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Simulating the effect of terminal drought stress by potassium iodide and its use in mapping QTLs for yield and yield components in bread wheat

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Abstract

Terminal drought is the most important and dominating stress in areas of wheat cultivation with Mediterranean climates as prevails in Iran. However, evaluation of plants response to natural drought is difficult due to lack of uniform drought stress in the field. Successful experiments of simulating the effect of terminal drought by chemical desiccants like potassium iodide (KI) during grain filling have already been reported. In the present work we evaluated a mapping population of 118 F2:7 recombinant inbred lines (RILs) from a cross between a typical Iranian drought tolerant landrace *Tabassi* and a highly bred and non-drought tolerant European wheat variety *Taifun* for yield and yield component QTLs in three drought stress environments i.e. (1) under natural post anthesis drought stress in Iran, (2) under drought conditions provided by an electro automated shelter in Hungary, and (3) under a potassium iodide induced post anthesis drought applied in Austria. In this paper, the efficiency of KI treatment to simulate the effect of post anthesis drought and its utilization for QTL mapping in comparison with a natural drought stress is discussed.

Keywords: land race, post anthesis drought, recombinant inbred lines (RILs), Quantitative trait loci (QTL), Wheat.

Introduction

Drought tolerance is a particularly difficult trait for molecular mapping since measuring tolerance with the same precision, as e.g. scoring resistance to a diseases or a morphological trait, is not possible. Screening for tolerance to drought under natural conditions is most unreliable due to lack of uniform drought stress in the field which renders screening ineffective limiting selection progress (Singh 2002). Moreover, testing drought tolerance experimentally by controlling field environment is expensive.On the other hand, for QTL mapping, accurate field phenotyping is crucial, for this reason appropriate data under drought on stress pattern in terms of time, duration, and severity has to be collected. CIMMYT defines three distinct drought stress patterns: (A) pre-flowering stress, (B) grain-filling stress, and (C) continuous or seasonal stress (Reynolds et al. 2005). Grain filling stress, or so-called terminal (end-season or post-anthesis) drought, is the most common drought stress in many cultivation areas of wheat like in Iran (Golabadi et al. 2006).
Grain development in wheat depends on three sources:

- Carbohydrates produced after anthesis and translocated directly to the grains,
- carbohydrates produced after anthesis, but stored temporarily in the stem before being re-mobilized to the grains, and
- Carbohydrates produced before anthesis, stored mainly in the stem, and remobilized to grains during grain filling (Ehdaie et al. 2006).

Under terminal drought, a rapid decline of photosynthesis after anthesis limits the contribution of current assimilates to the grain (Johnson et al. 1981). Flag leaf photosynthesis alone cannot support both respiration and grain growth under terminal stress (Rawson et al. 1983). Therefore, a substantial amount of the carbohydrates used during grain filling, must come from reserves assimilated before anthesis (Gent 1994). While root storage is important in some legumes and other species, there is no evidence that roots or leaves are as important as stems for reserve storage in small grained species (Blum 1998). Therefore, in dry areas wheat yield may highly depend on stem reserves used for grain filling, which do not play a significant role under well-watered conditions.

To what extend stored reserves in the stem may contribute to grain yield in wheat depends on plant's ability to store assimilates in the stem, and on the efficiency with which the stored reserves are mobilized and translocated to the grain. The latter is indeed a function of the genotype's sink strength, which depends on the number of grains per spike and grain weight (Ehdaie and Waines 1996).

The capacity of stem reserve utilization for grain filling, when the photosynthetic source is completely inhibited by stress, can be assessed by destroying the photosynthetic source at the onset of grain filling. Grain weight, with no current photosynthesis, is then measured in comparison with normal plants (Blum 1998). Spraying the plants with an oxidizing chemical, such as magnesium chlorate or potassium iodide (KI), destroys the photosynthetic sources. The chemical is applied by spraying the whole plant, or just the leaf canopy, about two weeks after anthesis. Spraying is therefore scheduled according to the different dates of anthesis of different genotypes. Non-treated control plants are required. Capacity of stem reserve support of grain filling is measured by the difference in final kernel weight between treated and non treated plants of any given genotype. While the chemical desiccant does not simulate drought stress, the effect of stress is simulated by inhibiting current assimilation. Correlation between the rate of reduction in grain weight by chemical desiccation and the rate of reduction by actual drought stress was found to be significant and reasonably high (Blum et al. 1993b, Nicolas and Turner 1993). In the present work we report on results of an experiment where chemical desiccation was applied on an F2:7 RIL populations developed from a cross of two wheat genotypes with highly contrasting adaptation.

