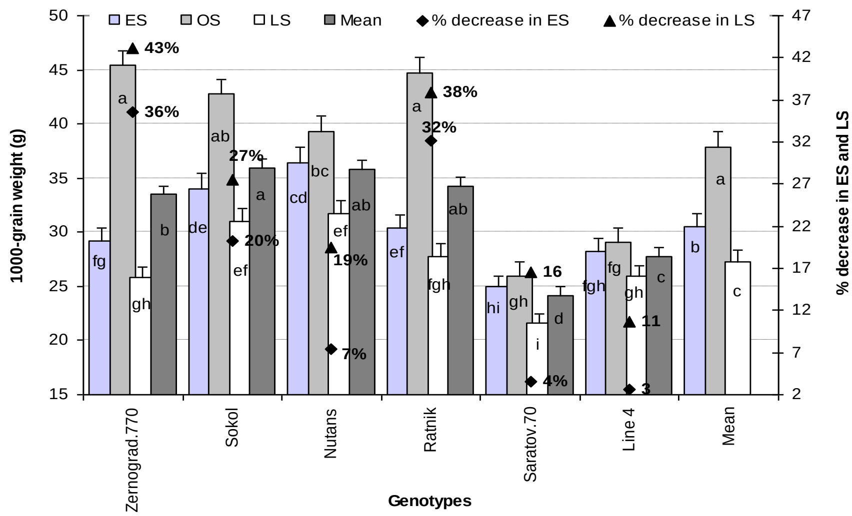

Figure 7. 1000-grain weight (g) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P ≤ 0.05 (LSD test).

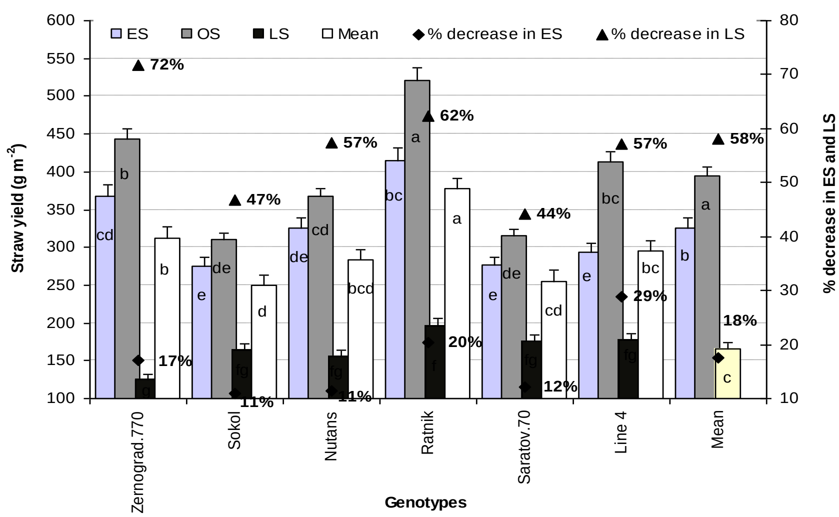

Figure 8. Straw yield (g m^{-2}) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P ≤ 0.05 (LSD test).

under chronic heat stress (27/22°C) when drought was applied simultaneously during flowering (Wardlaw, 2002).

Grain yield

In field conditions, most of the time, high temperatures follow drought, that is, drought and high temperature occur simultaneously causing significant yield loss (Lott et al., 2011). In our present study, all genotypes produced significantly higher GY in OS and less in LS (43 to 82% decreases) followed by ES (26 to 73% decrease). Among the genotypes, 'Ratnik' and 'Zernograd.770' produced the highest GY in OS. 'Saratov.70' produced the lowest GY in all sowing conditions (73 to 82% decrease), followed by 'Ratnik' (71 to 73% decrease) and 'Line4' (32 to 67% decrease) in LS and ES (Figure 9). In LS, climate and soil moisture were unfavourable (high temperature, low relative humidity in the air and low soil moisture) for crop production, which ultimately affected crop growth and yield (Hossain et al., 2012d and Figure 1). This assumption is also supported by Grigorova et al.

