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EFFECTS OF HIGH TEMPERATURE ON YIELD AND YIELD COMPONENTS OF NINE WHEAT CULTIVARS AND A TRITICALE

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ABSTRACT

Anthesis and grain filling period of wheat in many arid and semi-arid areas of the world is shortened by high temperature. An experiment was carried out to determine the effects of high temperature on yield and yield components of nine wheat (*Triticum aestivum* L.) cultivars ('Besostaya', 'Cross Rowshan 11', Falat, 'Ghods', 'Maroon', 'Hirmand', 'Morocco', 'Navid', and 'Rowshan') and a triticale (× *Triticosecale* Wittmack) cultivar 'Juvanillo-92'. High temperature treatments consisted of a control (no heat stress) and three levels of heat stress during different growth stages (a temperature of 28/23° C from the beginning of booting stage, anthesis, and grain filling to grain maturity). High temperature during any developmental stages significantly reduced wheat grain yield. The reduction was significantly less when high temperature was imposed for only a part of the reproductive stage than when it was imposed continuously from the booting stage to kernel maturity. The relative grain yield in the high temperature treatment from booting, anthesis and grain filling was only 5.6, 16.6 and 29.1 % of control plants which were grown at 17/15°C day/night, respectively. Triticale and 'Hirmand' prouced the highest yield after heat-stress during booting, and 'Besostaya', 'Rowshan', and 'Navid' yielded most after heat stress during anthesis. The highest

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yielding cultivars, when high temperature was imposed during grain filling period were 'Ghods' and triticale. Kernels per spikelet was the main yield component which reduced grain yield in the presence of heat stress. In conclusion, cultivars 'Ghods' and 'Navid' showed better performance than the other cultivars and 'Maroon' and Falat performed the poorest in the presence of heat stress. Therefore, these cultivars could be used as the relatively heat-tolerant and heat-susceptible genotypes, respectively.

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اثرهای دمای بالا بر عملکرد و اجزاء عملکرد ۹ رقم گندم و یک رقم تریتیکاله

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به ترتیب دانشجوی سابق دکترا (اکنون استادیار گروه زراعت دانشکده کشاورزی فردوسی، مشهد، ایران) و استاد بخش علوم کشاورزی و محیطی دانشگاه نیوکاسل، نیوکاسل، انگلستان.

چکیده

در این آزمایش که در سال ۱۳۷۳ در گلخانه های دانشگاه نیوکاسل انگلستان انجام شد تعداد ۹ رقم گندم ('بزوستایا'، 'کراس شماره ۱۱ روشن'، 'فلات'، 'قدس'، 'مارون'، 'هیرمند' 'موروکو'، 'نوید' و 'روشن') و یک رقم تریتیکاله در ۳ مرحله رشدی (تورم برگ پرچمی تا رسیدن، از گرده افشانی تا رسیدن و از تشکیل دانه تا رسیدن) در معرض تنش گرمایی۲۳-۲۸ درجه سانتیگراد قرار گرفتند. نتایج حاصل نشان داد که هر چه گیاه در مدت طولانی تری در معرض تنش گرمایی قرار گیرد، کاهش عملکرد بیشتر می شود. در این آزمایش،

مقدار عملکرد در تیمار های تنش در مرحله تـورم بـرگ پرچـم ، گـرده افشـانی و تشـکیل دانـه تـا رسیدن، به ترتیب ۶/۵، ۶/۱۶ و ۱/۲۹ درصد عملکرد گیاهان شاهد بود. در حالی کـه گیاهـان برای مدت طولانی مجبور به تحمل تنش گرمایی بودند، ارقـام گنـدم 'هـیرمند' و تریتیکالـه بهـترین عملکـرد دانـه را تولیـد کردنـد. در شـرایط تنـش گرمـایی بعـد از مرحلـه گـرده افشـــانی، ارقـــام 'بزوستایا'، 'قدس' و 'نوید' بیشترین عملکرد را داشتند، ولی کاهش عملکرد 'قدس' در اثر تنـش گرمایی کمترین مقدار بود. هنگامی که تنش گرمایی فقط در مرحله پرشدن دانه وارد شد، ' قدس' و تریتیکاله مناسب ترین ارقام بودند. در میان اجزای عملکرد، در تیمار تنـش در مرحلـه پـر شـدن دانه، فقط وزن دانه ودر تیمار تنش در مراحل بعد از گرده افشـانی و تـورم بـرگ پرچـم تـا رسـیدن دانه، تعداد دانه در سنبله و وزن دانه تحت تاثیر گرما قرار گرفتند.

