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RESEARCH ARTICLE

Evaluation of a new method for quantification of heat tolerance in different wheat cultivars

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Abstract

Heat stress seriously affects wheat production in many regions of the world. At present, heat tolerance research remains one of the least understood fields in wheat genetics and breeding and there is a lack of effective methods to quantify heat stress and heat tolerance in different wheat cultivars. The objective of this study was to use various wheat cultivars to evaluate stress intensity (δ) and a new method for quantification of heat tolerance and compare this technique with three other currently utilized methods. This new parameter for heat tolerance quantification is referred to as the heat tolerance index (HTI) and is an indicator of both yield potential and yield stability. Heat treatments were applied in a controlled setting when anthesis had been reached for 80% of the wheat. The stress intensity evaluation indicated heat shock was the main factor associated with kernel weight reduction while grain yield reduction was mainly associated with chronic high temperature. The methods evaluation showed that a temperature difference of 5°C from natural temperatures was a suitable heat treatment to compare to the untreated controls. HTI was positively correlated with yield under heat stress (r=0.8657, δ_{2010}=0.15, in 2009–2010; r=0.8418, δ_{2011}=0.20, in 2010–2011; P<0.01), and negatively correlated with yield reduction rate (r=–0.8344, in 2009–2010; r=–0.7158, in 2010–2011; P<0.01). The results of this study validated the use of HTI and temperature difference control for quantifying wheat heat tolerance that included the yield potential and the stability of different wheat cultivars under heat stress. Additionally, 10 wheat cultivars showed high HTI and should be further tested for their heat confirming characteristics for use in wheat heat tolerance breeding.

Keywords: wheat breeding, heat tolerance quantification, HTI, temperature difference controlling, stress intensity

1. Introduction

Extreme weather events in recent years have become frequent due to global warming. Heat waves and increased temperatures have become especially damaging, causing major decreases in crop yields (Gooding *et al*. 2003; Hoffmann *et al*. 2006; Figueiredo *et al*. 2015). Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world. As climates warm, heat stress during the post-anthesis period (terminal heat) has negatively

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affected wheat production. This increased temperature not only hastens the phenological stages of wheat development but also reduces the duration of the grain filling stages, thereby lowering grain yield and quality (Farooq *et al*. 2011). Wheat yield losses at this rate severely threaten national food security. According to Wiegand and Cuellar (1981), 1°C increases from mean daily air temperatures between 15.8–27.7°C during wheat development would shorten the grain filling period by 3.1 days and decrease the weight per grain by as much as 2.8 mg. Two different cultivars in two cropping systems were used in the aforementioned study and the effect of temperature was quantified by a regression equation. Here, we measured the effect of temperature on yield and kernel weight in 48 winter wheat cultivars. The effect of temperature variation on these two wheat quality characteristics were easily measured and still informative. Research on heat tolerance remains one of the most limited understandings in wheat genetics and breeding. This is mainly due to the lack of effective methods to quantify heat stress and heat tolerance in wheat cultivars. Currently, heat stress quantification methods have been utilized under different stress temperatures (i.e., 42°C, Tewari and Tripathy 1998; 45°C, Sharkey 2005; 40°C, Allakhverdiev *et al*. 2008). In this study, we used stress intensity for temporary analysis to offer more detailed research on temperature ranges for heat stress.

Many plant physiological processes are often measured as a gauge for heat tolerance phenotypes. One process is tetrazolium triphenyl chloride reduction, and is related to early heading high temperature index and stay-green, three phenotypes that may be used as heat tolerance indicators (Towill and Mazur 1974; Xu *et al*. 2000; Rane and Nagarajan 2004; Tewolde *et al*. 2006). However, there is no direct evidence elucidating the correlation between these processes and wheat cultivar yield. Other characteristics like photosynthetic rate, leaf chlorophyll content, canopy temperature depression, membrane stability, and flag-leaf stomata conductance may be correlated with field performance, especially with grain filling under heat stress (Reynolds *et al*. 1994, 1998; Amani *et al*. 1996; Blum *et al*. 2001). These characteristics may be used to select or screen wheat germplasm resources for heat tolerance. However, their numerical values cannot completely reflect the heat tolerance among different wheat cultivars. The ultimate indicator of cultivar-specific heat tolerance is manifested in the absolute yield and relative yield, that is, both yield potential and yield stability. An ideal cultivar-specific heat tolerance would exhibit a durable, consistent yield with the minimal yield reduction (YR) under heat stress conditions.

The aim of this study was to use various wheat cultivars to evaluate a new method for heat tolerance quantification and compare it to three established methods. We designed a portable greenhouse with temperature control for our experimental purposes. Using this design, we proposed a new measurement for heat tolerance that we designated the heat tolerance index (HTI). The results indicated that HTI calculated by yield and YR significantly correlated with cultivar-specific wheat yield and YR under heat stress. The new quantification method combining yield potential and yield stability could be a useful selection method for characterizing cultivar performance under heat stress.

2. Materials and methods

2.1. Cultivars

A total of 48 winter wheat (*Triticum aestivum* L.) cultivars (Table 1) in the North China Plain were evaluated for heat tolerance. These cultivars were mechanically sown by WINTERSTEIGER (Australia) at the research station in Hengshui City, Hebei Province (37°44´N, 115°42´E; elevation 20 m above mean sea level). A commonly used control wheat cultivar in Hebei Province regional experiments, Heng 4399, was selected as the control cultivar in this study.

The experiment was conducted on sandy loam soil in field conditions. A split block design with three replicates and two treatments was employed during the 2009–2010 and 2010–2011 crop seasons. Each cultivar was grown in a plot size of 11.16 m^2 (nine rows of 8 m length with 15.5 cm space between rows). After making an adjustment for seed size, the seed rate was maintained at a uniform population of 300 plants m^{-2} (3 million plants per hectare), according to

Table 1 The 48 winter wheat cultivars evaluated in this study

No.	Cultivar	No.	Cultivar	No.	Cultivar	No.	Cultivar	No.	Cultivar	No.	Cultivar
1	Nongda 211	9	CA0548	17	Heng 6632	25	Shi 4185	33	08CA95	41	Jimai 20
2	Nongda 212	10	CA0629	18	Hengguan 216	26	Shi 6207	34	08CA190	42	Jimai 22
3	Nongda 3432	11	CA0518	19	Heng 4399	27	02Ky119	35	Han 6228	43	DH155
4	Nongda 3492	12	Jingdong 8	20	Hengguan 33	28	Shi 8	36	Shannong 2149	44	67257
5	Nongda 3634	13	Zhongyou 206	21	Hengguan 35	29	Shi B07-4056	37	05CA349	45	Yannong 19
6	Nongda 413	14	Zhongmai 175	22	Heng 07-5114	30	Shimai 15	38	05CA306	46	56487
7	Nongda 189	15	CA0415	23	Heng 07-5205	31	Shiyou 17	39	55319	47	Jimai 6097
8	Nongda 318	16	Heng 4422	24	Shixin 733	32	Shi 05-6678	40	Jimai 19	48	Jimai 7251