Materials and Methods

A mapping population of 118 F2:7 inbred lines (RILs) from a cross between a typical Iranian drought tolerant spring wheat landrace *Tabassi*, and a highly bread, non-drought tolerant German spring wheat variety *Taifun* was developed by single-seed descent method. This population was evaluated under different drought stress conditions in three locations: Tulln-Austria, Ilam-Iran, and Szeged-Hungary during the summer 2007. In Iran plants were subjected to natural post anthesis (terminal) drought stress. In Hungary, an electroautomated rain shelter prevented plants to receive any rain after tillering, providing controlled drought stress condition. Finally, in Tulln-Austria, Potassium Iodide (KI), a moderate chemical desiccant, was applied to simulate the effect of post anthesis drought according to Blum 1993b. KI destroys photosynthetic sources in leaves and spikes thus for grain filling no assimilates are available. Plants were labelled at flowering (anthesis) time, and two weeks later, whole plants were sprayed by 0.5 %. KI (Fig. 1).

Figure 1: Spraying plants with Potassium Iodide (KI), two weeks after flowering (anthesis).

Parallel to these drought stress conditions, two more experiments were conducted, one in Tulln-Austria and the other in Szeged-Hungary under non-stress conditions where plant received enough water either by rainfall or by irrigation whenever it was necessary. At all location phenotypic data were collected for seven agronomic traits: total grain yield of 10 spikes (Yld), number of grains of 10 spikes (Gps), thousand kernel weight (Tkw), spike length (Sln), number of spikelet per spike (Sps), plant height (Pht), and ear

emergence time (Eet), as well as three morphologic traits: awnedness, waxyness, and hairy glume. In KI-experiment only total grain yield of 10 spikes, number of grains of 10 spikes, and thousand-kernel weight were measured. Field data were analysed using SPSS version 12.0 (SPSS Inc, 2003).
A total of 202 wheat SSRs together with 3 morphological markers, resulting in 217 polymorphic loci, were used to construct a linkage map (Kordenaeej et al, 2008) with 118 F2:7 lines of the Tabassi x Taifun cross combination, applying JionMap version 3.0 (Stam 1993). This linkage map was used for QTL identification by Windows QTL Carthographer version 2.5 software (Wang et al. 2007) applying composite interval mapping (CIM)-(Zeng 1993, 1994).

Results and Discussion

Drought tolerance can only be evaluated, if drought stress causes significant reduction in yield (Blum 1993a). Indeed, reduction in plant performance is the expected effect of drought stress; different patterns of drought stress are expected to have different effects on yield. Distribution of data for Yld, Gps and Tkw in 118 F2:7 RILs under non-stress conditions in Austria (rectangles in Fig. 2) and under natural post anthesis drought stress in Iran (triangles in Fig. 2) are clearly separated, demonstrating that drought stress resulted in an obvious reduction in Yld and Tkw and interestingly increase in Gps. Similarly, effect of drought stress, induced by KI (Fig. 2) also resulted in a visible differentiation of the F2:7 lines from those under non-stress condition in Austria. The mode of reaction of the plants under the two, natural and induced drought stress conditions were in the same direction.

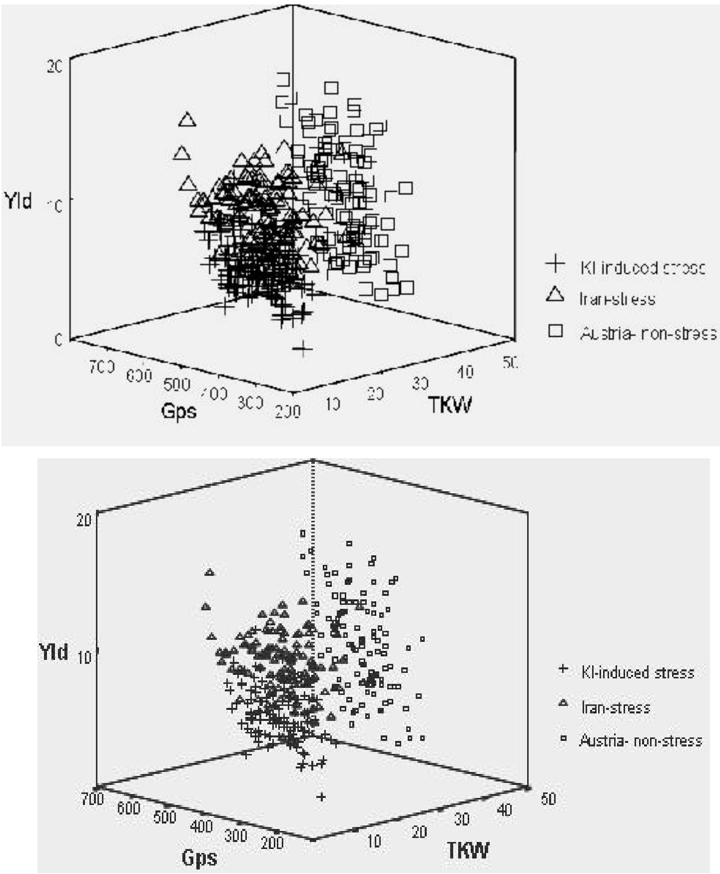

Figure 2: Scatter plot of Yld, Gps and Tkw of the F2:7 population under KI-induced stress condition (+) in comparison to the non-stress and stress conditions in Austria ( ) and Iran (Δ).