INTRODUCTION

In areas of the world with hot summers, wheat is generally sown in the autumn, when temperature is falling, and harvested at the end of spring or early summer prior to the hottest months of the year. In the north east of Iran, for example, sowing is commonly done in September to November and the grain is harvested in June or July (4). During these months the mean maximum temperature is much higher than the optimum for wheat growth (10). The reproductive stages of wheat plants, particularly anthesis and grain filling, are shortened by high temperatures. This factor is one of many factors that lead to reduction in wheat yield. In Britain, for instance, where yields are much higher than in Iran, the mean temperature is much lower during the periods of anthesis and grain filling. For example, the mean daily temperature at Oxford during grain filling is about 17° C, which is close to optimum (5).

The problem of high temperature becomes even more important in arid and semi-arid regions, where high temperature is accompanied by drought stress and salinity (16). Wardlaw *et al.* (19) found that among 28 wheat cultivars from different parts of the world, there was no clear regional superiority in yield stability and high temperature, but they mentioned that adequate variation has been established amongst cultivars for determining the physiological and biochemical basis of temperature sensitivity in developing grains.

The effect of high temperature at different developmental stages has been studied by many researchers (1, 6, 16, 17, 19, 20, 21). In wheat, there is good evidence for a reduction in grain number per ear associated with high temperature during the booting stage (14, 15). There has been little or no study of the responses of the wheat cultivars used in this experiment to high temperature, particularly their ability to yield under high temperature conditions in the later developmental stages.

The current experiment was carried out to determine the effects of high temperature at different growth stages from booting to grain maturity on yield and yield components of nine wheat and one triticale cultivars.

MATERIALS AND METHODS

Plant Materials

Nine wheat (*Triticum aestivum* L.) cultivars ('Besostaya', 'Cross Rowshan 11', Falat, 'Ghods', 'Maroon', 'Hirmand', 'Morocco', 'Navid', and 'Rowshan') and a triticale cultivar 'Juanillo-92' with different genetic constitution were used in this study. All these cultivars are grown or planned to be grown in the east and north-east of Iran (Khorasan province), an arid region with considerable harmful high temperature in late spring and summer (10).

Two wheat cultivars 'Besostaya' and 'Navid', have a semi-winter habit and the rest have a spring or facultative habit (4). To ensure a uniform flowering date as possible, 1-2 leaf seedlings of all cultivars were vernalized at 3-5°C with a fluorescent light for six weeks in a cold cabinet. Seeds of all cultivars were kindly provided by Khorasan Cereal Research Station.

Plant Growth

The experiment was carried out in a glasshouse at the University of New Castle upon Tyne. Before sowing, seeds were graded by sieving and a single grade (2.8-3 mm in diameter) was used.

Seeds were sown in shallow plastic trays filled with John-Innes No. 2 potting compost and after emergence and vernalization for six weeks, each seedling was transplanted to a 15 cm diameter, 20 cm height plastic pot. The pots were also filled with John-Innes No. 2 potting compost and watered with tap water.

