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FIELD-6595; No. of Pages 9
ARTICLE IN PRESS
Field Crops Research xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Field Crops Research
journal homepage: www.elsevier.com/locate/fcr

Response to drought and heat stress on wheat quality, with special emphasis on bread-making quality, in durum wheat

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A R T I C L E I N F O

Article history:
Received 9 October 2015
Received in revised form 3 December 2015
Accepted 3 December 2015
Available online xxx

Keywords:
Durum wheat
Processing quality
Pasta-making
Bread-making
Drought stress
Heat stress

A B S T R A C T

Durum wheat accounts for more than 50% of the total wheat-growing area in the Mediterranean region, where is used for the preparation of diverse food products, including pasta and bread. The effects of drought and heat stresses on grain morphology, grain composition (protein, iron and zinc micronutrients), processing and pasta and bread-making quality in durum wheat varieties were analyzed. The results revealed significant differences among the genotypes, as well as unique responses to the environmental stresses. Micronutrients concentration (iron and zinc), processing and pasta-making quality was favored by drought but not by heat stress. Overall, the durum wheat lines showed inferior values for bread volume compared to the bread-wheat checks. However, some durum genotypes in specific environment had almost the same performance. To develop durum wheat cultivars with similar bread-making quality to that of bread wheat, it is necessary to achieve a better balance of tenacity and extensibility. The development of durum lines with good bread-making quality could increase the commercial value of this crop.

1. Introduction

Durum wheat (*Triticum turgidum* ssp. *durum* Desf. em. Husn.) accounts for around 6% of total wheat production (37.7 million tonnes in 2013; International Grain Council October, 2014), occupying approximately 20 million hectares worldwide. In the Mediterranean region durum wheat accounts for more than 50% (reaching 90% in some countries) of the total wheat-growing area, due to its role as the staple food in many countries. Durum grain is used for the preparation of diverse food products, including bread, couscous, frekeh, bulgur, and most importantly, pasta. Pasta is generally recognized worldwide as beneficial to a nutritionally balanced diet (Ames et al., 1999), and consumer demand is reflected in the upward trend in pasta production. Almost 9.3 million tons were purchased in 2001, and two years later in 2003 almost 10.5 million tons were purchased. By 2012, approximately 13.5 million tons were produced (IPO, 2013), an increase, which is an important indicator of the increase in demand for durum wheat throughout the world.

At the International Maize and Wheat Improvement Center (CIMMYT) durum wheat breeding draws on a large, genetically wide, gene pool to develop germplasm, which is widely distributed among breeding programs of durum-producing countries. The priority of the wheat breeding program is to develop high-yielding, disease-resistant varieties that can tolerate drought, heat stresses, and produce high grain quality. The latter is essential in durum wheat varieties to be accepted by industry, local food manufacturers and consumers. The most important parameters affecting industrial quality for pasta-making from durum wheat grain are probably gluten quality (strength) and the yellow color of semolina. Although environmental and processing conditions play a significant role in these two traits, research has shown that they are under strong genetic control. The favorable dough or gluten properties of durum lines have been associated mainly with the presence of specific glutenins coded by the *Glu-B1* and *Glu-B3* loci (Ammar et al., 2000; Boggini and Pogna, 1989; Boggini et al., 1995; Brites and Carrillo, 2001; Pena et al., 1994). Semolina color will depend to a great extent on the genes involved in pigment accumulation (enzymes involved in pigment biosynthesis as phytoene synthase

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http://dx.doi.org/10.1016/j.fcr.2015.12.002
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and pigment degradation as lipoxygenase or polyphenol oxidase) (see Ficco et al., 2014 for a review). Apart from pasta, durum wheat is widely used to elaborate other non-baked goods as couscous and bulgur. In the former high yellow color is appreciated while in bulgur light yellow color is preferred (Belibagli et al., 2009). Both products also demand high protein content to avoid stickiness and to have high water absorption capacity (Bayram and Öner 2006; Ounane et al., 2006).

Although durum wheat generally exhibits inferior bread-making quality compared with bread wheat (*T. aestivum* L. ssp. *aestivum*.) in terms of loaf volume and crumb structure (Boggini et al., 1995; Pena et al., 1994), approximately 24% of the global durum wheat production, and up to 70–90% in some Middle East countries, is used for bread-making (Quaglia, 1988). Speciality breads made with durum are common in the south of Italy (Boggini et al., 1995), and this popularity is spreading to other countries (Sissons, 2008). In the regions of West Asia and North Africa 50% of durum wheat is processed into single and two-layered flat breads and 35% is used for leavened breads (Liu et al., 1996). In those countries durum breads are very popular with consumers probably due to their sensory properties, particularly to their pleasant aroma (Rao et al., 2010) and special taste. They are slow to go stale (Pasqualone et al., 2007) and consequently their longer shelf-life due to the high water absorption of durum wheat flour related to increased content in damage starch, is another desirable characteristic of durum wheat breads (Boyacioğlu and D'Appolonia, 1994). Besides, although yellow bread wheat flours are typically undesirable for bread-making, in the case of durum wheat breads a distinctive yellow color is an important factor influencing whether it is accepted by the consumer (Brescia et al., 2007; Pasqualone et al., 2004).

