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Bread and durum wheat yields under a wide range of environmental conditions

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ABSTRACT

It is frequently assumed that durum wheat is more tolerant to stress than bread wheat. Unfortunately few research papers compare the performance of both species side-by-side under a wide range of environments in field conditions. We aimed to compare durum and bread wheat performance in a field study under contrasting treatments of water and nitrogen during three experimental seasons. In addition we compiled a comprehensive database with data from field experiments in which both species were grown in the same field conditions. A cross-over interaction of yield from bread *vs.* durum wheat was found, but oppositely to the hypothesis, bread outyielded durum wheat in the low-yielding conditions while durum wheat tended to have higher potential yield. We then divided the database in decades in which the cultivars were released and found that in the 1960s bread wheat outyielded durum wheat in almost any comparison whilst in the 2000s durum wheat outyielded bread wheat in most comparisons. Grain weight was constitutively higher in durum than in bread wheat, likely associated with a lower fruiting efficiency in the former; but in both types of wheat grain number per m^2 was the component responsible for yield sensitivity to environmental changes. Differences in yield were also related to differences in water and nitrogen use efficiencies: under low-yielding conditions bread wheat was consistently more efficient than durum wheat and under high-yielding conditions durum wheat was more efficient.

1. Introduction

Bread wheat (*Triticum aestivum* L.) is the crop most widely grown, sown in almost every agricultural region of the globe (Slafer et al., 1994). In contrast, durum wheat (*Triticum turgidum* L. ssp. *durum*) is a cereal grown in a more restricted range of agricultural regions, noticeably in the Mediterranean basin which accounts for more than a half of the worldwide durum wheat growing area (International Grains Council, 2010). The Mediterranean region is characterised by having constitutive stresses affecting, rather critically, dryland cereal yield. The most important of them are water and high-temperature stresses occurring mainly in the terminal part of the growing season (Acevedo et al., 1999; Loss and Siddique, 1994). In the Mediterranean basin; where both bread and durum wheat are sown (in different proportions, depending on each particular country), it has been traditional to grow durum wheat in lower-yielding conditions and bread wheat in relatively high-yielding conditions (Acevedo, 1991; Ceccarelli et al., 1987). Furthermore in other regions such as in the Southern Prairies (Canada), in North Dakota (USA) or in the Southern part of Buenos Aires Province (Argentina) durum wheat is also grown in relatively low-yielding conditions (MAGP website, 2011; USDA website, 2011). The rationale for generally allocating lower-yielding environments to durum wheat could be the belief that it is more suitable for marginal environments than bread wheat, where as bread wheat would be assumed to have a higher yield potential. For instance, Monneveux et al. (2012) stated that "due to its high level of tolerance to terminal drought, most durum wheat is grown in Mediterranean environments". Other authors made similar observations (Bozzini, 1988; Elias and Manthey, 2005; López-Castañeda and Richards, 1994; Trethowan et al., 2001). The other reasoning behind the allocation of lower-yielding conditions to durum wheat may be its requirement of relatively high protein content together with the empiric evidences of negative relationships between yield and protein percentage (Kibite and Evans, 1984). However, as the requirements of a high protein can also be achieved under high-yielding irrigated conditions with the adequate fertilisation and genotype (*e.g.* Abad et al., 2004; Rharrabti et al., 2001), the main reason must have been the assumption of durum wheat being more tolerant to stresses and bread wheat higher-yielding in stress-alleviated conditions.

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Finding conclusive support for these assumptions in the literature is not straightforward. In fact, there have been only relatively few studies in which the performance of both bread and durum wheat was directly compared in experiments growing them side-by-side (*e.g.* Aggarwal et al., 1986a,b; Calderini et al., 2006; Fischer and Maurer, 1978; Josephides, 1993; Palumbo and Boggini, 1994; Zubaidi et al., 1999). In addition to the uncertainty given by the scarcity of studies, the results available in the literature are not consistent. While some studies do support the assumption that durum wheat is more drought-tolerant and would yield more in low-yielding conditions than bread wheat (López-Castañeda and Richards, 1994; Trethowan et al., 2001) others found opposite results (Josephides, 1993; Zubaidi et al., 1999). The inconsistency may be due to the lack of a wide range of experimental environments in each of the studies, or because cultivars used for both species would have not been selected with the same criterion (*e.g.* in terms of yield potential). It might also be the case that breeding of these two species had not progressed simultaneously and the relative behaviour might have changed with time along the last decades. For instance, it seems that new durum cultivars derived from lines produced by CIMMYT would have overtaken bread wheat yield in high-yielding environments (Pfeiffer et al., 2001; Ammar, CIMMYT, personal communication, 2011). Unfortunately there is no experimental evidence supporting whether this is an exceptional behaviour of recently released cultivars of durum wheat from CIMMYT or a more generalised situation with durum wheat breeding globally.

