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Genetic gains for grain yield in high latitude spring wheat grown in Western Siberia in 1900–2008

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ABSTRACT

Short season high latitude (50°N–56°N) spring wheat (*Triticum aestivum* L.) is grown on approximately 7 million ha in Western Siberia with average yield of 1.5–2.0 t/ha. A historical set of 47 varieties developed and grown in the region between 1900 and 2000 was evaluated at a trial in Siberian Research Institute of Agriculture (Omsk) in 2002–2008. The genetic gains for grain yield and associated changes in agronomic traits were analyzed for three maturity groups (early, medium and late) and four breeding periods (before 1930, 1950–1975, 1976–1985 and after 1985). The overall yield was 3.71 t/ha for modern varieties versus 2.18 t/ha for old varieties representing 0.7% increase per year in the course of 100 years. The genetic gains between the breeding periods indicated that the rate of progress for the early and medium maturity groups was more or less comparable from one breeding period to the other. For the late maturity group there was an obvious and sharp decline in genetic gain with time. Modern varieties were also characterized by average response to environmental mean and good grain yield stability evaluated according to Eberhart and Russell (1966). Thousand kernel weight and number of grains per unit area were linearly correlated with grain yield and genetic gain over time suggested their importance for breeding progress. Resistance to leaf rust in some modern varieties sustained and contributed to stability of genetic gains. The yield increase over time was not associated with plant height reduction and incorporation of *Rht* genes. The maturity range of the newer varieties is narrower compared to old germplasm as they tend to belong to medium maturity group. Translocation 1B.1R had limited contribution to Western Siberian germplasm being observed in only three varieties. The increase in adaptation, yield potential and its stability has been reached due to gradual accumulation of favorable genes through diverse crosses, robust selection and testing system. Resistance to leaf rust and other prevalent pathogens is of paramount importance for future progress.

1. Introduction

The region of Western Siberia of Russian Federation lies between 50°N and 56°N and 60°E and 95°E with a typical continental climate. The city of Omsk is a center of the region with average yearly precipitation of 325 mm. Rains in June are critically important for crop yield. Severe winters with heavy snow allow planting in May. Once in five years there is frost (0 °C or below) in the end of August, thus, limiting the frost-free period to 100 or even 90 days (Kaskarbayev, 1998). The history of wheat (*Triticum aestivum* L.) cultivation in Russian Siberia dates back to the 19th century when first settlers arrived from European Russia. In the middle of the 20th century the region was transformed into a very important agricultural area supplying high quality grain for the local population and the rest of the USSR. The wheat area at its maximum in the 1960s and 1970s reached 35 million ha between Northern Kazakhstan and Siberia (Morgounov et al., 2001). Currently the whole Western Siberia grows around 7 m ha. The grain yield is variable depending on the year but on average it was 1.5 t/ha in Omsk region in 1998–2007 ranging from 1.2 t/ha in 2000 to 2.2 t/ha in 2001 (Shamanin, personal communication). Most of the wheat produced in Siberia and Northern Kazakhstan can be classified as a hard red spring type according to North American classification. Little if any inputs are provided for wheat cultivation. The crop rotation is based on summer fallow followed by three to four years of contin-

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uous wheat. Wheat research in Western Siberia started with the establishment of Omsk experimental field in 1880 which initiated testing of local wheat varieties (Morgounov et al., 2001). The first spring wheat varieties originating from crosses were released by Siberian Research Institute of Agriculture (SRIA) in 1950s and contributed substantially to the grain production increase. Over the last 20–25 years varieties originating from SRIA on average occupied an estimated area of 5–6 m ha not only in Western Siberia but also in the European part of Russia and in Northern Kazakhstan.

