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Trends in drought tolerance in Chinese maize cultivars from the 1950s to the 2000s

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ABSTRACT

Drought is a key factor that has historically affected maize productivity. Thus, retrospective studies of the performance of cultivars used in China under water- limited conditions may provide some useful information and guidance for the improvement of maize yield. The objectives of the present study were to assess genetic gains in grain yield and the trends in related secondary traits, particularly increased drought-stress tolerance, in cultivars widely used in China from the 1950s to the 2000s. Trials were conducted at two locations (Sanya and Urumchi) under two water regimes per location during the 2010–2011 growing seasons. Results indicated that mean grain yield showed a significant linear increase from the 1950s to the 2000s, and that newer maize cultivars yielded more than older ones under either drought stress or fully irrigated treatments. The average yield gains under water-limited and unstressed environments were 62.6 and 100.3 kg ha^{-1} yr^{-1} respectively. Secondary traits associated with drought in maize have been improved over the past 50 years. The ASI and empty ear rate both decreased, while kernels per ear and weight per 100 kernels increased. The latter two parameters were the main sources of yield gain from 1950 to 2000 under drought stress treatment. To further improve yield under drought-stress conditions, the ASI and empty ear rate should both continue to be decreased during maize breeding. Further, genotypes with plant height and ear traits that are less affected by drought stress should be selected.

1. Introduction

Maize is a crop that is essential for global food security. The United States and China are global leaders in total land areas planted with maize, representing 19.8 and 18.6% of the global maize-growing area, respectively. The scientific consensus is that global climate change, and associated increases in temperatures, evapotranspiration, and regional drought are occurring (Hillel and Rosenzweig, 2002). China has significant regions of arid and semi-arid lands that occupy ~50% of the entire land area of the country, including northern and northwestern China (Li et al., 2004). Historically, drought is one of the foremost factors that limit maize production, and often results in 20–50% reductions in maize yield each year in China (Hu et al., 2004). The flowering stage in maize is critically sensitive to inadequate water, so maize is generally considered to be more susceptible than most other cereals to drought stresses at flowering. Yield losses are thus manifested as barren ears or reduced kernel numbers per ear (Bolaños and Edmeades, 1996). The susceptibility of maize yield to stresses during flowering was documented in early studies of U.S. Corn Belt germplasm (Claassen and Shaw, 1970; Shaw, 1977). These studies showed that the most stress-sensitive period encompassed the interval from around 1 wk before to 2 wk after 50% silking. Yield lost per day when stresses occur before or after flowering can range from 45 to 60% of the losses that occur when stresses occur at silking (Shaw, 1977). Similarly, Li (2002) found that silking is delayed and yield reduced 30% when drought occurred during the flowering stage.

Abbreviations: OPV, open-pollinated varieties; ASI, anthesis-silking interval.

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Yield losses due to drought stress can best be resolved by breeding new, drought-tolerant varieties and improving cultural practices (Edmeades et al., 2006). However, it can be more efficient and less expensive to take advantage of genetic improvements than to improve agronomic inputs and practices (Kamara et al., 2012). Therefore, the genetic improvement of maize drought tolerance and yield stability is an important approach to stabilizing production. Retrospective studies can provide useful information and guidance for improving or maintaining maize yield under stressful environments. Comparison of the drought tolerance of older and newer varieties can improve our understanding of the changes underlying breeding progress made in the past. Previous comparative studies of drought tolerance and yield traits have been performed in the U.S. For example, Castleberry et al. (1984) compared a series of U.S. Corn Belt hybrids and OPVs typically grown during the decades from 1930 to 1980 and showed linear gains in grain yield under either drought stress or fully irrigated conditions. Russell (1991) selected a set of Iowa-adapted varieties that were used from 1930 to 1980 and planted them in environments with either adequate or inadequate water availability and showed that the hybrids of 1980s had superior yields in all environments. Another series of 18 commercial hybrids adapted to central Iowa and representing the period 1953–2001 showed linear gains in grain yield under each of three different water regimes (Edmeades et al., 2003; Barker et al., 2005). Campos et al. (2004) designed five stress treatments during flowering and grain filling, and observed positive genetic gains for grain yield under full irrigation and all stress treatments.

Similar research was also launched in other countries. Derieux et al. (1987) compared 33 maize hybrids (of three maturity groups) grown in France from 1950 to 1982, and found that modern hybrids are more adapted to stresses such as low temperature and drought. The above-mentioned results indicate that breeders in the U.S. and France emphasized improvement of the drought tolerance of hybrids so that yield under drought kept pace with the increase in yield potential. In Ontario, Canada, Dwyer et al. (1991) found that a newer hybrid was more tolerant of short drought periods than an older hybrid. During a drought period, the newer hybrid continued to perform photosynthesis for about 2 h longer than the older one before starting to decline. Further study indicated that the two hybrids might have utilized different mechanisms to tolerate moisture stress (Nissanka et al., 1997).

