

# Study on the Differences in the Responses of Different Winter Wheat Cultivars to Dry Hot Wind

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## Research Article

**Keywords:** Dry hot wind, Photosynthetic parameters, Response difference, Variation characteristics, and Winter wheat.

**Posted Date:** July 14th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-658355/v1>

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# Abstract

Dry hot wind is one of the main prevailing agro-meteorological disasters during the grain filling stage of winter wheat in Northern China. In this study, three major winter wheat cultivars, including Henong 6119 (HN6119), Gaoyou 5218 (GY5218), and Jimai 325 (JM325) in Hebei Province were selected to analyze their responses to dry hot wind. Under the combined conditions of field natural dry hot wind and artificially simulated dry hot wind experiments, we characterized the three cultivars' physiological parameters as affected on the day with dry hot wind, and on the day before and after hot wind conditions. Comparative analysis of different correlations among the three cultivars' physiological parameters toward dry hot wind showed that, during field nature dry hot wind conditions, HN6119 showed less water loss of leaves by reducing the stomatal conductance and transpiration rate, while GY5218 and JM325 showed more water loss of leaves by increasing the stomatal conductance and transpiration rate. The net photosynthetic rate, transpiration rate, and stomatal conductance of HN6119 were recovered during the recovery time after dry hot wind conditions, while these parameters of GY5218 and JM325 showed a continuous decreasing trend. During dry hot wind day, HN6119 showed significant positive correlation between physiological parameters, while GY5218 and JM325 showed poor correlation. The stress of severe dry hot wind on thousand kernel weight (TKW) of HN6119, GY5218 and JM325 is 0.01%, 3.51%, 3.57%, respectively. The stress of mild dry hot wind on thousand kernel weight (TKW) of HN6119, GY5218 and JM325 is 0.36%, 8.12%, 8.84%, respectively. In summary, HN6119 showed strong resistance to dry hot wind, followed by GY5218, and JM325; JM325 had the weakest resistance to dry hot wind.

## 1 Introduction

Dry hot wind is a kind of catastrophic weather with high temperature, low humidity and wind, also it is of the main agro-meteorological disasters during the grain filling stage of winter wheat in Northern China, which could cause the reduction of wheat yield by 10–20% during severe dry hot wind condition (Yoshitaka et al. 2002). Hebei Province is one of the main wheats producing provinces in China (the planting area is more than 30 million acres), and a region with severe dry hot wind damage (Van, et al. 2020). Under the circumstances of global warming, the frequency and range of dry hot wind disaster are likely to increase in the future (IPCC report. 2007; Deng. 2009 and 2010; Zhang, et al. 2011; Chen, et al. 2014; De Vries, et al. 2014; Liao, et al. 2015; Tercero, et al. 2015; Liu, et al. 2016; Cheng, et al. 2019; Dong, et al. 2019; Azard, et al. 2020; Van, et al. 2020). Therefore, study on the responses of different winter wheat cultivars to dry hot wind is of great practical significance for understanding the characteristics of different winter wheat cultivars and the safe production of winter wheat.

Researchers from various countries have paid much attention to the study on the responses of winter wheat to the dry hot wind. The former Soviet Union began to study the indicators, causes, geographical distribution, and defense measures of dry hot wind in the 1920s (Research Cooperation Group of Hot Dry Wind in Northern wheat area, 1983). American scholars simulate the effect of dry hot wind on wheat growth by means of wind tunnel test, and found that dry hot wind reduced the number of spikes, grain number per spike and grain weight of winter wheat (Smika et al. 1980). The study of dry hot wind in China began in the late 1950s. In early 1980s, the damage mechanism, meteorological index and defense technology of dry hot wind were studied by Research Cooperation Group of Hot Dry Wind which consisted by thirteen provinces in Northern China wheat area. Some researchers discussed the difference of dry hot wind resistance among different wheat cultivars (Gong 1981; Lu Zhengduo et al. 1981). With the development of science and technology, based on the previous studies, the effects of dry hot wind on photosynthetic physiological parameters were studied by using the artificially simulated dry hot wind experiments (Zhao et al. 2013, Zhang et al. 2015). However, there are few studies on the differences in the

responses of different winter wheat cultivars to dry hot wind. Most of the existing studies focus on the comparison of photosynthetic physiological parameters before and after the affected by dry hot wind, while there are few studies on the variation characteristics of each parameter on the day affected by dry hot wind. And most of the studies were carried out by using a single variety. With the continuous updating of winter wheat cultivars, the previous research results cannot meet the needs of modern agricultural production.

