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Durum in a changing climate - drought stress during growing seasons in Syria

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Abstract

Durum wheat is mainly produced under rainfed but often sub-optimal moisture conditions in the Mediterranean basin. In the current study, a mapping population (drought×salt tolerant cultivar) was developed and the progeny examined for their ability to cope with moisture limiting conditions in Syria in two growing seasons. At the beginning of the second growing season, extreme reduced precipitation resulted in an extension of the days to heading and maturity and lead to a highly significant depletion in plant height, yield, harvest index and thousand grain weight. Quantitative trait loci (QTL) analyses revealed 15 highly significant QTL on chromosomes 1B, 2A, 2B, 3A, 4A, 4B, 5A, 5B, 7A and 7B. For grain yield in total five different QTL were found for the two growing seasons. In contrast, highly significant QTL for plant height (LOD=27) appeared on chromosome 4B in both growing seasons and explained a phenotypic variance up to 65%. Summarising, QTL for drought tolerance under 'natural' appearing moisture limiting conditions could be detected in durum wheat. However, strong interactions between genetic and environmental factors will challenge breeding programmes on drought stress for the future.

Keywords

Grain weight, grain yield, plant height, QTL, recombinant inbred lines, *Triticum durum*

Introduction

Durum wheat (*Triticum turgidum* L. var. *durum*), a tetraploid grass, originated in the Fertile Crescent (an area including Iraq, Iran, Eastern Turkey, Syria, Jordan, Israel, Lebanon and the West Bank) and has been farmed in this region for the last 12 000 years (HABASH et al. 2009). Nowadays, more than 34 million tons are produced globally every year which are 6% of the world wheat production. The cultivation area concentrates mainly in the EU (25%), Middle East (19%), North Africa (11%), Canada (11%), Kazakhstan (8%), USA (7%) and Australia (2%). Compared with bread wheat (*Triticum aestivum* L.) durum wheat has a harder endosperm which produces a granular product after milling. This granule, called semolina, is the basis ingredient to make pasta, bread, couscous, frekeh and bulgur (CONNELL et al. 2004).

Premium durum wheat quality is cultivated in the Mediterranean basin although environmental constraints as drought and temperature extremes limit the productivity ranging from 0 to 6 $t \cdot ha^{-1}$ (NACHIT and ELOUAFI 2004, HABASH et al. 2009, CECCARELLI et al. 2010). According to climate models there is a general trend that the Mediterranean basin will become hotter (+3 to +5°C) and drier (-20% precipitation) over the next century. These changes in seasonal precipitation and the occurrence of moisture and temperature stress during different developmental stages will have negative impacts on durum wheat production (HABASH et al. 2009).

Plants react on drought stress with a variety of physiological and biochemical responses which are usually initiated by stomatal closure. This protection mechanism influences CO_2 assimilation by leaves and results in membrane damages and enzyme disorder, especially those of CO_2 fixation. The enhanced metabolite flux through photo-respiratory pathway increases the oxidative load and generates reactive oxygen species which will cause further damages to macromolecules. However, plants are able to withstand drought stress by a range of protection mechanisms including reduced water loss by increased diffusive resistance, enhanced water uptake with prolific and deep root systems and its efficient use. Additional transpirational loss can be avoided by smaller and succulent leaves. Polyamines and several enzymes act as antioxidants and reduce the adverse effects of water deficit. At molecular levels several drought-responsive genes and transcription factors have been identified, such as the dehydration-responsive element-binding gene, aquaporin, late embryogenesis abundant proteins and dehydrins (FAROOQ et al. 2009, JALEEL et al. 2009).

By adopting different strategies, as mass screening and breeding and marker-assisted selection, drought stress tolerance in plants can be improved. The current study focuses on the detection of genetic regions which might be responsible for drought tolerance in durum wheat. Therefore the RIL population Omrabi5×Belikh2 was cultivated under moisture limiting conditions in Syria in two growing seasons. Results were quantitatively analysed and gave new insights into genetics of abiotic stress tolerance.

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Material and methods

Plant material

A set of 114 recombinant inbred lines (RILs) from a cross between the durum wheat lines (*Triticum turgidum* L. var. *durum*) 'Omrabi 5' (drought tolerant) and 'Belikh 2' (salt tolerant) was developed at the International Centre for Agricultural Research in the Dry Area (ICARDA), Syria. The RILs are genotyped with 265 microsatellite markers which have an average marker distance of 10.8 cM and cover the A genome with 1,423 cM (49.6%) and the B genome with 1,441 cM (50.3%).

Phenotyping

RILs were cultivated at the ICARDA experimental fields in Syria in 2007/08 and 2008/09. Phenological data as days to heading, days to maturity, plant height (cm), straw yield, grain yield, total yield (kg·plot^{-1}), harvest index (HI) and thousand grain weight (TGW, g) were collected during the growing seasons.

QTL analysis

The quantitative trait loci (QTL) analysis was carried out by composite interval mapping using the program QTL Cartographer V2.5 (WANG et al. 2011) with model 6 of forward regression. To control the effects of genetic background, five markers were used as cofactors with a window size of 5.0 cM. A LOD (logarithm of odds) score of 3.0 was used for calculating QTL positions and declare significant QTL ($P< 0.001$). The explained phenotypic variance (R^2) and the additive effect for each QTL as well as the position were estimated with QTL cartographer.