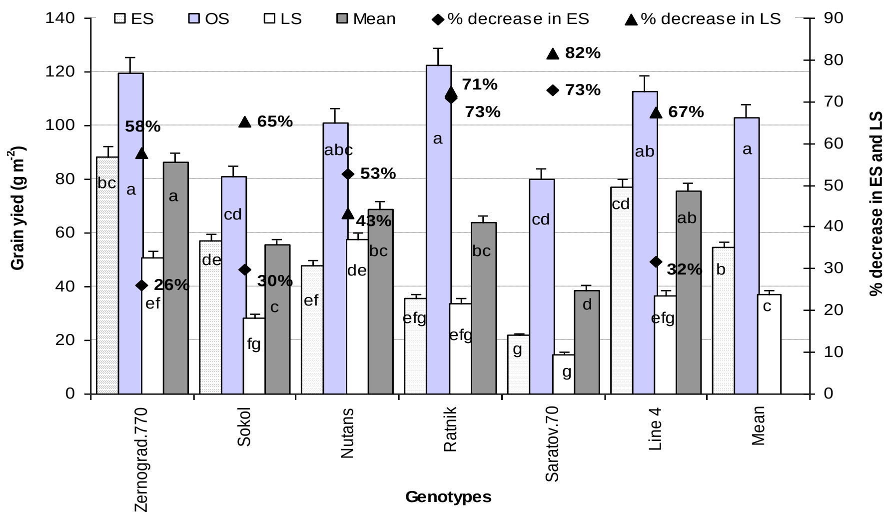

Figure 9. Grain yield (g m^{-2}) of different genotypes under early (ES), optimum (OS) and late sown (LS) conditions. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ (LSD test).

(2011), who stated that the combined effects of drought and high temperature on physiology, growth, water relations, and yield are significantly higher than the individual effects. Drought decreased GY spike^{-1} by about 70% when stress was applied during early seed development in spring wheat cultivars 'Cappelle Desperez' and 'Plainsman V' (Fabian et al., 2011). There was an approximately 40% decline in average GY ha^{-1} when drought stress was imposed on 30 wheat cultivars and 21 landraces from tillering to maturity by installing mobile roofs (Dencic et al., 2000).

Relative yield performance

Performance of different genotypes in stress condition may be observed by calculating relative performance (RP%) reported by Asana and Williams (1965), who also reported that higher value of RP% of a variety indicate that the variety is highly stress tolerant and lower value of RP% indicate that is susceptible to heat stress. Rahaman et al. (2009) also reported genotypic variation in RP% of sensitive and tolerance genotypes, and that a higher RP% indicated that the genotype was tolerant to stress. There is a similarity between the above findings and this present study. Compared with RP%, in LS (high temperature and drought) RP% range of all genotype were 18 to 57%. Among these 'Nutans' (57%) performed better than 'Saratov.70 (18%) (Figure 10). On the other hand, in early low temperature stress condition (ES), 'Zernograd.770' (74%) was highly tolerant to low temperature stress and 'Saratov.70' (27%) was found as heat sensitive (Figure 10). It was found that 'Saratov.70' was highly susceptible to stress (low temperature, high temperature and drought) than others.