Therefore, in this research, three main winter wheat cultivars in Hebei Province were taken as examples, field experiments under natural dry hot wind conditions were adopted to analyze the response differences among different cultivars to dry hot wind. The variation characteristics of physiological parameters such as net photosynthetic rate ( $P_n$ ), transpiration rate ( $T_r$ ), and stomatal conductance ( $G_s$ ) of winter wheat during the days affected by dry hot wind, as well as the variation characteristics of physiological parameters before and after the days affected by dry hot wind were analyzed, and also the correlations among the parameters. Meantime, combined with artificially simulated dry hot wind experiments, the stress of dry hot wind on each physiological parameter during and after the days affected by dry hot wind were analyzed. The results could reveal the resistance variation of different cultivars toward dry hot wind, which provide scientific basis for winter wheat cultivars selection and production layout.

## 2 Materials And Methods

### 2.1 Experimental Materials and Design

The experimental area is located at Mazhuang (37°58'N, 115°13'E) experimental station of Hebei Agricultural University in Xinji City, which is the main wheat region of Hebei Province. This area belongs to warm temperate zone with semi-humid continental climate, the annual average temperature is 13.6°C, annual average precipitation is 466.4 mm, the annual average relative humidity is 63%, and annual average sunshine hours are 2610.1 hours.

The tested winter wheat cultivars were Henong 6119 (HN6119), Gaoyou 5218 (GY5218), and Jimai 325 (JM325). The first flowering date was May 3rd, and there were no plant diseases, insect pests, and drought during the whole growth period. Dry hot wind with daily maximum temperature above or equal to 32°C, relative humidity below or equal to 30% at 14:00, wind speed above or equal to 3 m/s at 14:00 is defined as mild dry hot wind; dry hot wind with daily maximum temperature above or equal to 35°C, relative humidity below or equal to 25% at 14:00, wind speed above or equal to 3 m/s at 14:00 is defined as severe dry hot wind (Huo, et al. 2007).

Mild dry hot wind occurred on May 22nd, 2019, lasted from 13:00 to 18:00; severe dry hot wind occurred on May 23rd, 2019, lasted from 13:00 to 17:00 (Huo, et al. 2007). The measurements were carried out on May 21st to May 24th, May 28th, and May 31st when the weather condition is well. Table 1 shows the hourly meteorological element values on the day suffering from dry hot wind in 2019.

Table 1  
The hourly meteorological element values on the day suffering from dry hot wind

Time		10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
5/22	Temperature (°C)	28.1	30.1	31.3	32.4	33.6	34.4	33.2	34.7	32.8	28.6
	Wind speed (m/s)	1.2	1.5	2.1	3.3	3.0	3.0	3.8	3.0	3.0	3.2
	Relative humidity (%)	26	18	16	16	18	17	16	17	21	26
5/23	Temperature (°C)	29.6	32.0	34.3	34.0	35.7	37.1	34.9	34.6	31.9	30.6
	Wind speed (m/s)	1.1	0.7	1.7	3.0	3.0	3.0	3.5	3.0	3.2	3.8
	Relative humidity (%)	26	23	21	15	17	13	13	13	15	17

In 2020, the dry hot wind stress experiments were carried out with the dry hot wind simulation generator developed by the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences. No dry hot wind occurred before the experiment. A mild dry hot wind experiment was carried out from 13:00 to 16:00 on May 23rd, with average temperature of 35.8°C, relative humidity of 26.9%, and wind speed of 3 m/s; the observations were carried out on May 23rd (the experiment day), May 24th (the day after experiment day) and May 26th (three days after experiment day). A severe dry hot wind experiment was carried out from 10:00 to 17:00 on May 24th, with average temperature of 39.5°C, relative humidity of 20.8%, wind speed of 3 m/s. The observations were carried out on May 24th (the experiment day), May 25th (the day after experiment day) and May 27th (three days after experiment day). The weather condition from May 23th to May 27th is well.

## 2.2 Measurement Items and Methods

Flag leaf is the primary photosynthetic organ for grain filling, it has important effects on grain filling and the yield (Evans, 1975). Five flag leaves with a similar growth pattern were randomly selected for each cultivar to carry out the physiological parameter measurement. As an input parameter of the portable photosynthesis instrument (LI-6400XT), the natural light intensity was measured first on the measurement day. In order to avoid the influence of daily variation of different parameters (Chen and Xu, 2006; Xu and Shen, 2005; Xu, 2006) on the comparability of measurement results, measurement was carried out at 14:00 pm in 2019 (intensive observation at 10:00 am, 12:00 pm, 16:00 pm and 18:00 pm on dry hot wind days) and in 2020 the measurement was carried out right after the dry hot wind stress experiment. Three repeated measurements were carried out for each winter wheat cultivars. After these measurements, cut five leaves and weighed the fresh weight. Then weighed the dry weight after treatment at 120°C for 20 minutes and drying at 80°C for 10 hours in the oven. Then the relative water content (RWC) of the leaves is calculated by the following formula:

$$RWC = \frac{(\text{Fresh Weight} - \text{Dry Weight}) * 100\%}{\text{Fresh Weight}} \quad (1)$$

The stress of dry hot wind on each parameter is calculated by the following formula:

$$SI = \frac{|n_b - n_a|}{n_a} \times 100\%$$

(2)

Where,  $n_b$  is the value observed after the dry hot wind stress,  $n_a$  is the value without stress; if  $n_b > n_a$ , it indicates that there is no significant negative impact on crops after the dry hot wind stress. The greater the SI value is, the stronger the stress is.