Several cycles of hybrid replacement have occurred in China since the 1950s. Several studies on the yield gain of cultivars and their performance at different planting densities have carried out. Ci et al. (2011) found that average yield gain (74 kg ha^{-1} yr^{-1}) showed a significant linear increase from the 1970s to the 2000s in China. The newer hybrids showed greater tolerance to compound stress. Further increases in maize grain yield in China could be achieved through higher plant densities, which will require breeding for greater stress tolerance. A series of cultivars from 1950 to 2000, including OPVs, showed a linear increase in grain yield under different densities; thus, maize yield in China could benefit from agronomic management at higher plant densities. Wang et al. (2011) found that mean rates of genetic gain were 69 kg ha^{-1} yr^{-1} in the spring corn region and 52 kg ha^{-1} yr^{-1} in the summer corn region from 1964 to 2001 in China. In both regions, the newer hybrids yielded more than old hybrids. However, no information has previously been available for trends in drought tolerance of maize cultivars until now.

The objective of the present study was to assess genetic gains under drought stressed and fully irrigated conditions and to analyze trends in secondary traits in the cultivars in widespread use in China since 1950, as a basis for gaining valuable information for further yield improvement in China and elsewhere.

2. Materials and methods

2.1. Materials

Thirty-four maize cultivars were tested in the present experiments, including four open-pollinated varieties (OPV), four double-cross or tri-cross hybrids, and 26 single- cross hybrids that span six decades (from 1950 to 2000) and represent the most popular varieties of their time in the main maize-growing areas of China. All the entries were bred by China's public sector. Forty-seven parental lines of hybrids were also analyzed. Table 1 shows the release dates of cultivars and parental lines of the hybrids used in the present study. Maize germplasm used in China can be grouped into three heterotic populations: A, B, and D (Ci et al., 2011). Population A is comprised of two subpopulations: PA and Reid from the United States (Iowa Stiff Stalk Synthetic). Population B is comprised of two subpopulations: Lancaster and PB from the United States. Population D is domestic germplasm in China that is also comprised of two subpopulations: Lvda Redcob and Sipingtou (Zhang et al., 2002).

2.2. Experimental site, cultural practices and stress management

Field trials were performed at Urumchi (43°45′ N, 87°36′ E, elevation above sea level 690 m) and Sanya (109○31′E, 18○14′N, elevation above sea level 6.5 m) during the growing season of 2010 to 2011. Urumchi is located in the northwest of China and has gray desert soil and abundant light, but receives average rainfall of only about 30 mm per month with average relative humidity below 50% (Table 2). Sanya lies in southernmost China, in the tropic zone and receives very little rain during the growing seasons (Table 3). The soil in Sanya is a sandy loam with poor water-holding capacity, such that rainfall penetrates the soil quickly and cannot be efficiently absorbed by plants. The two locations have similar naturally dry conditions and therefore irrigation is required at both locations for crops growth in the two above dry cities.

The experimental field was plat land in both cities. Fertilizer Phosphoric acid two amine (25 g/667 m^2) was applied once before sowing and after fertilizer Urea (25 g/667 m^2) was conducted at planting. Herbcide was casted blocking out grass after planting. The treatments included drought stress and full irrigation, three replications, at an intermediate density of 67,500 plants ha^{-1}. No other stress exist in Urumchi and Sanya besides drought, so maize density is above 67,500 plants ha^{-1} during 1990 decade (Jiao and Cheng, 1997) and about 82500 plants ha^{-1} during 2000s without any lodging. So 67500 plant ha^{-1} should be middle density for these entries. Each plot consisted of two rows 0.6 m apart and 5 m long. The plot plant adopted artificial sowing with spacing rope. The whole plot was harvest by workers. Drip irrigation system was adopted to control water. Two rows of protection maize were around the water and drought treatments. Five meters water isolation belt was between the two treatments.There were some differences between the two locations in terms of water control and field management. In Urumchi, the drought stressed plots were watered once during the seedling stage, then irrigation was stopped, until the field was re-watered in the middle of the grain-filling period. The control plots were given full irrigation once for fifteendays after sowing seeds except for heavy rainfall. In Sanya, the drought stressed plots were irrigated at the seedling and shooting stages, and irrigation was stopped before flowering. Because of the sandy soil in Sanya, the stressed plots were then rewatered during the early days of the grain-filling period. The control plots were fully irrigated when the leaves rolling occurs during the entire growing season.