Stress susceptibility index

SSI provides a measure of stress tolerance based on minimization of yield loss under stress compared to optimum conditions, rather than on yield level under stress *per se*, which has been used to characterize relative drought tolerance of wheat genotypes (Fischer and Maurer, 1978; Clarke et al., 1984). In our present study, the SSI of 'Sokol', 'Ratnik', 'Saratov.70' and 'Line4' were higher than 1.0 in LS, indicating that these genotypes had no tolerance to high temperature (air, soil) and drought (deficit soil moisture). The SSI of the other two genotypes ('Zernograd.770' and 'Nutans') indicated their various levels of tolerance to LS (high temperature in combined with drought) (Figure 11). On the other hand, in ES (low temperature stress condition), the SSI of 'Nutans', 'Ratnik', and 'Saratov.70' was higher than 1.0, indicating that these genotypes had no tolerance to low temperature stress. The other three genotypes, 'Zernograd.770', 'Sokol' and wheat 'Line4' showed moderately low temperature stress tolerance in ES. Only 'Zernograd.770' showed moderate stress tolerance both in ES and LS (Figure 11). Hossain et al. (2011) also found the variation of tolerance in different spring wheat genotypes ('Sourav', 'Gourab', 'Shatabdi', 'Sufi', 'Bijoy', 'Prodip', 'BARI Gom-25' and 'BARI Gom-26') in ES and LS.

Conclusion

Results obtained from this study indicated that high temperature (air and soil) followed by drought (deficit soil moisture) in LS (from germination to reproductive) and low temperatures in the germination to vegetative stages

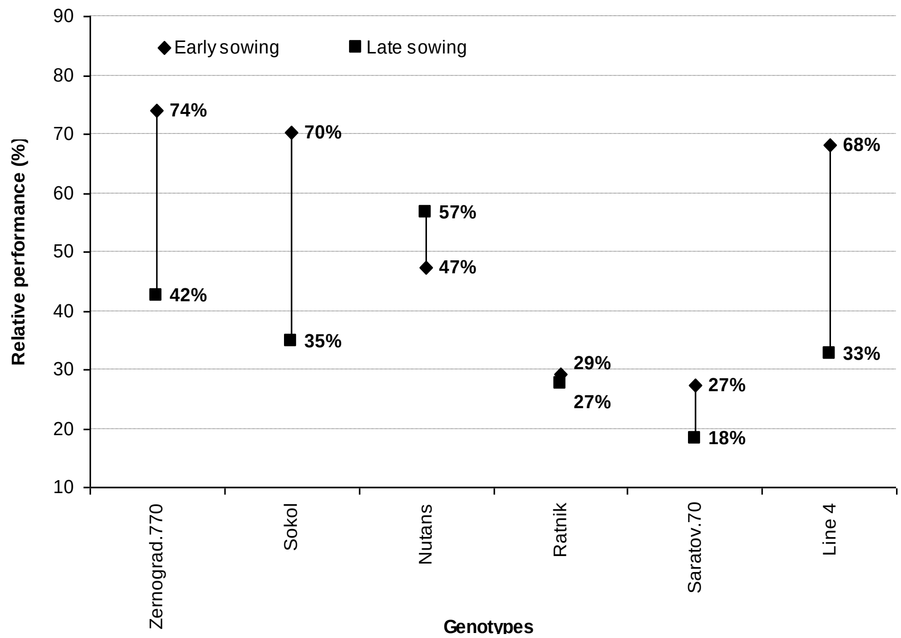

Figure 10. Relative yield performance (%) of different genotypes under early and late sowing.