F-test and correlation method were used to analyze the response of different winter wheat cultivars to dry hot wind. Table 2 shows the significance test results of photosynthetic physiological parameters measured in 2019.

Table 2  
Significant test of photosynthetic physiological parameters of different winter wheat cultivars

Date	HN6119			GY5218			JM325		
	Pn	Tr	Gs	Pn	Tr	Gs	Pn	Tr	Gs
5/21–5/22	**	---	**	---	*	---	---	**	---
5/22–5/23	---	---	---	---	**	**	**	**	**
5/23–5/24	---	**	---	*	**	**	*	**	---
5/24–5/28	*	---	**	**	---	**	**	**	**
5/28–5/31	**	**	**	**	**	**	**	**	**

Note: ---, \*, \*\* indicate that F test is not significant,  $P < 0.05$  and  $P < 0.01$  respectively.

## 3 Results

### 3.1 Differences in the Responses of Net Photosynthetic Rate ( $P_n$ ) of Different Winter Wheat Cultivars

Figure 1a is the change curve of  $P_n$  ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) of each cultivar from May 21st to May 31st. As shown in Fig. 1a and Table 2,  $P_n$  value of HN6119 showed a decrease trend from May 21st to May 28th and an increase trend from May 28th to May 31st. F test result of HN6119 was extremely significant from May 21st to May 22nd, and May 28th to May 31st, significant from May 24th to May 28th.  $P_n$  value of GY5218 showed no obvious change from May 21st to May 23rd and showed significant decrease from May 23rd to May 24th and extremely significant decrease from May 24th to May 31st.  $P_n$  value of JM325 showed increase trend from May 21st to May 23rd, and the change trend after May 23rd is similar to GY5218. F test result of JM325 was extremely significant from May 22nd to May 23rd.

Under the influence of dry hot wind, the variation characteristics of  $P_n$  showed differences among cultivars, which indicating that the responses of different cultivars to dry hot wind were different. For HN6119, the  $P_n$  on May 21st was in a high level; when happened, the crop responded to the dry hot wind by decreasing the  $P_n$ . While it showed a significant increase trend during May 28th to May 31st during the recovery time after dry hot wind conditions, it

indicates that dry hot wind had little effect on it. For GY5218, the  $P_n$  on May 21st also was in a high level; when dry hot wind happened, it showed no significant change and remained in a high level; when dry hot wind ended, there were no signs of recovery and showed a significant decrease trend, it indicates that dry hot wind had effect on it. For JM325, when dry hot wind happened, the crop responded to it by increasing the  $P_n$ ; when dry hot wind ended, there were no signs of recovery and showed a continuous decrease trend, it indicates that dry hot wind had effect on it too.

Figure 1b is the daily variation curve of  $P_n$  on the day suffering from dry hot wind. For HN6119, the daily change curve of  $P_n$  showed a bimodal pattern on the May 22nd, with peaks at 10:00 am and 16:00 pm respectively; which indicated that mild dry hot wind had no obvious effect on this cultivar. It is similar to the observation showed in the previous literature (Xu, 1984). On May 23rd,  $P_n$  still reached a higher level at 10:00 am, but followed with a continuous decrease when the temperature increased as showed in Table 1, and no peak appeared at 16:00, which indicated that severe dry hot wind had significant effect on this cultivar. For GY5218 and JM325, peak of  $P_n$  showed at 12:00 pm On May 22nd ; the peak time showed a significant difference from the previous literature (Xu, 1984). It indicates that the mild dry hot wind had a certain effect on these cultivars, but it was not severe. On May 23rd,  $P_n$  also reached a higher level at 10:00 am, and the change afterwards is similar to HN6119, which indicated that severe dry hot wind had caused damage to these cultivars.

Therefore, the characteristics differences of  $P_n$  among different cultivars showed that the resistance to dry hot wind of HN6119 is strong, while the resistance to dry hot wind of GY5218 and JM325 is weak.

## 3.2 Differences in the Responses of Transpiration Rate ( $T_r$ ) of Different Winter Wheat Cultivars

Figure 2a is the change curve of  $T_r$  ( $\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$ ) of each winter wheat cultivar from May 21st to May 31st. As shown in Fig. 2a and Table 2,  $T_r$  value of HN6119 showed a decrease trend from May 21st to May 28th, and an increase trend from May 28th to May 31st. F test result of HN6119 was extremely significant from May 23rd to May 24th, and May 28th to May 31st. The change trend of GY5218 and JM325 is similar, both showed continuous increase from May 21st to May 23rd, significant decrease from May 23rd to May 24th and May 28th to May 31st. The increase trend of GY5218 and JM325 from May 21st to May 23rd is significantly different, but the decrease trend is almost the same, the overall change trend from May 23rd to May 31st is decreasing.

