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Agronomic and physiological contributions to the yield improvement of soybean cultivars released from 1950 to 2006 in Northeast China

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ABSTRACT

Increasing yield is a high priority in most breeding programs. Approximately 600 soybean cultivars had been released by the end of the last century in Northeast China. Understanding the agronomic and physiological changes is essential for planning further plant breeding strategies in soybean. In this study, 45 representative soybean cultivars, from maturity groups 00 and 0, released from 1950 to 2006 in Northeast China were compared in field conditions for 3 consecutive years. A positive correlation between seed yield and year of cultivar release was indicated with a 0.58% average annual increase. Seed number per plant was the most important contributor to yield gain, with a 0.41% increase per year. Pod number per plant and seed size varied slightly with the year of cultivar release. Although variation in protein was from 37.0% to 45.5%, and oil concentration was from 16.7% to 22.0%, their concentrations were not consistently related to year of cultivar release. A 33% increase in the photosynthetic rate, 10.6% increase in plant dry weight and 19.0% increase in harvest index (HI) were found, while leaf area index (LAI) decreased by 17.3%. Modern cultivars have higher photosynthetic rates than their predecessors. The reduced plant height gave increased resistance to lodging, with the lodging score dropping from 3.2 in 1951 to 1.0 in 2006. Seed resistances to disease and pest infestation were also improved. Yield stability was enhanced over years, which could be attributed to the stable pod production across different environments. A flow diagram to explain the contributors to genetic improvement of soybeans in Northeast China was developed.

1. Introduction

Cultivar selection is an important way to increase crop yield (Ustun et al., 2001). In the north central region of the USA, the yield increase attributed to soybean breeding was between 10 and 20 kg ha^{-1} per year from 1902 to 1977 in maturity groups 00 through IV (Specht and Williams, 1984). A similar trend was found in the mid-southern region of the USA. Soybean yield increased from 1972 kg ha^{-1} grown from ancestral lines to 2609 kg ha^{-1} from fifth generation cultivars, and the annual gain was 14 kg ha^{-1} (Ustun et al., 2001). Nearly 79% of the yield increase in the northern states was attributed to genetic improvement (Williams and Specht, 1979).

Using 21 cultivars spanning more than 50 years of breeding, Luedders (1977) observed a 1.0% per year yield improvement, partially attributed to increased lodging resistance. Investigating 10 cultivars released from 1920 to 1974, Wilcox et al. (1979) found a 0.5% yield improvement without an expected change in phenotypic stability or lodging resistance, but with linear decrease in protein with year of release, accompanied by an increase in oil concentration. With 28 cultivars from maturity groups VI, VII and VIII, Boerma (1979) reported a 0.7% per year yield gain for cultivars released from 1942 to 1973. The yield increase was correlated with increasing pod number, while seed size and seeds per pod did not change greatly over time. Plant height decreased in maturity group VIII but did not change in groups VI and VII. In Canada, Morrison et al. (2000) tested 41 cultivars released over seven decades of breeding and selection, and found that the yield improvement had an association with a decrease in protein concentration and some reduction in lodging. Recent cultivars, compared with older cultivars, had a lower maximum leaf area, and higher photosynthetic rate and stomatal

Abbreviations: HI, harvest index; LAI, leaf area index; CAP, canopy apparent photosynthesis; CV, coefficient of variability.

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conductance per unit area (Morrison et al., 1999, 2000). Further studies on population density revealed that recent cultivars were more tolerant of population stress than older ones (Cober et al., 2005). Most recently, Morrison et al. (2008) found that seed isoflavone concentration significantly increased over 58 years of soybean breeding for yield in the short-season region, and recent cultivars were more environmentally influenced for isoflavone concentration than older cultivars. Isoflavone was positively associated with N-fixation and disease resistance (Zhang and Smith, 1995; Dixon, 2001).

Northeast China is the main soybean producing area in China, where the average soybean yield per hectare in 1990s increased by 71.4%, compared with that of 1950s, and the annual yield increase averaged 13.4 kg ha^{-1} (Xue et al., 2006). Northeast China had released approximately 600 soybean cultivars by the end of the last century (Liu et al., 2008). However, no investigation has been conducted on the agronomic and physiological changes in the released cultivars. As agronomic and physiological performance is the direct expression of genotype's genetic traits, understanding these changes is essential for planning further plant breeding strategies in soybean.

The best way of estimating genetic progress over time is to evaluate the history of cultivars in common environments (Cox et al., 1988). For this purpose, the following conditions are required: (1) experiments must be conducted under field conditions, (2) measurement must be done on comparable field plots, (3) cultivars released at different times must be compared simultaneously (Slafer et al., 1994), and (4) cultivars of a given maturity group must be grown in their adapted region.

In this study, 45 cultivars (maturity groups 00 and 0) that were released over the past 56 years in Northeast China were collected, and grown for 3 consecutive years to examine (1) the contribution of soybean breeding programs to yield increase, (2) what agronomic and physiological changes occurred which might be associated with yield improvement, and (3) whether the yield stability was related to genetic change over time.