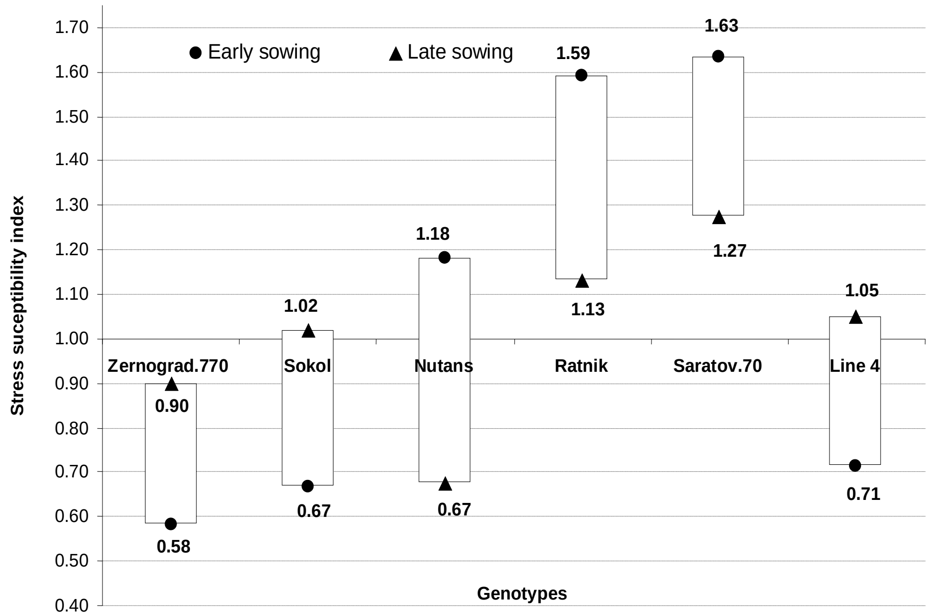

Figure 11. Stress susceptibility index of different genotypes under ES and LS.

of ES are the most important constraints to crop production in arid regions. From overall performance, genotype'Zernograd.770' is recommended for stress (both in ES and LS) conditions. Considering relative yield performance and stress tolerance capacity, genotype 'Nutans' is recommended only in LS, and 'Sokol' and 'Line4' are recommended only in ES low temperature stress condition in South-East of East European Russia. These genotypes may be of use in a future breeding program to develop stress-tolerant genotypes.

REFERENCES

Ali Y, Babar MA, Javed A, Philippe M, Zahid L (2008). Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. Pak. J. Bot. 40(5):2087-2097.

Asana RD, Williams RF (1965). The effect of temperature stress on grain development in wheat. Aust. J. Agric. Res. 16:1-3.

Bagci SA, Ekiz H, Yilmaz A, Cakmak I (2007). Effects of zinc deficiency and drought on grain yield of field-grown wheat cultivars in Central Anatolia. J. Agron. Crop Sci. 193(3):198-206.

Bai Y, Han X, Wu J, Chen Z, Li L (2004). Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature 431:181-184

Bayramov SM, Babayev HG, Khaligzade MN, Guliyev NM, Raines CA (2010). Effect of water stress on protein content of some Calvin cycle enzymes in different wheat genotypes. Proc. ANAS (Biological Sciences) 65(5&6):106-111.

Blum A (2007). Drought stress and its' impact. PlantStress.com

Boglae A, Tesfaye K, Geleto T (2011). Morphological and physiological attributes associated to drought tolerance of Ethiopian durum wheat genotypes under water deficit condition. J. Biodiver. Environ. Sci. 1(2):22-36.

Braun HJ, Atlin G, Payne T (2010). Multi-location testing as a tool to identify plant response to global climate change. In 'Climate change and crop production'. (Ed Reynolds CRP), CABI, London, UK.

Bruce WB, Edmeades GO, Barker TC (2002). Molecular and physiological approaches to maize improvement for drought tolerance. J. Exp. Bot. 53:13-25.

Charmet G (2009). 'Les causes du plafonnement du rendement en grandes cultures'. INRA. Presented to the 2009 salon international de l'Agriculture.

Chaves MM, Maroco JP, Pereira JS (2003). Understanding plant responses to drought-from genes to the whole plant. Func. Plant Biol. 30:239-264.

CIMMYT-ICARDA (2011). WHEAT-Global Alliance for Improving Food Security and the Livelihoods of the Resources-Poor in the Developing World'. Proposal submitted by CIMMYT and ICARDA to the CGIAR consortium board, in collaboration with Bioversity, ICRISAT, IFPRI, ILRI, IRRI, IWMI, 86 NARS Institute, 13 Regional and International Organizations, 71 Universities and Advance Research Institutes, 15 Private Sector Organizations, 14 NGOs and Farmers Cooperatives and 20 Host Countries. 197pp. Available online at: ttp://www.cimmyt.org/en/component/docman/doc_view/503-wheat-global-alliance-for-improving-food-security-and-the-livelihoods-of-the-resource-poor-in-the-

Clarke JM, Townley-Smith TF, McCaig TN, Green DG (1984). Growth analysis of spring wheat cultivars of varying drought resistance. Crop Sci. 24:537-541.