Under the influence of dry hot wind, the variation characteristics of  $T_r$  showed differences among cultivars, which indicating that the responses of different cultivars to dry hot wind were different. For HN6119, the variation characteristics of  $T_r$  is similar to  $P_n$ , the crop responded to the dry hot wind by decreasing the  $T_r$ , it indicates that dry hot wind had little effect on it. For GY5218 and JM325, the crop responded to the dry hot wind by increasing the  $T_r$ ; when dry hot wind ended, it showed a significant decrease trend, it indicates that dry hot wind had effect on it. The value of  $T_r$  was closely related to the amount of water loss in leaves. According to the difference of relative water content of leaves on the first day (May 24th ) after dry hot wind and the day (May 21st ) before dry hot wind, the relative water content of HN6119, GY5218, and JM325 decreased by 0.24%, 1.94%, and 3.71% respectively. It indicated that the  $T_r$  decrease of HN6119 resulted in less water reduction of leaves, while the  $T_r$  increase of GY5218 and JM325 resulted in more water loss from leaves.

Figure 2b is the daily variation curve of  $T_r$  on the day suffering from dry hot wind. For HN6119,  $T_r$  remained a low level from the beginning and showed a continuous decrease on the day suffering from severe dry hot wind. For GY5218 and JM325,  $T_r$  remained a high level from the beginning, and showed the peak at 12:00 pm on May 23rd. The results showed that when affected by dry hot wind the  $T_r$  of HN6119 was decreased in order to reduce the water loss of leaves; while  $T_r$  of GY5218 and JM325 was increased leading to the increased water loss of leaves.

Therefore, the characteristics differences of  $T_r$  among different cultivars showed that the resistance to dry hot wind of HN6119 is strong, while the resistance to dry hot wind of GY5218 and JM325 is weak.

### **3.3 Differences in the Responses of Stomatal Conductance ( $G_s$ ) of Different Winter Wheat Cultivars**

Figure 3a shows the change curve of  $G_s$  ( $\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$ ) of each winter wheat cultivars from May 21st to May 31st. It shows that the variation tendency  $G_s$  of different cultivars was significantly different. For HN6119,  $G_s$  showed a decreasing trend from May 21st to May 28th, and an increase trend from May 28th to May 31st. The variation characteristic is similar to  $P_n$  and  $T_r$ , and the significant changes were observed from May 21st to May 22nd, May 24th to May 28th and May 28th to May 31st. For GY5218 and JM325, the variation characteristic is similar, both showed a very significant increase trend from May 22nd to May 23rd and a decreasing trend after May 23rd. However, the significant decrease was showed in different period for GY5218 and JM325 as it is showed in Table 2.

Under the influence of dry hot wind, the variation characteristics of  $G_s$  showed the responses of different cultivars to dry hot wind is different. For HN6119, the crop responded to the dry hot wind by decreasing the  $G_s$ .  $G_s$  was recovered during the recovery time after dry hot wind conditions, it indicates that dry hot wind had little effect on it. For GY5218 and JM325, the crop responded to the dry hot wind by increasing the  $G_s$ ; when dry hot wind ended, it showed a continuous decrease trend and no signs of recovery, it indicates that dry hot wind had effect on it.

From Fig. 3b, it can be seen that  $G_s$  of HN6119 remained a low level from the beginning, which was consistent with the variation characteristic of  $P_n$  and  $T_r$ . HN6119 showed strong resistance to dry hot wind by reducing the stomatal conductance to reduce  $T_r$  and  $P_n$ , in order to reduce the damage caused by dry hot wind. For GY5218 and JM325,  $G_s$  remained a high level when affected by dry hot wind, which was consistent with the variation characteristic of  $T_r$ . However, the increase of  $G_s$  and  $T_r$  at 12:00 pm, 14:00 pm, and 16:00 pm on the day affected by severe dry hot wind was significant than the increase of  $P_n$ . It indicates that the increase of  $T_r$  did not cause the response of  $P_n$ , only increased the water loss of leaves, so the resistance to dry hot wind of GY5218 and JM325 is weak.

Therefore, the characteristics differences of  $G_s$  among different cultivars showed that the resistance to dry hot wind of HN6119 is strong, while the resistance to dry hot wind of GY5218 and JM325 is weak.

### **3.4 Differences in the Responses of Photosynthesis Physiological Parameters of Different Winter Wheat Cultivars**

In order to discern the differences in the responses to dry hot wind of each cultivar, the intensive observation was carried out on the day before affected by dry hot wind, the first day after affected by dry hot wind and the day

affected dry hot wind. The data were used to analyze the correlation differences of the photosynthesis physiological parameters of three cultivars.

