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Heat and drought stress on durum wheat: Responses of genotypes, yield, and quality parameters

Yun-Fang Li [a,b,c], Yu Wu [a], Nayelli Hernandez-Espinosa [b], Roberto J. Peña [b,*]

[a] Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu, China
[b] International Maize and Wheat Improvement Center (CIMMYT, Int), Apdo Postal 6-641, 06600 Mexico D.F., Mexico
[c] Graduate University of Chinese Academy of Sciences, Beijing, China

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ABSTRACT

Heat and/or drought stress during cultivation are likely to affect the processing quality of durum wheat (*Triticum turgidum* L. ssp. *durum*). This work examined the effects of drought and heat stress conditions on grain yield and quality parameters of nine durum wheat varieties, grown during two years (2008–09 and 2009–10). Generally, G and E showed main effects on all the parameters whereas the effects of G × E were relatively small. More precipitation in Y09–10 may account for the large differences in parameters observed between crop cycles (Y08–09 and Y09–10). Combined results of the two crop cycles showed that flour protein content (FP) and SDS sedimentation volume (SDSS) increased under both stress conditions, but not significantly. In contrast the gluten strength-related parameters lactic acid retention capacity (LARC) and mixograph peak time (MPT) increased and decreased significantly under drought and heat stress, respectively. Drought and heat stress drastically reduced grain yield (Y) but significantly enhanced flour yellowness (FY). LARC and the swelling index of glutenin (SIG) could be alternative tests to screen for gluten strength. Genotypes and qualtiy parameters performed differently to drought and heat stress, which justifies screening durum wheat for both yield and quality traits under these two abiotic stress conditions.

1. Introduction

Durum wheat (*Triticum turgidum* L. ssp. *durum*) is cultivated mainly in the Mediterranean Basin and North America, in irrigated and rainfed environments. It possesses harder kernel, considerably higher yellow pigment content, and relatively higher grain protein content than common wheat (*Triticum aestivum* L.). Durum wheat generally has inextensible gluten (Ammar et al., 2000; Liu et al., 1996) and therefore, most of the durum wheat produced world-wide is milled into semolina to make a compact and stiff dough to manufacture alimentary pasta. In West Asia and North Africa, durum wheat is used extensively to prepare regional foods such as couscous, frekeh, and bulgur. Dense durum wheat breads are popular in the Mediterranean Basin, partly due to their unique texture and flavor (Liu et al., 1996). Yellow pigment content, protein content, and gluten strength play a critical role in determining the pasta-making quality of durum wheat (Edwards et al., 2003; Peña et al., 2002).

Durum wheats frequently experience drought and/or heat stress in the SEWANA region (South Europe, West Asia, and North Africa), where they are mainly grown under rainfed conditions. Heat and drought stress, particularly during the grain filling period, often limit the expression of yield potential, may enhance grain protein content, and may improve or deteriorate processing quality. It is therefore very important to determine the effects of these environmental factors on durum wheat yield and quality. A few studies (Ames et al., 1999; Mariani et al., 1995; Rharrabtia et al., 2003a) have investigated the effects of genotype (G), environment (E), and their interaction (G × E) on durum wheat quality. In general, it has been seen that G × E effects are smaller than those of G and/or E. In addition, variations in the relative contributions of G, E, and G × E on different quality parameters, mainly due to different genotypes and environments studied, have been observed.

Studies of heat stress on wheat have been focusing on the period of grain filling (Borghi et al., 1995; Corbellini et al., 1997, 1998; Stone

Abbreviations: FP, flour protein content; FY, flour yellowness; GP, grain protein content; LARC, lactic acid retention capacity; MPT, mixograph peak time; SDSS, SDS sedimentation volume; SIG, swelling index of glutenin; TKW, thousand kernel weight; TW, test weight; Y, yield.

* Corresponding author. Tel.: +52 55 5804 2004; fax: +52 55 58047558.
E-mail address: j.pena@cgiar.org (R.J. Peña).

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and Nicolas, 1995), and have shown that two typical heat stresses are common during wheat grain filling. “Heat shock” is characterized by sudden, extreme high temperatures (>32 °C) for a short duration (3–5 days), while“ chronic heat stress” consists of moderately high maximum temperatures (20–30 °C) for a longer duration. Heat shock takes different forms, which are characterized by timing (days after anthesis) and by duration, which may also gave rise to different effects on the durum wheat quality (Corbellini et al., 1997). A “strengthening” effect has been observed with chronic heat stress whereas heat shock may have a “weakening” effect, both in common and durum wheat (Borghi et al., 1995; Wardlaw and Wrigley, 1994; Wrigley et al., 1994).

When compared with heat stress, there is limited literature on the effects of drought caused by erratic or deficient rainfall or limited irrigation on durum wheat quality. Flagella et al. (2010) found that technological quality and protein composition were affected by water scarcity, but that the severity was dependent on when the stress occurred. Moisture stress caused an increase in protein content and a reduction in thousand kernel weight (Rharrabtia et al., 2003a). Limited water input during grain filling decreased grain quality by reducing test weight and SDS sedimentation volume, and by increasing ash content (Rharrabtia et al., 2003b).