Demirevska K, Simova-Stoilova L, Vassileva V, Vaseval I, Grigorova B, Feller U (2008). Drought-induced leaf protein alternations in sensitive and tolerant wheat varieties. Gen. App. Plant Physiol. 34:79-102.

Dencic S, Kastori R, Kobiljski B, Duggan B (2000). Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. Euphytica 113:43-52.

Donald CM (1962) In search of yield. J. Aust. Inst. Agric. Sci. 238:171-178.

Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Pazuvayev V, Plummer N, Jamason P, Folland CK (2007). Maximum and minimum temperature trends for the globe. Science 277:364-367.

Fabian A, Jager K, Barrabas B (2008). Effects of drought and combined drought and heat stress on germination ability and seminal root growth of wheat (*Triticum aestivum* L) seedlings. Acta Biol. Szegediensis 52(1):157-159.

Fabian A, Jager K, Rakszegi M, Barrabas B (2011). Embryo and endosperm development in wheat (*Triticum aestivum* L.) kernels subjected to drought stress. Plant Cell Rep. 30:551-563.

Fischer RA, Maurer R (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912.

Frank AB, Bauer A, Black AL (2009). Effect of air temperature on head development in spring wheat'. Great Plains Research Laboratory, USDA-ARS, Mandan, ND, USA. http://library.ndsu.edu/tools/dspace/load/?file=/repository/bitstream/handle/10365/6154/farm_45_04_04.pdf?sequence=1

Grigorova B, Vaseva I, Demirevska K, Feller U (2011). Combined drought and heat stress in wheat: Changes in some heat shock proteins. Biol. Plant. 55:105-111.

Gupta NK, Gupta S, Kumar A (2001). Effect of water stress on physiological attributes and their relationship with growth and yield in wheat cultivars at different growth stages. J. Agron. 86:1437-1439.

Guttieri MJ, Stark JC, O'brien K, Souza E (2001). Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Crop Sci. 41:327-335.

Hassan IA (2006). Effects of water stress and high temperature on gas exchange and chlorophyll fluorescence in *Triticum aestivum* L. Photosynthetica 44:312-315.

Hellevang KJ (1995). Grain moisture content effects and management'. Department of Agricultural and Biosystems Engineering, North Dakota State University. Available online at: http://www.ag.ndsu.edu/pubs/plantsci/crops/ae905w.htm

Hossain A, Sarker MAZ, Hakim MA, Lozovskaya MV, Zvolinsky VP (2011). Effect of temperature on yield and some agronomic characters of spring wheat (*Triticum aestivum* L.) genotypes. Int. J. Agric. Res. Inf. Tech. 1(1&2):44-54.

Hossain A, Lozovskaya MV, Zvolinsky VP, Teixeira da Silva JA (2012a). Effect of soil and climatic conditions on yield-related components performance of spring wheat (*Triticum aestivum* L.) varieties in the northern Bangladesh. Natural Sciences. J. Fundam Appl. Res. 2(39):77-86.

Hossain A, Lozovskaya MV, Zvolinsky VP, Teixeira da Silva JA (2012b). Effect of soil and climatic conditions on phenology of spring wheat varieties in the northern Bangladesh. Natural Sciences. J. Fundam Appl. Res. 2(39):86-97.

Hossain A, Teixeira da Silva JA., Lozovskaya MV, Zvolinsky VP (2012c). The effect of high temperature stress on the phenology, growth and yield of five wheat (*Triticum aestivum* L.) genotypes. Asian Aust. J. Plant Sci. Biotechnol. 6(1):14-23.

