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Grain iron and zinc concentrations of wheat and their relationships to yield in major wheat production areas in China

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ABSTRACT

Maintaining adequate mineral content in wheat (*Triticum aestivum*) grain is critically important for human nutrition. In this study iron (Fe) and zinc (Zn) concentration, and grain yield of 655 field-grown wheat samples from major wheat production areas of China were investigated from 2009 to 2011. Grain yields were found as high as 5423 and 6565 kg ha^{-1} for spring and winter wheat, respectively, with a corresponding grain Fe concentration of 48.2 and 45.1 mg kg^{-1}, and Zn concentration of 30.4 and 30.3 mg kg^{-1}. Compared to the recommended grain nutrient concentrations, 63% and 72% of the spring and winter wheat samples were considered Fe inadequate, and 88% and 87% were Zn inadequate, respectively. Regionally, grain Fe and Zn concentration was found to be lower in high-yielding regions. Grain Fe concentration was significantly and positively correlated with Zn concentration for both spring and winter wheat. For each 1 mg kg^{-1} increase in grain Zn, the Fe concentration increased by 0.6 and 0.3 mg kg^{-1} for spring and winter wheat, respectively. However, the Fe and Zn concentration was significantly and negatively correlated with grain yield: for every 1000 kg ha^{-1} increase in grain yield, the Fe concentration decreased by 2.1 and 1.3 mg kg^{-1} for spring and winter wheat, respectively, and the Zn concentration decreased by 0.9 and 1.3 mg kg^{-1}, respectively. Therefore efforts to simultaneously increase grain yield and Fe and Zn concentration in wheat grain remain a challenging endeavour for wheat farmers.

1. Introduction

Iron (Fe) and Zinc (Zn) deficiencies are two of the most prevalent human micronutrient deficiencies in the world (Welch and Graham, 1999). Iron is an important component of haemoglobin, which has an essential role in oxygen and carbon dioxide transport, as well as in the maintenance of blood acid–base balance. Iron also participates in the metabolism of body energy and contributes to several immunologic functions. Iron deficiency, affecting over two billion people worldwide, leads to Fe deficiency anaemia, which adversely affects haemoglobin function, causing impaired physical and mental development and maternal mortality (Dallman et al., 1993). Zinc accelerates growth, coordinates the body's immune response, and is involved in the synthesis of many enzymes (e.g. DNA polymerase, carbonic anhydrase, and alkaline phosphatase) (Chen, 2006). Zinc deficiency leads to various health conditions including reduced bone growth, damaged immune systems, prevalence of contagious infection, and cancer development (Hotz and Brown, 2004; Gibson, 2006). In China alone, approximately 245 million and 100 million people suffer from Fe and Zn deficiency, respectively (Ma et al., 2008).

Wheat is one of the most important cereal crops worldwide, with a cultivated area accounting for more than 20% of the world's arable land (Schmitz and Bawden, 1973). Wheat grain yield is of great importance. It directly determines not only the income available to farmers, but also the quality of wheat-based food. Therefore, the concept of increasing grain yield has attracted much attention, and various measures have been undertaken to increase wheat production (Slafer and Andrade, 1989; Calhoun et al., 1994; El-Shakweer et al., 1998). Wheat grain yield in China increased from 730 kg ha^{-1} in 1952 to 4550 kg ha^{-1} in 2006, a more than 5-fold increase (Li et al., 2008). Some researchers have declared that yield may affect mineral concentrations through the dilution effect (when yield is high), or the concentration effect (when yield is low) (Oury et al., 2006; Morgounov et al., 2007; Fan et al., 2008). China is one of the primary wheat producing countries, with wheat

Abbreviations: RCFe, recommended Fe concentrations; RCZn, recommended Zn concentrations.

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grown in 30 provinces with a total cultivated area 24.3 million Ha (NBS, 2012). This is important as rural populations rely primarily on wheat-derived foods for trace elements (Fe, Zn, etc.) (Carter and Zhong, 1999). Much of the information on wheat grain Fe and Zn concentration is based on published studies conducted in Argentina (Lavado et al., 2001), Canada (Gawalko et al., 2002), United States (Garvin et al., 2006; Murphy et al., 2008), Central Asia (Morgounov et al., 2007), Iran (Karami et al., 2009), and China (Zhang et al., 2010). However, none of these studies provide a precise national estimate, and information on Fe and Zn concentration, and their relationship to grain yield of wheat grown in prevailing field conditions (as affected by geographical distribution) is not available.

Therefore, an investigation was performed in major wheat-producing provinces at harvest seasons of 2009, 2010, and 2011 in China by collecting 655 wheat grain samples to determine the following:

(1) Whether the current wheat grain could satisfy daily Fe and Zn requirements for the local population through consumption of wheat-based products;
(2) The distribution of Fe and Zn concentrations across different wheat production areas, and their relation to the yield distribution;
(3) The correlation among grain Fe and Zn concentrations, and yield of wheat grain sampled from different areas.

