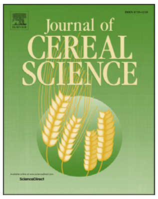
Journal of Cereal Science 69 (2016) 182–186

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs



Effect of drought and elevated temperature on grain zinc and iron concentrations in CIMMYT spring wheat

Govindan Velu [a], *, Carlos Guzman [a], Suchismita Mondal [a], Jorge E. Autrique [a], Julio Huerta [b], Ravi P. Singh [a]

[a] International Maize and Wheat Improvement Center (CIMMYT), Apdo Postal 6-641, Mexico DF 06600, Mexico
[b] Campo Experimental Valle de Mexico INIFAP, Apdo. Postal 10, 56230 Chapingo, Edo de Mexico, Mexico

ARTICLE INFO

Article history:
Received 13 October 2015
Received in revised form
4 March 2016
Accepted 5 March 2016
Available online 10 March 2016

Keywords:
Wheat
Abiotic stress
Zinc and Iron
Biofortification

ABSTRACT

Abiotic stress caused by increasing temperature and drought is a major limiting factor for wheat productivity around the world. Wheat plays an important role in feeding the world, but climate change threatens its future harvest and nutritional quality. In this study, grain iron (Fe) and zinc (Zn) concentrations of 54 wheat varieties, including CIMMYT derived historic and modern wheat varieties grown in six different environmental conditions, were analyzed. The objective of the study was to evaluate the effect of water and heat stress on the nutritional value of wheat grains with a main emphasis on grain protein content, Zn and Fe concentrations. Significant effects of environment on protein content and grain micronutrients concentration were observed. The protein and Zn concentrations increased in the water and heat stressed environments, whereas Zn and Fe yield per unit area was higher in non-stress conditions. The results suggest that genetic gains in the yield potential of CIMMYT derived wheat varieties have tended to reduce grain Zn, in some instances; however, environmental variability might influence the extent to which this effect manifests itself.

1. Introduction

Food and nutritional security is challenged by ever increasing population growth and increasing demand for nutritious healthy food due to changing food habits and growing middle class income. Food and nutritional security will be worsened by climate change-induced warmer temperatures and reduced water availability in most spring wheat growing environments (FAO, 2015). By 2050, the global population will reach 9.7 billion, 33 percent higher than today, mostly all of this population increase will occur in developing countries (FAO, 2015). Annual cereal production will need to rise to about 3 billion tons from 2.1 billion today (FAO, 2015). Recent research indicates that countries in the southern hemisphere may be most vulnerable to declining yields and greater frequency of extreme weather events (Ray et al., 2015). Malnutrition still represents major challenge and the number of chronically undernourished and malnourished people in the world has been rising (Welch and Graham, 2004; FAO, 2014). An estimated 26 percent of the world's children are stunted, 2 billion people suffer from one or more micronutrient deficiencies and 1.4 billion people are overweight, of whom 500 million are obese (Black et al., 2013). Most countries are burdened by multiple types of malnutrition, which may coexist within the same country, household or individual. Micronutrient malnutrition, resulting from diets primarily deficient in zinc (Zn) and iron (Fe), has been widely recognized as a major health problem affecting almost 2 billion people worldwide, especially in countries with a high consumption of cereals (Black et al., 2013). Zn is an essential trace element for all organisms and its role has been thoroughly reviewed in both plant and human health (Cakmak et al., 2000; Graham et al., 2007; Graham et al., 1999). About 17% of the world's population suffers micronutrient deficiency mainly due to inadequate Zn intake (Wessells and Brown, 2012), and annually more than 100,000 deaths of children under age five are attributed to Zn deficiency (Black et al., 2013). There is no storage system for Zn in the human body so it must be consumed daily (Rink, 2011). For resource-poor people in developing countries, Zn intake is largely dependent on cereal-based food, especially in South Asia where wheat and rice contribute the majority of dietary energy (Graham et al., 2001). The development and dissemination of bread wheat (*Triticum aestivum* L.)

---

* Corresponding author.
E-mail address: velu@cgiar.org (G. Velu).

http://dx.doi.org/10.1016/j.jcs.2016.03.006
0733-5210/© 2016 Elsevier Ltd. All rights reserved.

cultivars with genetically enhanced levels of Zn and Fe provide a cost-effective, sustainable solution to micronutrient deficiency (Pfeiffer and McClafferty, 2007; Bouis et al., 2011; Velu et al., 2014). Wheat is the second most produced cereal crop and constitutes about 28% of dietary energy and 20% protein to consumers in many parts of the world (Braun et al., 2010). Improving the nutritional levels of wheat is therefore of paramount importance. Climate change and related abiotic stresses such as drought and heat stress will likely affect nutritional composition of wheat grain. Therefore, this study set out to establish the effect of limited water and higher temperatures on grain nutritional factors and their association with agronomic traits in a set of historic and modern wheat varieties with varying levels of yield potential under stressed and normal conditions.