Hossain A, Teixeira da Silva JA, Lozovskaya MV, Zvolinsky VP (2012d). High temperature combined with drought affect rainfed spring wheat and barley in South-Eastern Russia: I. Phenology and growth. Saudi J. Biol. Sci. 19(4):473-487.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. p. 996.

Janusauskaite D, Auskalniene O, Psibisauskiene G (2011). Photosynthetic responses of spring barley varieties to different stand densities under field conditions. Acta Agriculturae Scandinavica (Section B - Soil & Plant Science). pp. 1-8.

Li RH, Gua P, Baumz M, Grand S, Ceccare S (2006). Evaluation of chlorophyll content and fluorescence parameters as indicators of drought tolerance in barley. Agric. Sci. China 5:751-757.

Lobell DB, Burke MB, Tebaldi C, Mastranddrea MD, Falcon WP, Naylor RL (2008). Supporting online materials for: Prioritizing climate change adaptation needs for food security in 2030. Science 319:607-610.

Lott N, Ross T, Smith A, Houston T, Shein K (2011). Billion dollar U.S. Weather disasters, 1980 - 2010. National Climatic Data Center, Asheville, NC, USA. Available online at: http://www.ncdc.noaa.gov/oa/reports/billionz.html.

Mamnouie E, Ghazvini RF, Esfahany M, Nakhoda B (2006). The effects of water deficit on crop yield and the physiological characteristics of barley (*Hordeum vulgare* L.) varieties. J. Agric. Sci. Tech. 8:211-219

MARTELL (Crop Projections) (2011). Crop worries from weather stress in Russia, China and Australia: Stressful hot finish in Russian grain belt'. Available online in: http://www.martellcropprojections.com/CropProductionReports/Crop-Worries-From-Weather-Stress-in-Russia-China-and-Australia

Nicolas ME, Glaeadow RM, Dalling MJ (1984). Effects of drought and high temperature on grain growth in wheat. Aust. J. Plant Physiol. 11:553-566. Available online:(http://blog.lib.umn.edu/efans/cropnews/2009/06/causes-of-seedling-stand-losse.html#comments)

OECD-FAO (2009) 'Agricultural outlook 2009-2018'. www.agri-outlook.org

Oosterhuis DM, Cartwright PM (1983). Spike differentiation and floret survival in semidwarf spring wheat as affected by water stress and photoperiod1. Crop Sci. 23:711-717.

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

Portmann FT, Siebert S, Doll P (2010). Mirca-2000-global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling. Global Biogeochem. Cycles 24:1-24.

Prasad PVV, Pisipati SR, Momcilovic I, Ristic Z (2011). Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast protein synthesis elongation factor (EF-Tu) expression in spring wheat. J. Agron. Crop Sci. 197(6):430-441.

Rahaman MA, Chikushi J, Yoshida S, Karima AJMS (2009). Growth and yield components of wheat genotypes exposed to high temperature stress under control environment. Bangladesh J. Agric. Res. 34(3):361-372

Rawson HM (1988). Effect of high temperatures on the development and yield of wheat and practices to reduce deleterious effects. In: Wheat Production Constraints in Tropical Environments' (Ed AR Klatt). pp. 44-62. CIMMYT, Mexico, D.F.

Renu KC, Suresh KS (1998). Prospects of success of biotechnological approaches for improving tolerance to drought stress in crop plants. Curr. Sci. 74(1):25-34.

Rizhsky L, Liang HJ, Shuman J, Shulaev V, Davletova S, Mittler R (2004). When defense pathways collide. The response of *Arabidopsis* to a combination of drought and heat stress. Plant Physiol. 134:1683-1696.

Rosegrant MW, Sombilla MA, Gerpacio RV, Ringler C (1997). Global food markets and US exports in the twenty-first century'. Paper prepared for the Illinois World Food and Sustainable Agriculture Program Conference 'Meeting the Demand for Food in the 21st Century: Challenges and Opportunities for Illinois Agriculture, May 27, 1997.