Table 3  
Correlation coefficient test of photosynthetic physiological parameters of different winter wheat cultivars

DATE		HN6119		GY5218		JM325	
		P <sub>n</sub>	T <sub>r</sub>	P <sub>n</sub>	T <sub>r</sub>	P <sub>n</sub>	T <sub>r</sub>
5/21	T <sub>r</sub>	0.912***		0.781***		0.905***	
	G <sub>s</sub>	0.891***	0.957***	0.862***	0.964***	0.874***	0.993***
5/22	T <sub>r</sub>	0.971***		0.952***		0.837***	
	G <sub>s</sub>	0.993***	0.973***	0.928***	0.997***	0.852***	0.996***
5/23	T <sub>r</sub>	0.981***		0.756**		0.473	
	G <sub>s</sub>	0.989***	0.998***	0.707**	0.997***	0.531	0.998***
5/24	Tr	0.991***		0.861***		0.990***	
	G <sub>s</sub>	0.993***	0.999***	0.876***	0.999***	0.992***	0.999***

Note: \*, \*\* and \*\*\* indicate that the correlation coefficient test reaches the significance level of 0.05, 0.01, and 0.001 respectively.

As shown in Table 3 (intensive observations not included), the correlation coefficients of T<sub>r</sub> and G<sub>s</sub> of three cultivars on all measurement date showed significant positive correlation ( $P < 0.001$ ); the correlation coefficients of P<sub>n</sub>, T<sub>r</sub> and G<sub>s</sub> before and after suffering from dry hot wind also showed significant positive correlation ( $P < 0.001$ ). While the correlation coefficient tests of P<sub>n</sub>, T<sub>r</sub> and G<sub>s</sub> on the day suffering from dry hot wind were different. For HN6119, the correlation coefficients at all measurement time showed significant positive correlation ( $P < 0.001$ ). For GY5218, the correlation coefficients significant level declined ( $P < 0.05$ ). For JM325, the correlation coefficients showed significant positive correlation except the correlation coefficients of P<sub>n</sub> and T<sub>r</sub> at 16:00 pm and 18:00 pm on May 22nd and the correlation coefficients of P<sub>n</sub>, T<sub>r</sub> and G<sub>s</sub> at 14:00 pm and 16:00 pm on May 23rd. The correlation coefficients between some parameters showed nonsignificant correlation, it is closely related to the effect of dry hot wind. According to the hourly meteorological element values, the dry hot wind lasted from 13:00 pm to 18:00 pm on May 22nd and lasted from 13:00 pm to 17:00 pm on May 23rd. The correlation of P<sub>n</sub> and T<sub>r</sub> of JM325 was affected by the dry hot wind at 16:00 pm on May 22nd and continued to be affected until May 23rd. The affection on correlation of P<sub>n</sub> and T<sub>r</sub> was exacerbated when a severe dry hot wind occurred as the temperature reached 35.7 °C at 14:00 pm and 37.1 °C at 15:00 pm on May 23rd and affected the correlation of P<sub>n</sub> and G<sub>s</sub>. The difference in correlation of these parameters discerned that HN6119 showed better self-stability when affected by dry hot wind, the correlation coefficients of P<sub>n</sub> and T<sub>r</sub> showed significant correlation. The metabolism balance was not disturbed and still maintain normal regulation. For GY5218 and JM325, the correlation coefficients of P<sub>n</sub>, T<sub>r</sub> and G<sub>s</sub> showed poor correlation when affected by dry hot wind, which indicated that the regulation effect had been disrupted.

It can be seen from the correlation analysis that HN6119 showed strong resistance to dry hot wind, while JM325 and GY5218 showed weak resistance to dry hot wind.

### 3.5 Difference in the Test of Resistance to Dry Hot Wind of Different Winter Wheat Cultivars

As the dry hot wind is sporadic, in order to recover the deficiency of natural dry hot wind samples, the dry hot wind stress simulation experiment was carried out in 2020 and the samples were used to verify the reliability of above conclusions. Table 4 shows the stress value of photosynthesis physiological parameters of each cultivar after dry hot wind stress.

Table 4  
SI (%) of photosynthesis physiological parameters of different winter wheat cultivars

Stress treatment		HN6119			GY5218			JM325		
		P <sub>n</sub>	T <sub>r</sub>	G <sub>s</sub>	P <sub>n</sub>	T <sub>r</sub>	G <sub>s</sub>	P <sub>n</sub>	T <sub>r</sub>	G <sub>s</sub>
5/23	Mild	14	43	54	27	56	66	37	56	65
5/24	Mild	–	15	17	16	49	35	24	47	37
	Severe	49	50	46	51	45	42	71	56	57
5/25	Severe	26	46	36	31	48	35	40	42	21
5/26	Mild	–	8	16	8	19	32	4	41	54
5/27	Severe	–	27	30	21	47	46	29	48	57

Note: –indicates that  $n_b > n_a$ , there is no significant impact after the dry hot wind stress.