Treatments

The experimental design was a 10×4 factorial in randomized complete block design with two replications. Wheat cultivars as the first factor had 10 levels, and the second factor, temperature, consisted of the control (no heat stress) and three levels of heat stress during different growth stages (a temperature of 28/23° C from the beginning of booting stage to kernel muturity, from anthesis to kernel maturity, and from grain filling to grain maturity[1]). Before imposing heat stress, all pots were kept in the standard control condition. The temperature in the control condition was 17/15°C about 14/12 hours day/night and the temperature in the stress cubicle was 28/23°C day/night. This is the approximate temperature which these cultivars receive in the northeast of Iran at these growth stages (4). To achieve the proper temperature conditions, the raising and lowering of temperature were imposed by using heat radiators and coolers, respectively. The light conditions for all treatments were the sunlight. Because of high radiation in the mid-day, the cooler could not produce the proper temperature in the cubicle, and the high level of high temperature increased up to 33°C for one to two hours in some sunny days. Plants were distributed randomly among the treatment groups and were transferred to the stress cubicle according to the developmental stage of the main culm. At each developmental stage of the main culm, tillers, obviously, were later than particular developmental stage of main culm. For instance, at the time of booting stage of the main culm, the tillers were between three leaf stage to flag leaf emergence.

1. Booting stage in wheat is achieved when the ear is still hidden in the sheath of flag leaf, and this sheath is swelled. Anthesis is 6-10 days after booting stage, when filaments are out of the gellumes. Grain filling is 6-8 days after anthesis, when grain set is finished.

Measurements

All measurements were done in three pots with one plant per pot. The plants were harvested 83 days after transplanting stressed plants and 101 days after transplanting for control plants. The plants were harvested at maturity and the main stem height, number of spikes per plant, number of spikelets per spike, grain number and grain and straw weight were determined. For comparisons among cultivars that may differ widely in yield components, relative reduction of yield components in response to high temperature was emphasized.

The data were subjected to balanced analysis of variance by Minitab Statistic Software for Windows version 9.2 (Minitab Inc., 3081 Enterprise Drive, PA 16801-3008, USA).

RESULTS

Grain Yield

High temperature decreased grain yield compared with control (Table 1). Significant differences were observed among wheat and triticale cultivars. Interaction of heat stress and cultivars was also significant, so that heat stress at any developmental stage of the cultivars significantly reduced grain yield (Table 1). The grain yield reduction was significantly less when high temperature was imposed for only a part of the reproductive stage than when it was imposed continuously after the booting stage (Table 1). The relative grain yield in the high temperature treatment after booting, anthesis and grain filling was only 5.6, 16.6 and 29. 1 % (LSD 5% = 3.17) of control plants, respectively. The two high-yielding cultivars under control conditions were 'Ghods' and 'Navid' and the two low-yielding cultivars were 'Maroon' and Falat (Table 1). In the heat stress treatment after the booting stage, triticale and 'Hirmand' had maximum yields. In the high temperature treatment from anthesis, the highest yielding cultivars were 'Besostaya', 'Rowshan', and 'Navid'. The highest yielding cultivars when high temperature was imposed during grain filling were 'Ghods' and triticale (Table 1).

Table 1. Mean grain yield (g) per plant of nine wheat cultivars and one triticale cultivar under controlled conditions and after exposure to high temperatures from three growth stages to maturity.

Cultivars	Control	Booting	Anthesis	Grain filling	Mean
'Besostaya'	5.95	0.048	1.696	1.780	2.367
'Cross Rowshan 11'	5.69	0.330	0.650	1.147	1.953
'Falat'	3.58	0.189	0.395	0.915	1.269
'Ghods'	7.31	0.395	0.950	2.131	2.297
'Hirmand'	4.17	0.555	0.553	1.313	1.648
'Maroon'	2.85	0.237	0.246	0.696	1.008
'Morocco'	4.15	0.120	0.682	1.274	1.558
'Navid'	7.06	0.257	1.221	1.703	2.561
'Rowshan'	4.44	0.217	1.229	1.522	1.853
Triticale	6.04	0.466	0.907	1.964	2.347
Mean	5.13	0.281	0.852	1.444	LSD=0.294
$LSD_{0.05}$	1.08	1.075	1.075	1.075	0.537

Straw Yield

Heat-stress significantly reduced straw yield (the harvestable amount of leaves, stems and sheaths), but the relative reduction was less than grain yield, because these parts of plants were already established before grain setting. Among the wheat cultivars, 'Besostaya', 'Ghods' and 'Navid' had the highest straw per plant, and 'Falat' had the least straw (Table 2). The overall relative straw yield of all cultivars after high temperature during booting, anthesis and grain filling stage were 33.6, 45.3 and 58.4% of the control, respectively. Although straw yield is expected to be fixed after anthesis, some senescenced leaves might be lost by falling from the plant. Moreover, translocation of soluble sugar to growing grain might be affected. Some young tillers also might have grown after the main stem anthesis and caused increment of straw yield in non-stressed plant compared to heat stressed plants.