Results and discussion

Syria is an arid and semi-arid country with limited water resources. Between 2006 and 2009 Syria experienced a serious drought, the worst in four decades. Generally, for the Mediterranean basin, drought ranks among the most important abiotic stresses. Therefore, breeding has been focused in drought adaptation of crops by improvement of water use efficiency (NACHIT and ELOUAFI 2004, TUBEROSA et al. 2007) using 'molecularly' informed breeding approaches as marker-assisted selection based on information of QTL (TUBEROSA and SALVI 2006, TUBEROSA et al. 2007, DIAB et al. 2008)

The current experiments were carried out in two years with reduced precipitation in Syria. Both years differed additionally in the precipitation pattern which influenced significantly plant productivity. Comparing average yields between growing season 2007/08 and 2008/09 the results show strong reductions in grain, straw and total yield including significant effects on HI in growing season 2008/09. Due to the long dry period from previous years and additional 100 consecutive days of no observed precipitation in summer 2008, plants suffered moisture stress and restricted growth after planting in November 2008. This is reflected by the increased days to heading (22 more days) and maturity (37 more days) and results in a reduction of plant height (-10%), grain yield (-45%), HI (11%) and TGW (-14%) (*Table 1*).

The growth conditions during the two periods were beneficial to find relevant QTL for drought tolerance in durum wheat. In total 15 highly significant QTL were found on 10 chromosomes.

Positive alleles in grain yield, plant height and HI were contributed by the drought tolerant parent 'Omrabi 5', whereas positive alleles in days to heading and maturity and TGW came from the salt tolerant parent 'Belikh 2' (*Table 2*). On chromosome 4A and 7B, QTL for grain yield have been already found in comparable regions with seed parameters (seed length, width) and osmotic stress (normal seedlings and root length), respectively (NAGEL et al., unpublished). The most significant QTL, explaining a phenotypic variation up to 65%, is presented for plant height on chromosome 4B. The associated markers are also linked with coleoptile length after osmotic stress (NAGEL et al., unpublished) and are in comparable regions to the reduced height (*Rht*) genes on chromosomes 4B and 4D of the wheat (*Triticum aestivum* L.) genome (BÖRNER et al. 1997). Interestingly, semi-dwarf cultivars carrying *Rht-B1b* or *Rht D1b* alleles showed reduced stand establishment and lower yield after abiotic stress which is attributed to a reduced initial seed vigour (BOTWRIGHT et al. 2001, REBETZKE et al. 2001).

Drought is one of the most complex abiotic stresses and breeding is complicated by the lack of fast, reproducible phenotyping and repeatable water stress conditions (COLLINS et al. 2008, REZA et al. 2009). In the current study a RIL population could be tested under 'natural' drought stress condition and resulted in valuable genetic information of quantitative trait yield. The appearance of different QTL in different growing season indicates a strong dependability of environmental factors which will challenge the marker-assisted selection in durum wheat breeding in future.

Table 1: **Average performance of 114 RILs at the ICARDA experimental fields in two seasons**

	Season 2007/08			Season 2008/09		
Traits	Mean	Min	Max	Mean	Min	Max
Days to heading	96.80	91.00	111.00	128.89	121.05	143.05
Days to maturity	140.11	136.00	156.00	177.09	161.68	199.98
Plant height (cm)	73.91	52.55	100.05	66.39	40.73	91.59
Grain yield (kg·plot^{-1})	1.66	0.58	2.81	0.89	0.39	1.66
Straw yield (kg·plot^{-1})	3.80	0.88	7.34	2.41	1.17	4.54
Total yield (kg·plot^{-1})	5.47	1.46	9.62	3.30	1.65	5.44
HI (%)	30.66	20.60	39.58	27.25	14.41	49.27
TGW (g)	43.67	29.81	61.18	37.39	25.32	53.48

Table 2: **Quantitative trait loci (QTL) detected by composite interval mapping of the RIL population Omrabi 5×Belikh 2.** A QTL was assigned when LOD was >3 and defined by the chromosome (Chr.), markerloci, position, explained phenotypic variance (R^2) and additive effects. Positive additive effects indicate a contribution by the parent 'Omrabi 5', negative additive effects by the parent 'Belikh2'.

Trait	Season	Chr.	Markerloci	LOD	R^2	Additive effects
Days to Heading	1	2A	*Xwmc177*	3.68	0.12	1.53
	1	2B	*Xwmc597*	3.77	0.09	-1.30
	2	2B	*Xgwm410*	5.18	0.13	-1.99
Days to Maturity	1	5A	*Xbarc197*	3.13	0.09	-1.29
	1	7A	*Xgwm1065*	4.99	0.17	-1.83
	2	2A	*Xwmc177*	4.32	0.11	2.70
	2	5B	*Xgwm1016*	4.94	0.13	-2.99
Plant Height	1	4B	*Xbarc193*	27.45	0.65	10.21
	2	4B	*Xbarc193*	21.36	0.56	9.16
Grain Yield	1	1B	*Xgwm752*	3.45	0.11	152.86
	1	2B	*Xgwm47*	3.42	0.11	153.63
	2	3A	*Xgwm674*	4.03	0.13	94.35
	2	4A	*Xgwm160*	6.01	0.18	104.30
	2	7B	*Xwmc426*	3.48	0.12	87.04
Harvest Index	1	2B	*Xgwm148*	3.49	0.11	1.32
	2	5B	*Xbarc4*	3.02	0.10	1.53
TGW	1	2A	*Xgwm425*	3.09	0.09	-1.82

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