Some traits of low temperature germplasm wheat under extremely unfavorable weather conditions*

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Abstract Through a long-term observation on the canopy temperature and some traits of wheat the temperature germplasm of wheat was found to result in the wheats having either a high or a low plant temperature. Under normal weather conditions, the wheat having a low temperature germplasm (LTG) demonstrated several advantageous physiological and agronomic traits than those having a high temperature germplasm (HTG). Under the extremely unfavorable weather conditions, such as rainy weather or severe drought, LTG wheat still could maintain its superiority to HTG wheat in physiological and agronomic traits including leaf functional duration, chlorophyll content, malondialdehyde content, transpiration rate, net photosynthesis rate, root vitality and kernel plumpness. The wide adaptability of LTG wheat to a wide range of meteorological conditions could provide a valuable germplasm in breeding of good strains with broad-spectrum stress resistance.

Keywords: wheat, rainy weather, drought, low temperature germplasm, traits.

It has been reported in several studies that there widely exists a difference in canopy temperature among different wheat genotypes under the identical climatic, soil and farming conditions\(^{[1-4]}\). The prerequisite to extend a new wheat variety in any agro-ecological zone is that its main agronomic traits exceed those of the dominant varieties used in local agricultural production, and so the authors of this paper first put forward the concept that these dominant varieties should be adopted as the references in defining temperature types of wheat germplasm. If a variety has a canopy temperature equivalent to or lower than that of a selected reference variety, it is called a low temperature germplasm (LTG); otherwise, a high temperature germplasm (HTG). The difference in canopy temperature between LTG and HTG wheats appears before the heading and anthesis period, and will become more obvious during the kernel-filling period, a key period for wheat to form kernels. Therefore, this research is focused on the physiological and agronomic traits of wheat during the kernel-filling period. Related studies\(^{[5-7]}\) have shown that the temperature type of germplasm materials of wheat does not change whatever the year and whatever the kind of weather. In meteorological normal year, the LTG wheat varieties are much superior to control wheat varieties and much superior to HTG ones in leaf functional duration, chlorophyll content, protein nitrogen content, superoxide dismutase activity, catalase activity, peroxidase activity, transpiration rate and net photosynthesis rate. These superiorities of LTG

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wheat make itself wheat germplasm for breeding of excellent high-yield wheat varieties. But whether LTG wheat can maintain its superiorities to HTG wheat under unfavorable weather conditions, such as rainy weather or severe drought, requires serious consideration in breeding. The main objective of this research is to examine the physiological and agronomic traits of LTG wheat under the weather stress.

1 Materials and methods

1.1 Experimental design

Trials were carried out in the Agricultural Experiment Station of the Northwest Science and Technology University of Agriculture and Forestry, Yangling, Shaanxi Province, China. The station lies in the uppermost terrace area of Weihe River Valley, which is within the Huanghuaihai winter wheat region, one of the most important wheat production regions of China with warm-temperate and semi-humid climate.

Field experiments had been conducted for over 12 consecutive years (1989 ~ 2000). During kernel-filling period of the 12 growing seasons, the wheat varieties or lines used in the trials experienced several severe droughts or waterlogging stresses, and their traits expressed themselves thoroughly. In 1996, the total rainfall reached as high as 135.3 mm during the kernel-filling period that was well above the long-term average of 83.0 mm, and the drought-waterlogging index came to the highest point of +9.31 in the last twenty years. In 1998, 117.5 mm of rainfall and +6.34 of drought-waterlogging index were recorded during the kernel-filling period. Drought occurred in 1997, only 6.8 mm of rainfall was recorded during the kernel-filling period, much lower than the long-term average with the drought-waterlogging index of a minimum of -12.11 for the same period in the last twenty years. At that time, the average daily temperature above 25.0°C lasted 3 days. In 2000 a drought-simulating shelter which allowed sunshine to go inside was built for the trials and all wheat varieties were planted in the shelter; from the second ten days of April (head-forming period) to the first ten days of June (maturing period), the varieties were kept off natural rainfall and irrigation in the shelter so that a microclimate with severe drought was formed for them.

For many years hundreds of germplasm materials had been chosen for the field trials and some of them having typical germplasm had been systematically examined year after year. The practices for wheat sowing and field management were as follows: (i) a one-pass wheat planting system was practiced; (ii) the land of the trials had a medium soil fertility that could produce a wheat yield of 6.0 ~ 7.5 tons/hm² with basic and topdressing fertilizers applied; (iii) for the trials, a randomized complete block design with four replications was adopted and 13 ~ 15 genotypes of wheat were chosen; (iv) in the trials, the plots had seven 2.67 m rows of wheat and the germplasm materials had a row space of 25 cm and a plant space of 3 cm; (v) the germplasm materials were dibble-sown in the first ten days of October of each year that is the optimal planting period in Yangling; (vi) the farming for the trials was conducted according to the standards of wheat varieties for Huanghuaihai winter wheat area.