Table 2. Mean straw yield (g) per plant of nine wheat cultivars and one triticale cultivar under control conditions and after exposure to high temperature from three growth stages to maturity.

Cultivars	Control	Booting	Anthesis	Grain filling	Mean
'Besostaya'	6.997	2.252	3.660	3.808	4.18
'Cross Rowshan 11'	4.453	1.091	1.774	2.715	2.51
'Falat'	2.511	1.075	1.256	1.572	1.60
'Ghods'	5.672	1.793	2.063	2.904	3.11
'Hirmand'	3.568	1.279	1.625	1.888	2.10
'Maroon'	2.883	1.001	1.171	2.008	1.77
'Morocco'	3.963	1.120	1.921	2.330	2.33
'Navid'	6.654	2.295	2.441	3.069	3.62
'Rowshan'	4.809	1.60	2.561	2.838	2.95
Triticale	4.302	1.403	1.913	2.523	2.54
Mean	4.581	1.492	2.039	2.566	LSD=0.21
$LSD_{0.05}$	0.660	0.660	0.660	0.660	0.33

Harvest Index

Harvest index (HI), the ratio of grain yield to total above ground biomass, was quite sensitive to high temperature. Among the four treatments of exposure to high temperature, HI decreased with increasing duration of exposure to high temperature (Table 3). For example, in the control condition, mean HI was 52% while it was 15.9, 28.0 and 35.6% in stressed plants after high temperature during booting, anthesis and grain filling, respectively. Cultivars also showed different HI in the presence of high temperature. The interaction of high temperature and cultivar for HI was statistically significant (Table 3).

Table 3. Mean harvest index of nine wheat cultivars and one triticale cultivar under control conditions and after exposure to high temperatures from three growth stages to maturity.

Cultivars	Control	Booting	Anthesis	Grain filling	Mean
'Besostaya'	0.46	0.02	0.32	0.32	0.28
'Cross Rowshan 11'	0.56	0.22	0.26	0.30	0.34
'Falat'	0.58	0.15	0.24	0.27	0.34
'Ghods'	0.56	0.16	0.32	0.42	0.36
'Hirmand'	0.54	0.30	0.25	0.41	0.37
'Maroon'	0.50	0.19	0.17	0.26	0.28
'Morocco'	0.51	0.10	0.26	0.36	0.31
'Navid'	0.50	0.10	0.33	0.36	0.32
'Rowshan'	0.48	0.11	0.32	0.44	0.39
Triticale	0.58	0.24	0.32	0.44	0.39
Mean	0.53	0.19	0.28	0.36	LSD=0.03
$LSD_{0.05}$	0.09	0.09	0.09	0.09	0.05

Yield Components

Total and fertile tillers. Because high temperature was imposed after the tillering stage, there were no significant differences in total tillers among the growth stages when plants were exposed to heat stress, but fertile tillers (spikes per plant) decreased with increasing duration of exposure to high temperature (Table 4). The number of tillers did not increase after booting stage in controls or heat treatments, so the differences between tiller numbers in heat treatments is due to tiller abortion. The number of tillers might seem low, but it should be noted that the main stem was not included in the table. The relative fertile tillers per plant were 51.2, 62.7 and 71.3% of the control after high temperature at booting, anthesis and grain filling, respectively.There were cultivar differences in the response of fertile tiller number to high temperature treatments (Table 4). Two wheat cultivars, 'Besostaya' and 'Ghods', had significantly more fertile tillers than the others within stress treatments. The interaction between high temperature and cultivar on fertile tiller number was not significant.