Reduction in yield under natural stress and stress induced by chemical desiccants showed ahighly significant correlation (r=0.69). This is in full agreement with data reported by Blum (1993,. and Nicolas and Turner (1993), who found high correlation between the rate of reduction in grain weight by chemical desiccation and the rate of reduction by actual drought stress (Table 1). The comparable high correlations in these three different studies strongly support the assumption that plants' capability of stem reserve remobilization plays a very important role in tolerance to terminal drought stress. Reduction in kernel weight under stress may serve as an indirect selection criterion for grain yield (Sharma et al. 2008).

Table 1: Comparison of correlation coefficients of yield reductions caused by chemicaldesiccation and natural drought stress.

	Chemical desiccant experiments		
	Blum 1993 b	Nicolas and Turner 1993	present study
Natural drought stress	0.81**	0.79**	0.69**

Utilizing data on yield and yield components for QTL identification under artificially induced effect of terminal drought stress by chemical desiccation was not yet reported.

Due to the correlation as well as the similarity of data distribution between the two experiments in Iran and in Tulln, the KI-experiment showed a high reliability for QTL analysis. The number of QTLs, which were identified under drought stress in Iran and in the KI-experiment, is shown in Fig. 3. For the three traits, i.e., Yld, Gps, and Tkw, which were evaluated in both experiments (Kordenaeej 2008), 19 QTLs were found in Iran and 15 in the KI-experiment, indicating a high efficiency of the latter to provide conditions similar to naturally occurring post anthesis drought. Indeed, disregarding the chromosomal locations of the QTLs found in the two experiments which were expected to be different, compared to natural environment, for QTL identification the KI-experiment showed an almost 80% efficiency. For each trait, i.e. Yld, Gps, and Tkw one major QTL was identified having a minimum LOD score of 3, explaining a minimum phenotypic variation of 10 %.

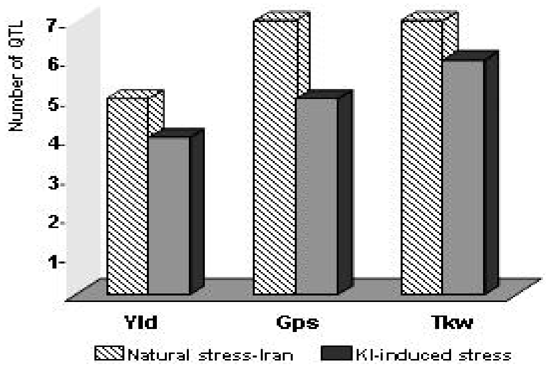

Figure 3: Comparison of the number of QTLs under drought stress in Iran and the KI-experiment.

For example, a major QTL for yield designated as QYld.ifa-3B with an R^2=18.2% was identified in the KI-experiment. Along with this QTL, two minor QYld.ifa-3B were found in the KI- and the Hungary-stress experiments. The three together explain 33.9% of variation for Yld on chromosome 3B. The presence of these QTLs on 3B is in agreement with QTLs for grain weight per spike, which was found under non-stress conditions in previous studies by Huang et al. (2003, 2004) and Sishen et al. (2007). The complete map of all QTLs found under drought and non-drought stress conditions is presented in Kordenaeej (2008) and Kordenaeej et al. (2008).

A major Gps QTL was found in the KI-experiment, explaining 10.8% of phenotypic variation. According to Quarrie et al. (2006) 7A can be considered to be an important chromosome for yield and yield component QTLs under drought stress.

For Tkw, a major QTL is located on chromosome 5A, QTkw.ifa-5A, and was found in the KI experiment. Tkw QTLs found on group 5 chromosomes are in agreement with the results of Börner et al. (2002), Huang et al. (2003), Jun-Ying Su et al. (2006), and Sishen et al. (2007).

Beside these major QTLs, 12 minor QTLs were identified in the KI-experiment. They were confirmed by some QTLs by other experiments of this study (Kordenaeej 2008) and by some previous studies which were mostly carried out under non-stress conditions, e.g. Jun-Ying et al. (2006), Huang et al. (2004), and Querrie et al. (2006).

This study shows that the effect of drought stress during grain filling can be efficiently simulated by chemical desiccation and the resulted data are reliable for QTL mapping.

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