2. Materials and methods

2.1. Plant material and field experiments

A field trial consisting of 54 bread wheat cultivars were grown in the 2012–2013 and 2013–2014 crop seasons in Norman E. Borlaug Research Station (Campo Experimental Norman E. Borlaug -CENEB), Ciudad Obregon, in the state of Sonora, in northwestern Mexico. The trial was planted with three replicates with an alpha lattice design under five environmental conditions: Optimum or full irrigation (FI), reduced irrigation or moderate drought stress (MDS), severe drought stress (DS), medium heat stress (MHS) and severe heat stress (HS). Grain samples from first two replicates were used for grain quality analysis. All the trials were planted in November except MHS (planted in January) and HS (planted in February). Irrigation through drip system was applied in FI, MDS, DS and MHS. Basin irrigation system was followed for HS. Seeding density used was 138 kg ha^{-1} in FI, MDS, MHS and HS, and 92 kg ha^{-1} for DS. All the trials had full irrigation (>500 mm) except MDS (300 mm) and DS (180 mm). Standard control procedures for weed, diseases and insects were followed. Nitrogen rates varied between environments, 300 kg ha^{-1} N was applied to FI while 200 kg ha^{-1} was applied in other environments. At maturity, whole plots were harvested and 20 grams of seed from each of the wheat lines was used for analyzing the nutritional quality traits.

The meteorology data of the experimental station in Ciudad Obregon was characterized by almost no precipitation during the wheat growing season, with maximum temperatures of 31–32 °C in March–April during grain filling for all sowing in November and January. The late-planted HS was exposed to warm growing season with maximum temperatures reaching above 35 °C during grain filling. Flowering time and physiological maturity in most cultivars used to 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 wheat in Ciudad Obregon, drought stress was continuous from stem elongation to grain ripening in DS and MDS (Supplementary Fig. 1).

2.2. Grain analysis

Plant materials were harvested at complete maturity when grains were dry (8–10% moisture content). Grain samples (approximately 20 g) of each entry were carefully cleaned to discard broken grains and foreign materials and were used for micronutrient analysis. Grain Zn and Fe concentrations (unit: mg kg^{-1}) were determined by using a “bench-top,” non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (model X-Supreme 8000, Oxford Instruments plc, Abingdon, UK), which has been standardized for high throughput screening of Zn and Fe in whole grain wheat (Paltridge et al., 2012).

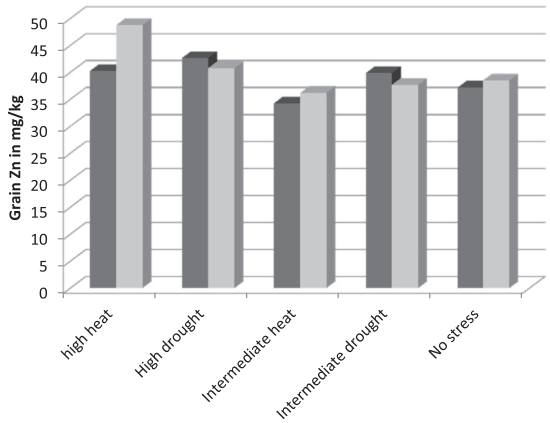


Fig. 1. Effect of heat and drought on grain Zn concentration.

A SeedCount digital imaging system (model SC5000, Next Instruments Pty Ltd, New South Wales, Australia) was used to measure Thousand-Kernel Weight (TKW) (g 10^{-3} kernels) as it can rapidly and accurately analyze samples of wheat grains and determine the grain number and their physical characteristics based on software and flatbed scanner technology.

Grain Protein Content (GPC, %) 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 International, 2010). GPC values were reported at 12.5% moisture basis. Grain Zn yield and Fe yield (g ha^{-1}) was calculated by multiplying the grain yield by the grain Zn and Fe concentrations, respectively.

2.3. Statistical analysis

Analysis of variance (ANOVA) for agronomic and grain quality traits was performed to determine significant differences among environments, years and their interactions using GENSTAT statistical package version 10.1 (Rothamsted Experiment Station, Herpenden, Herts AL52JQ, UK) (Payne et al., 2010). A mixed model analysis was performed in META-R to estimate the Best Linear Unbiased Predictor in each environment and across years and environments. Broad-sense heritability (H^2) (repeatability) was estimated across environments using the formula $H^2 =$

$$\frac{\sigma g^2}{\sigma g^2/(\sigma g^2 + \sigma ge^2/y + \sigma e^2/ry)}$$

where σg^2 is the genotypic variance, σge^2 is the Genotype − Environment interaction variance, and σe^2 is the residual error variance, 'r' = number of replications and 'y' = number of years.

3. Results

Analysis of variance (ANOVA) showed significant differences among entries (G) as well their interactions with the environments (G × E) for all seven traits in the study (Table 1). However, the interactions of entries with years (Y × E) were significant for grain Fe, Zn, and GPC and test weight (Table 1). Clearly, the variability attributable to interaction of entries with the environments was much smaller in comparison to those attributable to individual environments *per se* for all the traits suggesting varying environmental conditions influence expression of grain micronutrients and GPC. The means of relative ranges for grain Zn tended to be higher at high stress environments of heat (31–53 in year 1 and 36–72 in