2. Materials and methods

2.1. Culture practices and experimental design

Field experiments were conducted in 2006, 2007 and 2008 at Hailun Agroecological Experimental Station (47°26′N, 126°38′E, altitude 240 m), Chinese Academy of Sciences, Heilongjiang Province, China. Annual average sunshine at the research site is around 2600–2800 h, and growing degree days (GDD) (Dwyer et al., 1999) is 1362. The soil is the typical Mollisol (Black soil). The textural class of the black soil is silty clay loam or silty clay. Chemical characteristics were: soil organic matter of 50.77 g kg^{-1}, total nitrogen of 2.14 g kg^{-1}, total phosphorus of 0.98 g kg^{-1}, total potassium of 22.0 g kg^{-1}, alkali-hydrolysable N of 167.6 mg kg^{-1}, available P (Olsen et al., 1954) of 40.2 mg kg^{-1}, ammonium acetate extractable K of 140 mg kg^{-1}, and pH of 7.31 (1:5 v/v) in 2006.

Forty-five cultivars released over a 56-year period from 1950 to 2006 were chosen representing maturity groups 00 and 0 in Northeast China (Table 1). These cultivars were grown in a randomized complete block design with three replications at the station. Each plot consisted of 5 rows 5 m long with an inter-row spacing of 0.67 m. The seeds were sown on May 6, 2006, May 8, 2007 and May 4, 2008. The plants were thinned to a uniform stand of 27 plants m^{-2} after emergence. Di-ammonium phosphate of 50 kg ha^{-1} (N 18%, P_2O_5 46%), and composite fertilizer of 150 kg ha^{-1} (N 18%, P_2O_5 16%, K_2O 16%) were applied before sowing.

Table 1
Cultivar name, year of release, maturity group and days to maturity for the chosen 45 soybean cultivars.

Cultivar name	Year of release	Maturity group	Days to maturity
Xiaohuangjin	1951	MG0	128
Zihua 4 hao	1952	MG0	127
Yuanbaojin	1953	MG0	127
Ke 4430-20	1959	MG0	120
Fengshou6hao	1960	MG0	115
Hejiao 6 hao	1962	MG0	118
Keshansilijia	1962	MG0	118
Dongnong 4 hao	1963	MG0	125
Fengshou 10	1966	MG0	115
Xiaolidou 9 hao	1967	MG0	127
Heinong10	1969	MG0	118
Heinong16	1970	MG0	118
Mufeng 5 hao	1972	MG0	120
Nenfeng 1 hao	1972	MG00	113
Suinong 3 hao	1973	MG0	115
Hefeng 22	1974	MG0	115
Nenfeng 4 hao	1975	MG00	113
Hefeng 23	1977	MG0	118
Fengshou 17	1977	MG0	117
Hongfeng 2 hao	1977	MG00	110
Nenfeng 9 hao	1980	MG00	111
Suinong 4 hao	1981	MG0	115
Heinong 27	1983	MG0	120
Suinong 5 hao	1984	MG0	115
Dongnong 37	1984	MG00	113
Beifeng 3 hao	1984	MG00	108
Hefeng 25	1984	MG0	120
Beifeng 5 hao	1986	MG00	108
Suinong 8 hao	1989	MG0	120
Heinong 35	1990	MG0	120
Suinong 9 hao	1991	MG0	118
Kenong 4 hao	1992	MG0	118
Suinong 10	1994	MG0	125
Suinong 11	1995	MG0	117
Beifeng 11	1995	MG00	110
Suinong 12	1996	MG0	120
Suinong 14	1996	MG0	125
Suinong 15	1998	MG0	123
Heinong 45	2003	MG0	115
Kefeng 12	2004	MG0	117
Suinong 21	2004	MG0	120
Hefeng 47	2004	MG0	120
Suinong 22	2005	MG0	118
Hai 635	2006	MG0	123
Hai 5052	2006	MG0	125

2.2. Data collection and measurements

Phenological dates were recorded using the Fehr and Caviness (1977) growth stage key. During the period of maximum leaf area, i.e. full pod (R4) to beginning seed (R5) stage, a random 0.5 m^2 area in each plot was selected for sampling. The plants were cut at the soil surface, and were separated into stems, leaves, and pods. Leaf area per sample was measured by CI-203 portable laser leaf area analyzer (CID, USA). The leaf area was used to determine LAI that is the ratio between leaf area and the corresponding land area. The components were dried at 70 °C for at least 72 h before weighing. During the same period, a portable photosynthesis system (LI-6400; Li-COR Biosciences Inc.) was used to measure photosynthetic rate on penultimate fully expanded leaves. Measurements were done between 9:00 AM and noon on days with full sunlight. Lodging score was rated on a 1–5 scale (erect [1] to prostrate [5]) at the R5 to R6 stage (Morrison et al., 2000).

At full maturity (R8), plants in the central 4 m^2 of each plot were taken for seed yield measurement, and the yields were adjusted to 135 g kg^{-1} moisture content. Fifteen plants were selected for measurements of height, weight, seed number per plant, pod number per plant, seed size, and seed percentage with diseases and pests. Seed protein and oil concentrations were determined by