As shown in Table 4, for HN6119, the variation characteristics of parameters under mild and severe dry hot wind are similar, the stress value reached the highest level on the day suffering from dry hot wind and then showed a decrease trend, especially P<sub>n</sub> showed the highest decreasing speed, the stress value reached the control level on the first day after mild dry hot wind stress and third days after severe dry hot wind stress. The stress value of mild and severe dry hot wind on thousand kernel weight (TKW) was 0.01% and 0.36% respectively, indicating that dry hot wind had little damage to HN6119 and showed the characteristics of resistance to dry hot wind.

For GY5218 and JM325, P<sub>n</sub> showed the most significant variation characteristics, the stress value showed a decrease trend, but the stress value still didn't reach the control level on the third days after dry hot wind stress. T<sub>r</sub> and G<sub>s</sub> showed no obvious consistent variation characteristics after dry hot wind stress. The stress value was still in a high level on the third days after dry hot wind stress, indicating that dry hot wind had caused damage to the crop. The stress value of mild and severe dry hot wind on thousand kernel weight (TKW) was 3.51%, 3.57% for GY5218, and 8.12%, 8.84% for JM325, respectively. It indicated that GY5218 and JM325 showed weak resistance to dry hot wind.

Under the influence of simulated dry hot wind, the experimental parameters can't be measured, so the analysis procedure of 2020 is different from 2019. However, the results obtained by two experiment methods are consistent, indicating that the conclusion of "HN6119 showed strong resistance to dry hot wind, while JM325 and GY5218 showed weak resistance to dry hot wind" is credible.

## 4 Discussion And Conclusion

## 4.1 Discussion

Under the combined conditions of field natural dry hot wind and artificially simulated dry hot wind experiments, differences in the responses of physiological parameters such as photosynthesis and transpiration were analyzed, in order to discern the differences in the responses to dry hot wind of each cultivar.

In this study, it was found that the cultivar with strong resistance to dry hot wind showed stronger stomatal regulation ability on the natural dry hot wind day. Through stomatal conductance adjustment, the transpiration rate and leaf water loss were reduced in order to avoid serious damage to plants. The physiological functions could be gradually recovered after the end of dry hot wind. While the cultivar with weak resistance to dry hot wind showed more water loss of leaves by increasing the stomatal conductance and transpiration rate, and the physiological parameters showed significant decrease and no signs of recovery when the dry hot wind ended. As shown in the previous literature (Xu, et al. 1984), the transpiration intensity and stomatal aperture under dry hot wind conditions were observed, the results showed that dry hot wind increased the transpiration intensity and stomatal aperture, which resulted in water loss of leaf cells. It is consistent with the response of cultivars with weak resistance to dry hot wind on hot wind day in this study. However, the conclusion in the previous literature was for a certain cultivar, it didn't discern the response of cultivars with stronger resistance to dry hot wind on the day suffering from dry hot wind. Few research results about the recovery of physiological functions after suffering from dry hot wind were mentioned in previous literature.

This study shows that physiological parameters of cultivars with strong resistance to dry hot wind could maintain a significant positive correlation when affected by dry hot wind, new balance would be established between the parameters, it indicates that these cultivars have better self-regulation ability. While physiological parameters of cultivars with weak resistance to dry hot wind showed worse correlation when affected by dry hot wind, especially the severe dry hot wind. It indicates that the regulation function of the plant was damaged and affected the normal physiological functions such as photosynthesis and transpiration. This finding has not been involved in previous studies.

In this study, the photosynthetic physiological parameters of different cultivars under the condition of natural dry hot wind were measured on different dates. The results show that the net photosynthetic rate, transpiration rate and stomatal conductance of three cultivars all decreased on the first day after the end of dry hot wind. Under the condition of artificial simulated dry hot wind, the photosynthetic physiological parameters of different cultivars all decreased compared with the value without stress, it indicates that dry hot wind has retarding effect on photosynthetic physiological parameters. As shown in the previous literature (Zhao, et al. 2013), under the condition of artificial simulated dry hot wind, the photosynthetic transpiration of wheat flag leaves at grain filling stage were significantly retarded and caused partial closure of stomata, while a similar study (Zhang, et al. 2015) showed that the net photosynthetic rate, transpiration rate, and stomatal conductance of wheat flag leaves on the first day after suffering from dry hot wind were lower than the control group. The conclusion is similar to our study. As shown in the previous literature (Zhao, et al. 2013), the observation of stomatal opening and closing and the determination of transpiration intensity under artificial simulated dry hot wind experiment condition were performed, the results showed that the maximum value of stomatal opening of cultivars with no resistance to dry hot wind showed a trend of earlier appearance, the duration was significantly prolonged and the transpiration intensity had no significant change. The maximum value of stomatal opening of cultivars with strong resistance to dry hot wind showed no significant change, and the transpiration intensity had a significant trend of decreasing. There were

some differences with the conclusions of this study, which may be related to the difference in resistance of cultivars.