Xiaoyan6, an LTG wheat, was chosen as the control wheat. The other two varieties, Shaan229 and NR9405, were chosen as LTG wheat and HTG wheat, respectively. The growing periods of the
three wheat varieties did not differ much, and Shaan229 and NR9405 matured only one day earlier or later than Xiaoyan6 in meteorological normal years.

1.2 Measurements

The physiological and agronomic characteristics of the germplasm materials were measured mainly during the kernel-filling period. Leaf chlorophyll content was measured with a UVIKON810 spectrophotometer. Leaf malondialdehyde (MDA) content was determined by the method of Heath et al. [8]. Leaf transpiration and net photosynthesis rates were measured with a portable LI-6400 photosynthesis system (LI-COR Inc.). Root vitality was estimated by the method described in Ref. [9]. The size of fresh kernels and the sun-dried kernels was measured with a volumenometer. Kernel plumpness index was presented by the ratio of the percentage of the sun-dried kernel size to that of the maximum fresh kernel.

2 Results and discussion

2.1 Leaf functional duration

Leaf functional duration is the ratio of the duration from anthesis to leaf death to the duration from anthesis to kernel maturity. The higher the percentage is, the longer the leaf functional duration will be, and vice versa. Fig. 1 shows the functional durations of flag leaf, the 2nd leaf and the 3rd leaf from the top of the wheat. The three leaves of LTG wheat had an obviously longer functional duration than those of HTG wheat under the stress of rainy weather or drought, and the difference in leaf functional duration between LTG and HTG wheats became more obvious as the leaf position went down. For the 2nd and the 3rd leaves, no big difference could be seen in the functional durations between Shaan229 and Xiaoyan6, but the flag leaf of Shaan229 that has a lower plant temperature than that of Xiaoyan6 (the control wheat variety) had a longer functional duration than that of Xiaoyan6. Therefore, the functional durations of the top three leaves of wheats as the main sources for kernel filling indicate that LTG wheat has a robust vitality.

![Fig. 1](image)

**Fig. 1** Functional durations of the top three leaves. (a) In rainy weather, (b) in drought.

2.2 Leaf chlorophyll content

Figure 2 illustrates chlorophyll contents of the flag leaves of LTG and HTG wheat varieties under
the weather stress. It can been seen that chlorophyll content of the flag leaves of all wheat varieties showed a declining tendency no matter in what kind of weather, only to different extents. Shaan229 had the highest chlorophyll content, Xiaoyan6 the middle, and NR9450 the lowest. When NR9405 was near its maturity, its leaves became nearly dry and thus it had such a low chlorophyll content as could hardly be measured. For the LTG and HTG wheat varieties, the chlorophyll contents of the 2nd and the 3rd leaves from the top varied as the flag leaves. These observations are consistent with the observation of the leaf functional durations as shown previously.

Fig. 2 Changes of chlorophyll contents of flag leaves. (a) In rainy weather; (b) in drought.

2.3 Leaf malondialdehyde content

MDA is a product of membrane-lipid peroxidation, and its content in the leaves will increase as leaf senescence proceeds. So the accumulating rate of MDA content during the kernel-filling period of wheat can be used to indicate the extent to which leaf vitality of wheat deteriorates. Fig. 3 illustrates the changes in MDA content of flag leaves of LTG and HTG wheat varieties during the kernel-filling period in rainy weather and drought.

Fig. 3 Changes of MDA contents of flag leaves. (a) In rainy weather; (b) in drought.

Figure 3 shows that MDA content of the all genotypes of wheats in the trials will significantly increase with the process of their development, which reflects a declining tendency of vitality of the plant, but the declining rate of vitality differs from one wheat to another. No matter in what unfavorable weather, Shaan229 of LTG has the lowest declining rate of vitality, NR9405 of HTG has the highest declining rate, and Xiaoyan6 as the control is in between. This changes in vitality of wheat plants correspond well to the changes in leaf functional durations and leaf chlorophyll contents.
2.4 Leaf transpiration rate

Figure 4 shows the weighted average transpiration rate of the top three leaves of the LTG and HTG wheat varieties under the weather stress. In the calculation of the so-called weighted average transpiration rates the contributions leaves at different positions of wheat culms make to kernel filling were taken into account\(^\text{[10]}\).

![Graph showing changes in transpiration rate over time](image)

Fig. 4 Changes of weighted average transpiration rates of leaves. (a) In rainy weather; (b) in drought.