To attempt resolving the uncertainties derived from the scarce number of comparative analyses, fragmentarily available in the literature and generally considering a limited range of environments in each particular study, we (i) run a set of field experiments with well adapted bread and durum wheat cultivars exploring a very wide range of environments in a Mediterranean agricultural region, and (ii) searched in depth the literature to identify papers reporting on performance of both wheat species were grown together under field conditions, and analysed all collected data together to draw general conclusions on the likely species-by-environment interaction that would be behind the pattern of land allocation to them. In addition to yield comparisons, we also analysed several physiological bases for differences in yield across environments. Therefore, based (i) on the consistent pattern of distribution of these crops with respect to the yielding conditions, particularly in the Mediterranean basin, and (ii) on references made in the literature, regarding durum wheat being more stress-tolerant, we hypothesised that durum wheat would outyield bread wheat under low-yielding conditions though under stress free conditions bread wheat would outyield durum wheat.

2. Materials and methods

2.1. Field experiments

Three field experiments were carried out within a region of rainfed cereal production systems, in the Mediterranean location of Agramunt, province of Lleida (Catalonia, North-Eastern Spain; lat. 41°47′17″N, long. 1°5′59″E, altitude 337 m). In all cases the experiments were installed in actual farmers fields, with a soil classified as Fluvisol calcari (FAO, 1990). In these experiments we directly compared the performance of both bread and durum wheat under a wide range of environmental conditions given by the combination of different growing seasons (2004–2005, exp. I; 2005–2006, exp. II; 2006–2007, exp. III) and water × nitrogen treatments (these treatments were imposed to create drastic differences, not to determine curves of responsiveness to these factors) in each of the seasons.

Sowing date was always in November (Table 1) within the optimal period for sowing cereals in the region and plant density was also within the ranges normally recommended (200–250 plants m^{-2}; Table 1). Weeds and diseases were controlled using agrochemicals following the manufacturer's recommendations for application.

Table 1
General conditions and treatments imposed in each of the three field experiments carried out in Agramunt (Catalonia, Spain).

Exp.	General conditions				Treatments			
	Sowing date and density	Initial soil content*		Rainfall (mm)	Irrigation		Fertilisation (kg N ha^{-1})	Genotype
		Mineral N (kg N ha^{-1})	Available water* (mm)		Treatment	Amount (mm)		
I	16-November-04	67	108	163	Rainfed	0	Unfertilised	Anza (Bread) Claudio (Durum) Provinciale (Bread) Simeto (Durum)
	250 plants m^{-2}				Irrigated (from jointing to harvest)	165	Fertilised (200 kg N ha^{-1})	Soissons (Bread) Vitron (Durum)
II	28-November-05	97	214	95	Rainfed	0	Unfertilised	Provinciale (Bread) Claudio (Durum)
					Irrigated (from jointing to harvest)	162		
	200 plants m^{-2}				Irrigated (from jointing to anthesis)	107	Fertilised (200 kg N ha^{-1})	
					Irrigated (from anthesis to harvest)	55		
III	6-November-06	87	162	326	Rainfed	0	Unfertilised	Provinciale (Bread) Claudio (Durum)
					Irrigated (from jointing to harvest)	316		
	200 plants m^{-2}				Irrigated (from jointing to anthesis)	228	Fertilised (200 kg N ha^{-1})	
					Irrigated (from anthesis to harvest)	88		

* To 1 m deep; available water is total water content minus the percentage that is under the permanent wilting point for each soil.