In conclusion, the environmental factors such as CO<sub>2</sub> concentration and soil moisture of each measurement date were consistent in this study.

## 4.2 Conclusion

The experimental result in a condition of natural dry hot wind conditions in 2019 showed that:

(1) the similarities in the impacts of dry hot wind on photosynthetic physiological parameters of different cultivars: the net photosynthetic rate, transpiration rate, and stomatal conductance of all cultivars showed decreasing trend on the first day after suffering from day hot wind; the differences: the net photosynthetic rate, transpiration rate, and stomatal conductance of HN6119 was recovered during the recovery time after dry hot wind conditions, while GY5218 and JM325 still showed a continuous decrease trend;

(2) there were differences in responses of different cultivars to dry hot wind; HN6119 showed less water loss of leaves by reducing the stomatal conductance and transpiration rate, indicating that HN6119 showed the characteristics of resistance to dry hot wind. GY5218 and JM325 showed more water loss of leaves by increasing the stomatal conductance and transpiration rate, both stomatal conductance and transpiration rate significantly decreased when the dry hot wind ended, indicating that GY5218 and JM325 were damaged and showed weak resistance to dry hot wind;

(3) both the correlation coefficients of  $T_r$  and  $G_s$  on all measurement date and the correlation coefficients of  $P_n$ ,  $T_r$  and  $G_s$  on the day without dry hot wind for three cultivars showed significant positive correlation ( $P < 0.001$ ); the correlation coefficients of  $P_n$ ,  $T_r$ , and  $G_s$  for HN6119 at all measurement time on the day suffering from dry hot wind showed significant positive correlation, the correlation coefficient significant level for GY5218 declined; the correlation coefficients of  $P_n$  and  $T_r$  for JM325 showed nonsignificant correlation at 16:00 pm and 18:00 pm on May 22nd, and also the correlation coefficients of  $P_n$ ,  $T_r$ , and  $G_s$  at 14:00 pm and 16:00 pm on May 23rd. It indicated that HN6119 showed better self-stability when affected by dry hot wind, and the metabolism balance was not disturbed and still maintain normal regulation, while the regulation effect of GY5218 and JM325 had been disrupted;

(4) the difference in characteristics and difference in correlation of  $P_n$ ,  $T_r$  and  $G_s$  among different cultivars showed that HN6119 showed strong resistance to dry hot wind, while JM325 and GY5218 showed weak resistance to dry hot wind.

The results of artificially simulated dry hot wind experiment in 2020 showed that the stress of severe dry hot wind on thousand kernel weight (TKW) of HN6119, GY5218 and JM325 is 0.01%, 3.51%, 3.57%, respectively. The stress of mild dry hot wind on thousand kernel weight (TKW) of HN6119, GY5218 and JM325 is 0.36%, 8.12%, 8.84%, respectively.

In conclusion, HN6119 showed strong resistance to dry hot wind, while JM325 and GY5218 showed weak resistance to dry hot wind.

## 5 Declarations

## Conflict of Interests

The authors of this article declare that there is no conflict of interests regarding the publication of this article. The authors of the manuscript do not have a direct financial relation that might lead to a conflict of interest for any of the authors.

## Fundings

We thank the anonymous reviewers for their valuable comments and suggestions. This study was supported by National Key Research and Development Plan Grant No.2017YFD0300906 and Basic Research Project of Hua Feng Meteorological Media Group (Grant No.CY-J2020003)

## Author's Contribution

Corresponding author Chunqiang Li and Rongwei Liao are co-corresponding author contributed to this work equally. main research ideas and article structure organization, manuscript revision and important suggestions.

Xiyan Kang and Zhangyan Le are co-first authors. Xiyan Kang and Zhangyan Le are co-first authors contributed to this work equally. original draft, data processing.

Liqin Dai, Chang Quan and Minghua Shi: data calculation.

## Availability of data and material

We understand that our manuscript and associated data and material will be shared for the delivery of the author dashboard.

## Code availability

Our data and codes support the findings of this study and can be obtained from the corresponding author if necessary.

**Ethics approval** This study did not involve ethical issues.

**Consent to participate** This research has been approved by all authors and signed on the signature.

**Consent for publication** The authors agree to the publication of this research and the copyright statement.

## Acknowledgments

We thank the anonymous reviewers for their valuable comments and suggestions. This study was supported by National Key Research and Development Plan Grant No.2017YFD0300906 and Basic Research Project of Hua Feng Meteorological Media Group (Grant No.CY-J2020003)

