Field Crops Research 177 (2015) 117–124

Contents lists available at ScienceDirect

Field Crops Research

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

Wheat yield improvements in China: Past trends and future directions

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ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 21 March 2015
Accepted 22 March 2015
Available online 7 April 2015

Keywords:
Breeding
China
Grain number
Wheat
Yield
Yield components

ABSTRACT

Wheat has been cultivated in China for at least 4000 years, but it took until 1914 in Nanjing before cross-breeding programs commenced. Wheat breeding has made substantial contribution to China's wheat production capacity over the years. Data on more than 1850 Chinese wheat varieties from the 1920s to 2014 (categorized into north winter wheat, south winter wheat and spring wheat varieties) were collected in order to (1) better understand progress in agronomic performance, (2) analyze the evolution of yield-related traits, and (3) formulate strategies for future breeding.

Since the 1920s, average grain yield has increased annually by 1.29% for north winter wheat, 1.5% for south winter wheat and 0.52% for spring wheat. For north and south winter wheat, kernel number per spike and 1000-kernel weight (TKW) have increased significantly, with no change to spike number per unit area. Spike number per m^2 has not changed significantly in any of the three major agro-ecological production zones. Average plant height of north winter wheat declined from the 1950s to 2000s to stabilize at 80 cm; south winter wheat declined from the 1930s to 1990s to stabilize at 86 cm; and spring wheat decreased from the 1960s to 1990s to stabilize at 89 cm. Seedling density in both north and south winter wheat has significantly reduced, with no significant changes for spring wheat. Variability of varieties in yield and agronomic traits has declined since the 2000s.

Breeding programs for wheat varieties have contributed to food security in China. Yields for north and south winter wheat have steadily increased since the 1920s, following the rule of thumb to increase TKW and kernel number per spike without changing spike number per unit area. For spring wheat, average grain yield has increased annually significantly since the 1920s, and reached its peak in the 1980s but has since decreased. Future increase in yield may be achieved through improvement in kernel size and kernel number per spike. This paper comprehensively evaluates the historical development of wheat varieties in three main agro-ecological regions of China, and will act as a guide for future wheat breeding and production technology.

1. Introduction

China is the largest wheat producer and consumer in the world (He et al., 2001). Tremendous progress has been achieved in Chinese wheat production with average yields increasing from less than 1 t ha^{-1} in 1949 to 5 t ha^{-1} in 2013, with total production currently at 126 Mt in 2014 (Fig. 1). However, with increasing population pressure and the subsequent demand for agricultural products, China will need 776 Mt grain by 2030 to feed its own people, a increase of 36% from 2014 (Li et al., 2014). Research efforts should focus on breeding new wheat varieties with more yield potential and improving production technologies to help meet the increasing demands of population growth and food consumption (Foley et al., 2011).

Studies on genetic improvement in grain yield usually compare old and new varieties which are grown over two or three years in different environments; a critical analysis of yield-related factors will identify opportunities for future yield improvements (Siddique et al., 1989a; Evans, 1993). Genetic improvements have contributed to the increases in wheat yield, mostly in the development of new varieties (FAO, 2006; Ortiz et al., 2008; Wang et al., 2009). Recent evaluations of wheat breeding have occurred in China (Zhou et al., 2007a, 2007b; Zheng et al., 2011; Zhang et al., 2011), the USA (Graybosch and Peterson, 2010), Australia (Siddique et al., 1989a, 1989b; Loss and Siddique, 1994; Calderini and Slafer, 1999), Argentina (Calderini et al., 1995), Mexico (Fischer, 2007; Manes

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http://dx.doi.org/10.1016/j.fcr.2015.03.013
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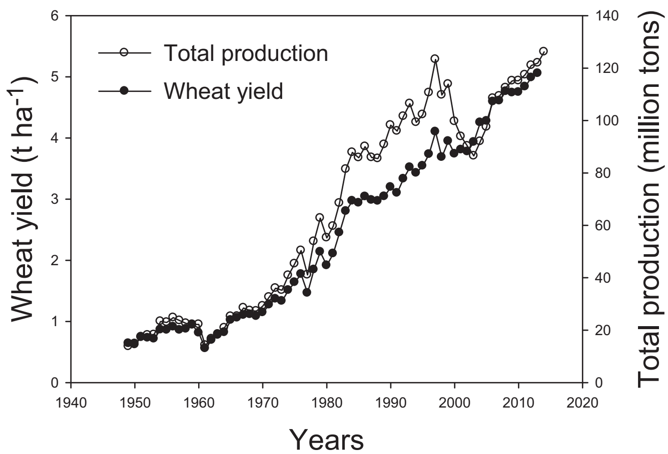

Fig. 1. Average wheat yields per area and total production from 1949 to 2014 in China. Data were provided by the Ministry of Agriculture of China and National Bureau of Statistic of China (Average wheat yields per area in 2014 was not included, http://www.moa.gov.cn/, http://data.stats.gov.cn/english/).

et al., 2012; Sharma et al., 2012), the UK (Austin, 1999; Shearman et al., 2005), France (Brancourt-Hulmel et al., 2003; Brisson et al., 2010) and Spain (Acreche et al., 2008).