Although there existed some fluctuations in the general declining tendency due to the varying weather conditions, the leaf transpiration rate of the varieties of LTG and HTG wheat showed a general declining tendency as the two kinds of wheat varieties advanced near their maturity. As shown in Fig. 4, during the time of rainy weather and drought, Shaan229 of LTG had the highest leaf transpiration rate on all the sampling dates, Xiaoan6, the control wheat variety, had the moderate leaf transpiration rate on most of the sampling dates, and NR9405 of HTG had the lowest rate. The nearer the three varieties to the late period of maturity, the clearer the above-mentioned ranking order of leaf transpiration rates became.

The temperature types of wheat germplasm are closely related to the intensity and duration of wheat leaves transpiration, which can be presented by the energy balance equation at a crop canopy\(^\text{[11]}\). Because the varieties of LTG wheat have a high intensity and a long duration of leaf transpiration, the net radiation used in the transpiration will increase significantly; thus the net radiation used to warm the leaves and culms of wheat will inevitably decrease proportionally. The situation about the HTG wheat is contrary to that of LTG wheat. Accordingly, the canopies of LTG wheat varieties have a lower canopy temperature than those of HTG wheat varieties. Even in rainy weather and drought, there exist no signs indicating that LTG wheat will not surpass or be equal to HTG wheat in the intensity and duration of leaf transpiration. This explains to some extent why LTG wheat can keep a lower canopy temperature than HTG wheat under any unfavorable weather conditions and why the canopy temperature can be used as an important indicator for plant metabolisms.

2.5 Leaf net photosynthesis rate

Leaf net photosynthesis rate is an important physiological trait to which a good deal of attention had been paid. It indicates the potential capacity of plant leaves as the main source to produce and export photosynthesize for kernel filling. Fig. 5 shows the changes of weighted average net photosynthesize..
sis rate of the top three leaves of LTG and HTG wheat varieties during kernel-filling period.

Fig. 5 Changes of weighted average net photosynthesis rates of leaves. (a) In rainy weather; (b) during drought.

Along with the development of the wheat varieties, their net photosynthesis rate showed a declining tendency during their kernel-filling period. Between LTG and HTG wheat varieties, their net photosynthesis rate differed remarkably, whether in rainy weather or in drought. Comparatively speaking, Shaan229 had the highest net photosynthesis rate, Xiaoyan6 was the next, and NR9405 the lowest. When the wheat varieties nearly reached their complete maturity, the leaves of HTG wheat varieties had dried up completely and had no photosynthetic ability, and LTG wheat varieties still had some photosynthetic ability, showing that among all types of wheats with different plant temperatures, only the varieties of LTG wheat have the ability to supply their kernel filling with sufficient carbohydrates under the weather stress.

2.6 Root vitality

Root vitality was estimated by bleeding root-sap amount. The procedure to measure bleeding root-sap amount was as follows: to choose main stems of typical wheat plants at different stages of kernel-filling period, cut them at a height of 3 ~ 4 cm aboveground, collect the root sap bleeding from the cutting surfaces of the stems and finally measure the root-sap amount. The measurement was conducted four times during different growing periods.

Figure 6 shows that among all the wheat varieties, the bleeding root-sap amount of Shaan229 of LTG ranks first, that of Xiaoyan6 second and NR9405 of HTG third. This can well explain the performances of wheat traits aboveground as described before, i.e. the strong root of LTG wheat varieties contribute a lot high metabolism rate and vitality of the plant, even under the extremely unfavorable weather conditions.

2.7 Kernel plumpness index

The kernel plumpness index is a parameter to quantify the degree of kernel plumpness. The higher the kernel plumpness index is, the more plump wheat kernels will be and vice versa. According to the measurements in the trials, in the year when rainy weather occurred, the kernel plumpness indices of Shaan229, Xiaoyan6 and NR9405 were 62.1%, 59.7% and 56.1%, respectively; in the year when severe drought occurred, the kernel plumpness indices of the three wheats were 67.8%,
62.0% and 60.6%, respectively. Therefore LTG wheats have a higher kernel plumpness index than that of HTG wheats no matter in what unfavorable weather.

According to the results of this study, we conclude that LTG wheat possesses many excellent physiological and agronomic traits, performing well and maintaining a good adaptability even under the extremely differing unfavorable weather conditions. It can be used as a very valuable species for high- and stable-yield wheat breeding. Meanwhile, the research results on this temperature type of wheat germplasm will have great theoretical and practical significance in probing resistance mechanism and metabolic capacity of LTG wheat, and in further understanding of living activities of wheat.

References