Russell OF (1994). MSTAT-C v.2.1 (A computer based data analysis software). Crop and Soil Science Department, Michigan State University, USA.

Saleem M (2003). Response of durum and bread wheat genotypes to drought stress: biomass and yield components. Asian J. Plant Sci. 2:290-293.

Samarah NH, Alqudah AM, Amayreh JA, McAndrews GM (2009). The effect of late-terminal drought stress on yield components of four barley cultivars. J.Agron.Crop Sci.195(6): 427-441.

Sangtarash MH (2010). Responses of different wheat genotypes to drought stress applied at different growth stages. Pak. J. Biol. Sci. 13:114-119.

Sattar A, Cheema MA, Farooq M, Wahid MA, Wahid A, Babar BH (2010). Evaluating the performance of wheat varieties under late sown conditions. Int. J. Agric. Biol. 12:561-565.

Shafazadeh MK, Yazdansepas A, Amini A, Ghannadha MR (2004). Study of terminal drought tolerance in promising winter and facultative wheat genotypes using stress susceptibility and tolerance indices. Seed Plant 20(1):57-71

Shah NH, Paulsen GM (2003). Interaction of drought and high temperature on photosynthesis and grain-filling of wheat. Plant Soil. 257:219-226.

Sharma AD, Kaur P (2009). Combined effect of drought stress and heat shock on cyclophilin protein expression in *Triticum aestivum*. Gen. Appl. Plant Physiol. 35:88-92.

Shirazi MU, Gyamfi JA, Ram T, Bachiri H, Rasyie B, Rehman A, Khan MA, Mujtaba, SM, Ali M, Shreen A, Mumtaz S (2010). Selection of some suitable drought tolerant wheat genotypes using carbon isotopes discrimination (CID)Technique.Pak.J. Bot. 42(5):3639-3644.

Slafer GA, Andrade FH (1991). Changes in physiological attributes of the dry matter economy of bread wheat (*Triticum aestivum* L.) through genetic improvement of grain yield potential at different regions of the world. Euphytica. 58:37-49.

Tawfelis MB (2006). Stability parameters of some bread wheat genotypes (*Triticum aestivum* L.) in new and old lands under Upper Egypt. J. Plant Breed. 10(1):223-246.

Trethowan R, Pfeiffer WH (1999). Challenges and future strategies in breeding wheat for adaptation to drought stressed environments: A CIMMYT wheat program perspective. In 'Molecular approaches for the genetic improvement of cereals for stable production in water-limited environments' (Eds JM Ribaut, D Poland) pp. 45-48. A strategic planning workshop held at CIMMYT, El Batan, Mexico. Jun 21-25, 1999. CIMMYT, Mexico, DF, Mexico.

USDA (United State Department of Agriculture) (2011). 'Russia: Agriculture Overview. Production Estimates and Crop Assessment Division Foreign Agricultural Service'. (www.pecad.fas.usda.gov).

Wahid A, Gelani S, Ashraf M, Foolad MR (2007). Heat tolerance in plants: An overview. Environ. Exp. Bot. 61:199-223.

Wardlaw IF (2002). Interaction between drought and chronic high temperature during kernel filling in wheat in a controlled environment. Ann. Bot. 90:469-476.

Wigley TML, Raper SCB (2001). Interpretation of high projections for global-mean warming. Sci.293:451-454

Wollenweber B, Porter JR, Schellberg J (2003). Lack of interaction between extreme high temperature events at vegetative and reproductive growth stages in wheat. J. Agron. Crop Sci. 189:142-150.

Xu ZZ, Zhou GS (2006). Combined effects of water stress and high temperature on photosynthesis, nitrogen metabolism and lipid peroxidation of a perennial grass *Leymus chinensis.* Planta 1:1-11

Zabihi-E-Mahmoodabad R, Jamaati-E-Somarin S, Khayatnezhad M, Gholamin R (2011). Effect of cold stress on germination and growth of wheat cultivars. Adv. Environ. Biol. 5(1):94-97.