Breeders in North America, South America and Europe (Brancourt-Hulmel et al., 2003; Pedró et al., 2012; Bustos et al., 2013) tend to concentrate on improving grain number per unit area and 1000-kernel weight (TKW), while Chinese breeders focus on three yield components (TKW, spike number per m^2 and kernel number per spike) to improve grain yield potential (Wu, 1990). Yield potential can be improved by increasing one or more of these components (Brancourt-Hulmel et al., 2003; Pedró etal., 2012; Sun et al., 2014; Wu et al., 2014). Plant height, sowing density and harvest index are also important attributes for breeders to consider (Siddique et al., 1989a, 1990; Sun et al., 2014).

The wheat-growing regions of China are divided into three major agro-ecological production zones: northern China winter wheat region, southern China winter wheat region and spring wheat region (Jin, 1961; Zhou et al., 2007a, 2007b; Zhang et al., 2011;Fig. 2). The northern China winter wheat region is the most

Fig. 2. Three distinct wheat production agro-ecological zones in China: (I) northern China winter wheat region, (II) southern China winter wheat region and (III) spring wheat region.

important wheat-producing area – producing 60 to 70% of the total wheat production in China (He et al., 2001) – followed by the southern China winter wheat region with 25% (He et al., 2001). An evaluation of genetic improvement in grain yield in the northern China winter wheat region found no common trends for changes in spike number per m^2, kernel number per spike, TKW or aboveground biomass; from 1960 to 2000, grain yield improvement was primarily attributed to increased kernel weight per spike, reduced plant height and increased harvest index (Zhou et al., 2007a). From 1949 to 2000 in the southern China winter wheat region, genetic improvement in grain yield was primarily attributed to increased TKW (0.65%, $P < 0.01$) and kernel weight per spike (0.87%, $P < 0.01$), reduced plant height and increased harvest index (Zhou et al., 2007b). For spring wheat in the Sichuan, Yunnan, Gansu and Xinjiang provinces, grain yield improvement was primarily attributed to increased kernel number per spike (Zhang et al., 2011).

However, comparing new and old varieties excludes any interactions between genotype and environment, or the influence of global warming (Parry and Carter, 1989). Other disadvantages include fewer varieties in the analyses, limited reliability of the most-relevant yield components, and that genetic improvement trends based on two or three years' research may not be reliable.

China has a long history of wheat cultivation, but crossbreeding programs were not initiated until 1914, which was later than most European countries. For this review, we collected records from regional testing data on more than 1850 Chinese wheat varieties from the 1920s to 2014; this data will supplement existing research by providing (1) a better understanding of the progress in agronomic and physiological performance, (2) an analysis of the evolution of yield-related traits, and (3) a summary of breeding strategies for future breeding.

2. Data collection and analysis

Data on more than 1850 Chinese wheat varieties representing a geographically-broad sample were collected from records (Jin and Liu, 1964; Jin, 1985, 1997) and breeding reports (data from Department of Agriculture Seed Management Station). Data from breeding reports were based on regional tests conducted across or within zones in China.

An average value was taken for data from a regional test and a median value for the range of data. Data from variety breeding in China prior to the 1980s did not include spike number per unit area. Different regions within China have different breeding strategies, based on the climatic features of each region, such as annual average temperature, winter air temperature, rainfall, and production agronomy. The 1850 wheat varieties were divided into three groups based on regional distribution: north winter wheat, south winter wheat and spring wheat. Based on agronomic characteristics, the wheat varieties were divided into 11 groups: landrace varieties, 1920s, 1930s, 1940s, 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, 2010s (groups with less than three values for a particular characteristic were not included in the analysis).

Grain yield, 1000-kernel weight (TKW), spike number per m^2, kernel number per spike, plant height and seedling density (live seedlings per area, m^2) were analyzed using one-way analysis of variance. Tests of significance for differences in these characters were made between levels of agro-ecological production zones. Least significant difference (LSD) values were calculated at the 5% probability level using the Statistical Analysis System (SAS Institute Inc., 1997). Regression analysis with a standard linear model applied to cultivar means was used to calculate the rates of change for traits and grain yield with decade of release (landrace varieties were not included):

$$y_i = a + bx_i + u$$