Table 4. Mean number of total tillers per plant, spikes per plant, spikelets per spike, kernels per ear and kernel weight of nine wheat cultivars and one triticale cultivar under control conditions and after exposure to high temperatures from three growth stages to muturity.

Factors	Traits				
Temperature stress at	Total tiller plant^{-1}	Fertile tiller plant^{-1}	Spikelet spike^{-1}	Kernel ear^{-1}	Kernel weight (mg)
Control	3.30	3.37	16.44	35.19	45.44
Booting	2.53	1.63	15.41	10.54	18.58
Anthesis	2.73	2.00	15.38	20.41	20.57
Grain filling	2.65	2.25	16.86	32.32	20.60
$LSD_{0.05}$	ns†	0.26	ns	2.98	1.78
Cultivars					
'Besostaya'	3.12	2.92	18.01	17.96	29.97
'Cross Rowshan 11'	2.91	2.63	15.21	21.49	25.34
'Falat'	3.08	1.71	17.00	29.24	19.91
'Ghods'	2.63	2.92	16.38	25.63	26.66
'Hirmand'	2.25	1.58	12.90	32.27	26.61
'Maroon'	2.54	1.67	15.09	19.96	24.12
'Morocco'	3.21	2.33	16.08	21.86	23.06
'Navid'	3.67	2.37	16.95	32.59	25.27
'Rowshan'	3.38	2.70	15.29	17.05	31.52
Triticale	3.75	2.29	17.38	28.18	30.54
$LSD_{0.05}$	0.75	0.41	1.24	4.71	2.82

† ns Non-significant.

Spikelets per spike. There were no significant differences in number of spikelets per spike between the control plants and those exposed to high temperature during the grain filling. There were no significant differences in spikelets per spike between plants exposed to high temperature during booting and anthesis. Cultivars showed significant differences in spikelets per spike, but the interaction between high temperature and cultivar on the number of spikelets per spike was not significant (Table 4).

Kernels per spikelet. The kernel number per spikelet decreased in response to duration of heat stress. The number of kernel was reduced 64.1, 35.1 and 6.7% of the control by high temperature after booting, anthesis and grain filling, respectively. In the grain filling stage, the amount of kernel reduction was not statistically significant. Among the wheat cultivars, 'Hirmand' had the most kernels per spikelet, while 'Besostaya' had the least kernels per spikelet (Table 5). The interaction between heat stress and cultivar was also significant. At all levels of heat stress, cultivar 'Hirmand' had the most and cultivar 'Besostaya' had the least numbers of kernels per spikelet.

Table 5. Mean number of kernels per spikelet of nine wheat cultivars and one triticale cultivar after exposure to high temperature from three growth stages to maturity.

Cultivars	Control	Booting	Anthesis	Grain filling	Mean
'Besostaya'	1.64	0.06	0.81	1.49	1.00
'Cross Rowshan 11'	1.86	0.95	1.12	1.69	1.41
'Falat'	2.33	0.61	1.71	2.12	1.70
'Ghods'	2.64	0.49	1.20	1.83	1.54
'Hirmand'	3.05	1.78	2.09	2.94	2.47
'Maroon'	1.25	1.28	1.25	1.50	1.32
'Morocco'	1.79	0.34	1.38	1.76	1.32
'Navid'	3.18	0.49	1.79	2.06	1.88
'Rowshan'	1.41	0.48	0.98	1.58	1.11
Triticale	2.27	0.71	1.12	1.26	1.59
Mean	3.37	1.63	2.00	2.25	LSD=0.26
$LSD_{0.05}$	0.55	0.55	0.55	0.55	0.28

Kernels per spike. Kernels per spike, might be a better indicator for selecting a genotype, because in heat-stressed wheat cultivars, the number of spikelets per spike had an inverse relationship with the number of kernels per spikelet and fertile tiller. High temperature stress significantly reduced the number of kernels per spike in booting and anthesis treatments, i.e., when stress imposed before seed setting (Table 4). There were no significant differences between the control and heat stress in grain filling in kernel number per spike, because in this treatment seed set was completed in optimum conditions.