Heat stress experiments can be achieved by late sowing in the field, by plots covered with tunnels, or by transferring pots into the greenhouse during grain filling. For studies comparing the variation in timing and duration for different stress types, the tunnel or greenhouse methods are preferable (Corbellini et al., 1997), though differences in results may occur between the two methods themselves (Borghi et al., 1995). The fact that heat stress occurs in the field should promote more field-based research on the effects of stress on wheat quality. Although it has been shown that the responses of durum wheat genotypes to heat stress vary regardless of the timing and duration treatment (De Stefanis et al., 2002; Mariani et al., 1995), no research focusing on genotype responses to drought stress in durum wheat is available. Therefore, more attention should be given to the selection of cultivars showing adaption to both heat and drought conditions.

In order to breed for acceptable durum wheat quality under drought and heat stress, it is necessary to screen hundreds of lines in the early segregating stage, using rapid and reliable small-scale tests. When breeding for durum wheat quality, the SDS-sedimentation (SDSS) test is commonly used to predict gluten strength (Brites and Carrillo, 2001; Peña et al., 1994). Other rapid gluten strength-related screening tests exist but these are applied mainly to common wheat. The lactic acid retention capacity (LARC) test was designed to estimate gluten strength of soft wheat (Gaines, 2000), and it was highly positively associated with gluten strength parameters of Farinograph and Mixograph (Ram et al., 2005). The swelling index of glutenin (SIG) was recently developed for estimating insoluble glutenin content, and can be used for predicting gluten strength (Wang and Kovacs, 2002a,b). LARC and SIG both meet the requirements (rapid small-scale tests) for screening in the early stages of breeding; therefore, these two methods may be good options, alternative to the SDSS test, to rapidly estimate gluten strength. These two tests were evaluated with respect to their performance in drought and heat stress conditions for common wheat (Li et al., 2013), but how these small-scale tests may perform to heat and drought stresses in durum wheat is unknown.

The objectives of this study were: to examine the influence of G, E, and G × E on ten parameters of nine durum wheat cultivars possessing contrasting quality attributes, and to determine how genotypes and parameters will respond under heat and drought stress relative to optimum growing conditions.

2. Materials and methods

2.1. Materials and field experiment

Seven Mexican durum wheat (*T. turgidum* L. ssp. *durum*) cultivars (Banamichi, Samayoa, Jupiter, Aconchi, Yavaros, Cocorit, Rio Colorado), one USA cultivar (Mohawk), and one advanced experimental line (CMH83.2578) from the CIMMYT durum wheat breeding program were used. All the materials were planted with two replicates over two crop cycles, 2008–09 (Y08–09) and 2009–10 (Y09–10), in Ciudad Obregon, Sonora, northwestern Mexico, with a randomized complete block design. Two 80 cm wide and 2.5 m long rows per cultivar were planted. In all the trials, N was applied (pre-planting) at a rate of 200 kg/ha, using a seed rate of 80 kg/ha. Weed, diseases, and insects were all well controlled. The environmental conditions established were: E1, optimum irrigation (one pre-planting and 4 auxiliary); E2 drought stress (irrigation: one pre-planting and one auxiliary 30 days after planting); E3, heat stress (irrigation: one pre-planting and 5 auxiliary throughout the crop cycle). Planting dates were November 28, 2008 and 2009 for the E1 and E2 treatments, and January 15, 2009 and 2010 for the E3 treatment. Irrigation was applied when 50% available water has been depleted in the top 60 cm of the soil profile.

The meteorology data of the experimental station in Ciudad Obregon was characterized by almost no precipitation during the whole wheat growing season, with maximum temperatures between 34 and 35 °C in early-May, which was the harvesting time for E1 and E2 treatments, and maximum temperatures above 36–38 °C in mid-June, which was the harvesting time for the heat-stress treatment (E3). Flowering time and physiological maturity in most of the cultivars used occur at similar times, due to the fact that these genotypes were bred for the same growing area. The exception may be Mohawk and Rio Colorado, which flower a few days later, depending on water supply and morning temperatures during the crop season. According to the general growing stages of durum wheat in Ciudad Obregon, drought stress was continuous from stem elongation to grain ripening while heat stress started in the grain filling stage and remained until ripening. Therefore, drought (E2) and heat stress (E3) could be achieved through less irrigation and late-planting, respectively, allowing comparison of yield and quality performance among no stress environment (E1) and stress (E2; E3) conditions. Detailed meteorology data, irrigation times and intervals of three treatments (E1, E2, and E3) of two crop cycles (Y08-09 and Y09-10) during the wheat growing season in Ciudad Obregon were previously reported (Li et al., 2013).

2.2. Grain physical parameters and quality parameters

Grain yield (Y), test weight (TW), thousand kernel weight (TKW) of all samples were evaluated using conventional means. Grain moisture and protein content (PC) were determined by near-infrared spectroscopy (NIRS, Foss-NIRSystems), and then grain samples were tempered and milled into flour using a Brabender Senior mill. Flour moisture and flour protein content (FP) were determined by NIRS (INFRATEC 1255, Foss-Tecator). GP and FP were expressed at 12.5% and 14% moisture basis, respectively. Sodium dodecyl sulfate sedimentation (SDSS) volume was measured according to a modified SDSS test using 1 g flour (Peña et al., 1990). Flour yellowness (FY, as the b value of a Minolta color meter, Minolta Co.), Mixograph (National Mfg. Co.) dough peak time (MPT, using 35 g flour samples), and lactic acid retention capacity (LARC) were determined according to AACC methods 14-22, 54-40A, and 56-11A, respectively (AACC, 2000). Swelling index of glutenin (SIG) was determined according to the method of Wang and Kovacs (2002a), using the isopropanol-lactic acid variant.