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## Figures

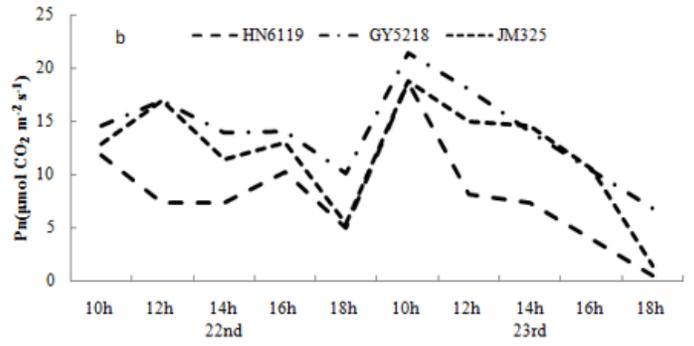
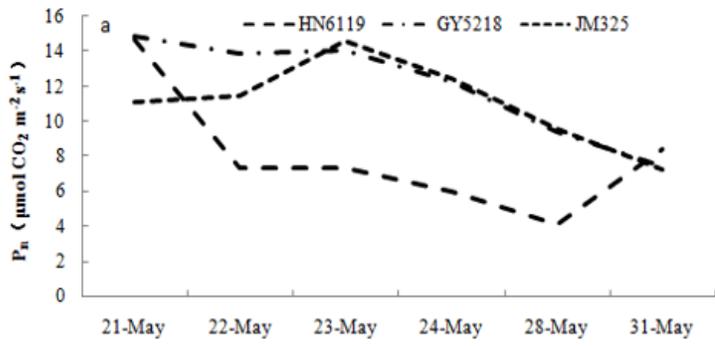


Figure 1

Pn Change curves of different winter wheat cultivars affected by dry hot wind.

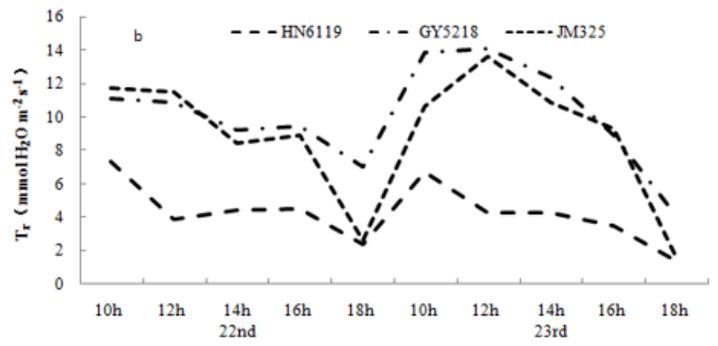
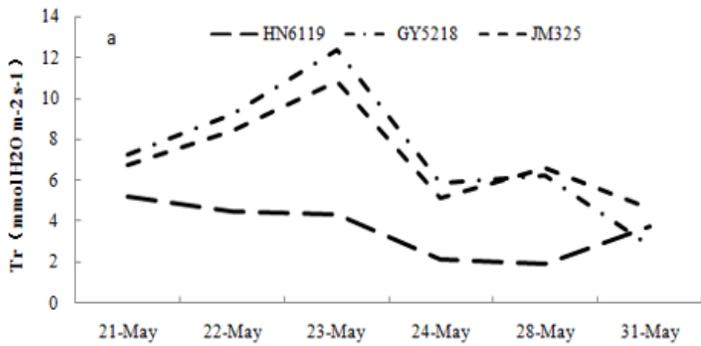


Figure 2

Tr Change curves of different winter wheat cultivars affected by dry hot wind

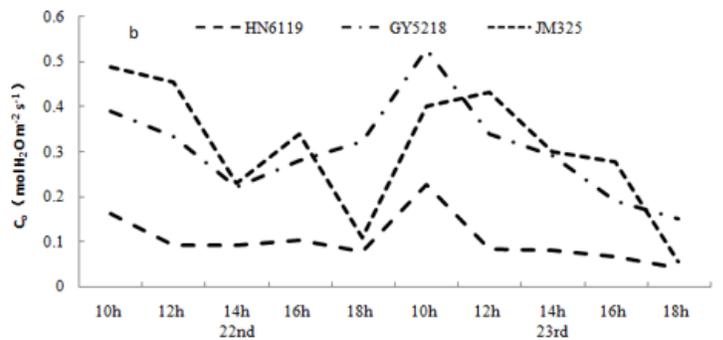
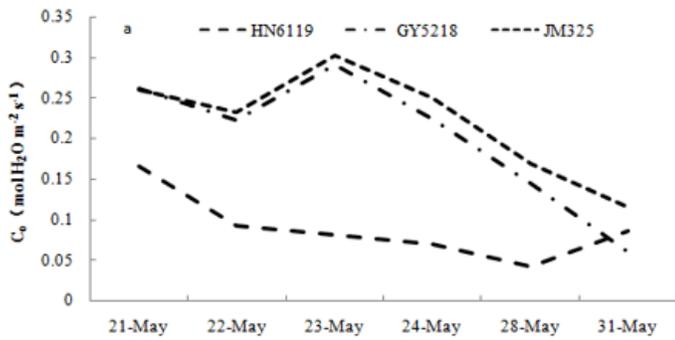


Figure 3

Change curves of Gs at different winter wheat cultivars affected by dry hot wind