Significant research has been done to identify the traits necessary to enhance durum bread-making quality, and in this process several durum genotypes with acceptable bread-making characteristics have been identified (Ammar et al., 2000; Edwards et al., 2007; Pena et al., 1994). Gluten strength (determined by glutenins composition) has generally been accepted as the main component that must be increased to improve baking performance of bread wheat, but gluten extensibility should also be improved (Ammar et al., 2000; Boggini et al., 1995; Edwards et al., 2007; Rao et al., 2010). However, very little information is available about the effect of the environment on the bread-making characteristics of durum wheat. In typical areas of durum wheat cultivation (Mediterranean and countries in western Asia), water deficiency and high temperatures during grain filling are major factors that define quality. The effect of those stresses in some durum quality traits (semolina milling and pasta making quality) has been previously studied (De Stefanis et al., 2002; Flagella et al., 2010; Li et al., 2013).

Besides processing and end-use quality, nutritional quality is also becoming an important priority in wheat breeding. Wheat is good source of diverse beneficial compounds including fibre, phytochemicals and micronutrients. Among different micronutrients, iron and zinc are deficiency in the diet of two billion people (WHO, 2012), and because of this have become the focus of micronutrient biofortification, which serves to enhance iron and zinc grain concentration. Modern wheat cultivars have been shown to be poor sources of these micronutrients for meeting daily requirements for humans (Cakmak et al., 2010). Not much research has been carried out about durum wheat and iron and zinc content. According to Ficco et al. (2009), there is some genetic variation to breed for iron and zinc in durum wheat, although more studies screening for larger genetic variability and examining the environment effect are required.

The objective of this study was to analyze the effects of drought and heat stresses on different quality traits with special emphasis on bread-making quality in a set of durum wheat varieties, which are representative of CIMMYT durum germplasm.

2. Materials and methods

2.1. Plant materials/agronomic trials

A trial consisting of six CIMMYT durum wheat cultivars (Mexicali C75, Yavaros C79, Altar C84, Atil C2000, Jupare C2001 and Cirno C2008) and two bread wheat ones (Kachu and Roelfs F2007), were sown in 2012–2013 and 2013–2014 crop seasons in Ciudad Obregon, Sonora, in northwestern Mexico. The trial was planted with two replicates in a randomized complete Block Design under six different environmental conditions: full drip irrigation (optimum conditions), full basin irrigation, reduced irrigation or medium drought stress, severe drought stress, medium heat stress, and severe heat stress. All the trials were planted in November except medium heat stress (planted in January) and heat stress (planted in February). All the trials had full irrigation (>500 mm) except medium drought stress (300 mm) and severe drought stress (180 mm). Weed, diseases, and insects were all well controlled. In all the trials, N was applied (pre-planting) at a rate of 50 kg of N/ha and at tillering 150 additional units of N were applied in all the trials except in severe drought stress (50 N units). At maturity whole plots were harvested and 1 kg of seed from each of the wheat lines was used for analyzing the quality traits.

The meteorology data of the experimental station in Ciudad Obregon was characterized by almost no precipitation during the wheat growing season. Maximum temperatures were between 31 and 32 °C in March and April, the grain filling time for all treatments, except for plants under heat stress at temperatures between 35 and 36 °C during grain filling in May. 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. According to the general growing stages of durum wheat in Ciudad Obregon, drought stress was continuous from stem elongation to grain ripening in moderate and severe drought stress trials during stem elongation and flowering. In severe heat stress trial, higher temperatures than in the normal planting time started from shoot elongation and remained in the grain filling stage until ripening. Detailed temperature data is shown in ESM1.

2.2. Grain and flour parameters

Grain morphological characteristics were evaluated with digital image system SeedCount SC5000 (Next Instruments, Australia). Thousand kernel weight (g) and test weight (kg/hl) were obtained. Grain iron and zinc content (mg/kg) were measured using a bench-top, non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (model X-Supreme 8000, Oxford Instruments Plc, Abingdon, UK), previously standardized for high throughput screening of iron (Fe) and zinc (Zn) in whole wheat grain (Paltridge et al., 2012). Grain protein (%) and moisture content were determined by near-infrared spectroscopy (NIR Systems 6500, Foss Denmark) calibrated based on official AACC methods 39–10 and 46–11A (AACC, 2010). Grain samples previously conditioned at 16% of moisture were milled into flour using Brabender Quadrumat Jr. (C.W. Brabender OHG, Germany). Whole-meal flour samples were also obtained with a UDY Cyclone mill carrying a 0.5 mm screen. The protein and moisture content in flour was estimated using near-infrared spectroscopy (NIR Systems 6500, Foss Denmark) calibrated based on the AACC methods commented above. Grain protein and flour protein content values were reported at 12.5% and 14% moisture basis, respectively. Flour yellowness and