2. Materials and methods

2.1. Wheat growing areas

Wheat is one of the major food crops in China, of which 1.9 million ha (8%) are spring wheat, and 22.3 million ha (92%) are winter wheat. Spring wheat is mainly grown in the northeastern, central northern and northwestern parts of China, including provinces of Heilongjiang, Jilin, Liaoning, parts of Inner Mongolia in the northeast, parts of Ningxia and Inner Mongolia in the central north, and parts of Gansu, Xinjiang and Qinghai in the northwest (Fig. 1), where the very low air temperature limits growth of winter wheat. Winter wheat is widely distributed in eastern China including Shandong, Hebei, and parts of Anhui, Henan, and Jiangsu, in central China in parts of Gansu, Ningxia, Shaanxi and Shanxi, in the northwest in Xinjiang, in southern China including Hubei, Shanghai, Zhejiang, and parts of Anhui and Henan, and in southwestern China including parts of Chongqing, Sichuan, Guizhou, and Yunnan. Air temperature, precipitation, sowing date and harvest date for spring wheat and winter wheat are presented in Table 1.

2.2. Sampling and analyses

A total of 655 field-grown wheat grain samples, including 320 cultivars, were collected from major wheat production areas in China in 2009 ($n = 171$), 2010 ($n = 241$), and 2011 ($n = 243$) (Fig. 1). The number of samples collected was dependent on the size of the province's wheat growing area (i.e. more samples were collected from provinces with larger wheat production areas). Sampling sites were randomly determined at the county level. Selected fields were required to be far away from industrial areas to keep plant from contamination, and wheat cultivars were those widely used by local farmers. At harvest, wheat grain samples were collected from fields by local farmers, researchers, extension workers, or students. For each sample, grains were collected from at least 5 different sampling points within each field, and then blended to form a composite sample. Samples were then packaged in uniformly designed sample bags, and mailed to the laboratory of College of Resources and Environment, Northwest A&F University.

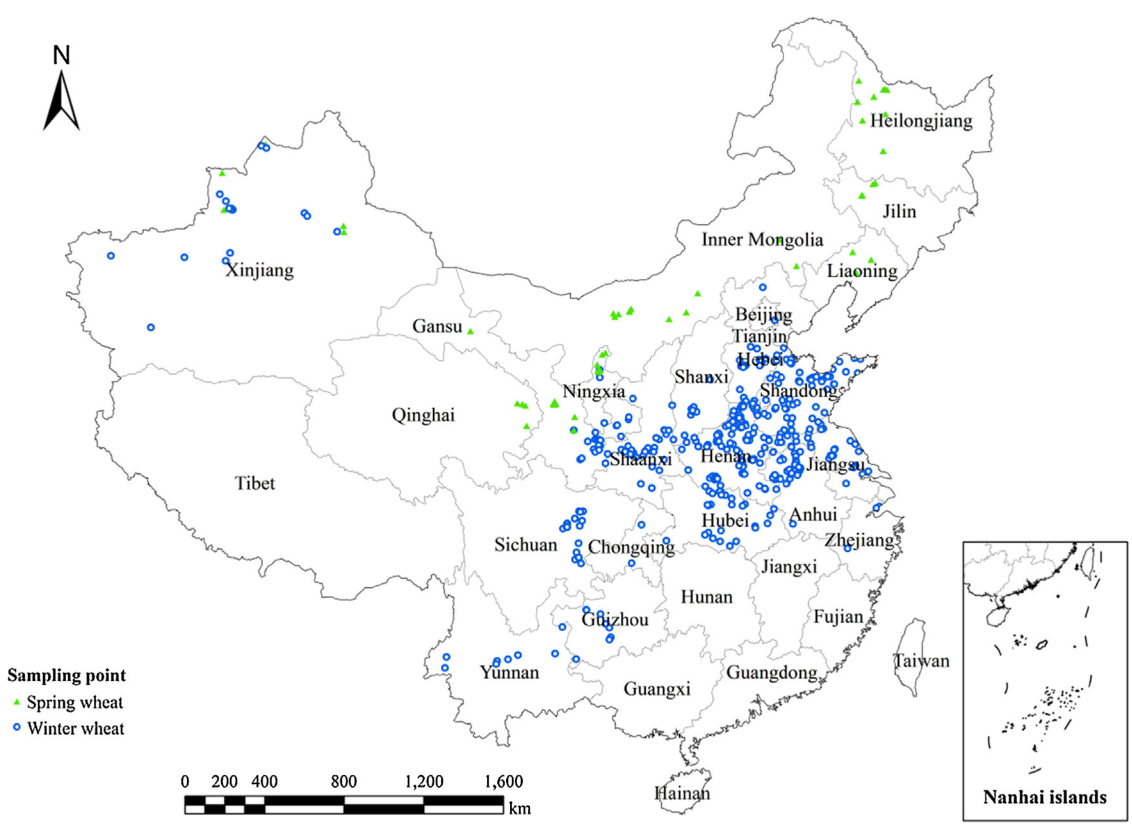

Fig. 1. Sampling sites for 655 field-grown wheat from 2009 to 2011.