Kernel weight. Weight per kernel of all genotypes over high temperature treatments for all growth stages was about 57% lower than the control. Although there were significant differences in kernel weight between the control and the heat-stress treatments, there were no significant differences among stages of heat stress. Genotypes had significant differences in kernel weight. In controls, 'Rowshan', 'Maroon' and 'Cross Rowshan 11' had the heaviest kernels, while 'Morocco', 'Falat' and 'Besostaya' had the lightest kernels. After high temperature during the booting stage, there was no significant differences in kernel weight among cultivars, but after anthesis, 'Besostaya' and 'Rowshan' had the highest kernel weight, and after grain filling, 'Besostaya', 'Rowshan', 'Hirmand' and 'Ghods' had the highest kernel weights (Table 4).

DISCUSSION

High temperature significantly affected only those yield components that were developed during the growth phase in which the treatment was imposed. Therefore, yield components such as total tillers and number of spikelets per spike, which were completed before heat stress was imposed, did not show significant reduction due to high temperature. Although total tiller number was not affected by high temperature, the number of fertile tillers, which is the major determinant of grain yield per plant, decreased with increasing duration of exposure to high temperature. These young tillers might not produce spike, and be excluded from the fertile tiller counting. Rickman *et al.* (13) reported that tillering appears as a predefined developmental stage, but stress may delay the appearance of a tiller or, if sufficiently severe, causes the tiller to fail to appear. This reduction in fertile tiller per plant in the booting stage treatment may be due to tiller abortion. The results of this work are in agreement with those of Gallaghar and Biscoe (8) who stated that tiller abortion in wheat, generally begins when tiller appearance stops, after terminal spikelet differentiation, and that abortion stops just before anthesis. McMaster *et al.* (12) and Francois *et al.* (7) also reported a similar effect from shading and salt stress in wheat, respectively. Although fertile tillers did not differ after heat stress during the anthesis and grain filling stages, there was a reduction in fertile tillers in comparison with the control. The possible reason for this reduction is that in the young tillers that did not abort but could not produce heads, the spikes did not develop fully and remained in the flag leaf sheath until death.

The reduction in grain number per spikelet was the main effect of heat stress during the reproductive stages. High temperature during booting greatly reduced grain number per spikelet and had only a small effect on grain size, while the main effect of high temperature during grain filling was to reduce grain size with only a small effect on grain number. The reduction in kernel number at the booting stage due to high temperature was not compensated ~~for~~ ~~by~~ ~~an~~ increase in weight per kernel. This is in agreement with the findings of Wardlaw *et al.* (19) and Saini *et al.*(15).

Generally, conditions such as high temperature, long days, water stress and salinity reduce floret number and grain set per spikelet (9). Moreover, yield stability in cereals is often the result of yield component compensation. However, kernel number was reduced by the booting and anthesis stress treatments, adjustment of grain number according to growth conditions at booting and anthesis buffered final grain size against extreme variation in cultivars in which high temperature has less effect on growth rate per grain than growth rate per ear.

The kernel weight over all heat-stress treatments within cultivars was less than 50% of the control and the best cultivar had a 37% kernel weight reduction. Kernel weight is largely determined by the duration and rate of grain filling (11, 21). Sofield *et al.* (17) also found that both duration and rate of grain growth in wheat can vary substantially depending on cultivar and environmental conditions. Therefore, environmental stresses that shorten the grain filling period, reduce the final grain weight (1). Some workers have considered the possibility that the increased respiratory losses of carbon that occur with a rise in temperature may be detrimental to yield (2, 4). Heat stress accelerates maturation and grain filling in some cereal crops. Sofield *et al.* (17) found that a rise in temperature from 15/10°C to 30/25°C reduced the duration of grain filling by two-thirds..

In conclusion, cultivars 'Ghods' and 'Navid' showed superior performance than other cultivars under all treatments. Therefore, they could be recommended for growing in the regions of the country with hot springs. Cultivars 'Maroon' and 'Falat' were the least productive. Therefore, they could be used as relative heat-tolerant and heat-susceptible genotypes in future experiments, respectively. Triticale also showed a better performance than some wheat cultivars in this experiment.

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