Historical genetic gains are considered from two major viewpoints: (a) the progress in yield or other important agronomic and quality traits; (b) associated phenotypic and genotypic changes in the course of the breeding to develop possible avenues for further variety enhancement. The recent review by Araus et al. (2008) provides a detailed analysis of the studies with the focus on physiological changes. The studies on yield genetic gains have covered the progress made in most of the important wheat producing regions of the world. It is commonly accepted that introduction of *Rht* genes contributed to substantial yield increase in irrigated environments (Sayre et al., 1997) and was also beneficial for the dry areas like the ones in Australia (Richards, 1992) or across the globe (Chapman et al., 2007). The 1B.1R translocation has proven to have positive effect both under irrigated and dry environments (Snape et al., 2007). However, many of the breeding and physiological studies on genetic gains are hardly relevant as such to low input short season Western Siberia environment.

The areas of high latitude short season spring wheat production similar to Western Siberia are in Canada, Northern Great Plains of USA, Scandinavia and possibly Australia due to its low yields limited by moisture availability. DePauw et al. (2007) summarized the studies with the Canadian Western Red Spring Wheat class. The genetic gains in the period 1984–2001 were much higher ($b = 0.74$) compared to the period 1908–1986 ($b = 0.33$) which is attributed to more intensive breeding programs and increase of population size. Modern Canadian varieties when compared to Marquis had more grain per spike and spike yield as well as higher harvest index as a result of higher biomass and slightly shorter stem (Wang et al., 2002). Newer Canadian varieties also extracted more moisture from 50 to 120 cm soil profile demonstrating higher water use efficiency as compared to old varieties (Wang et al., 2007). In Northern Europe (Finland) spring wheat demonstrated consistent genetic gains of 36 kg/year during 1970–2005 (Peltonen-Sainio et al., 2009) which was attributed to shorter stem, higher harvest index and higher weight of a single grain (Peltonen-Sainio et al., 2008). It is pointed out that high latitude Northern growing conditions are quite unique and the avenue for grain yield increase might be different from higher yielding environments with longer growing season. Muurinen and Peltonen-Sainio (2006) drew attention to the importance of radiation use efficiency for Northern growing conditions due to the short season. However, their study showed no evidence of consistent changes in radiation use efficiency between old and modern spring wheat varieties.

Perry and D'Antuono (1989) demonstrated that the genetic gain in breeding in Western Australia was associated with increase in harvest index for both modern tall and semi-dwarf varieties. The number of grains per spike and per unit area were strongly correlated with yield and explained the achieved genetic gains. This study is relevant for Siberia because the grain yield level is similar in a range of 1.5–2.0 t/ha. Another study in a similar environment in North Dakota with Hard Red Spring Wheat evaluated the genetic gains made during 1968–2006 (Underdahl et al., 2008). The genetic gains of 1.3% per year were attributed to improvement of yield potential as well as improvement in resistance to leaf rust (*Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici*) and Fusarium head blight (*Fusarium graminearum* Schwabe). Interestingly, genetic gains in North Dakota were not associated with substantial height reduction or days to maturity changes. Improved disease resistance resulted in higher test weight and 1000 kernel weight. In summary, the studies of the genetic gains of high latitude short season spring wheat breeding demonstrated consistent yield increase which in some cases was associated but not necessarily with height reduction and higher harvest index, higher number of grains per unit area variable changes in maturity and improved disease resistance.

Trethowan et al. (2006) compared the performance of high latitude Canadian, North American, Kazakh, Siberian, Chinese and Mexican germplasm through multilocational trial in these countries. North American germplasm evolved more towards shorter plant stature and day-length insensitivity as compared to Kazakh and Siberian varieties. However, the yield of Kazakh and Siberian germplasm was quite high not only in Siberia but also competitive with the Canadian varieties in Canada. It was obvious that tall stature and day-length sensitivity of Siberian germplasm played important role in the adaptation of the germplasm to local conditions and possibly contributed to a broader adaptation. From this angle it is interesting to analyze the genetic gains in Siberian varieties and their avenue for yield improvement as compared to other high latitude short season spring wheat regions of the world.

So far no systematic study has been published internationally on spring wheat genetic gains in Western Siberia. Zykin et al. (2001) in 1996–1999 studied a set of 18 varieties bred since 1929 at SRIA. The grain yield almost doubled in the course of breeding and the modern varieties were characterized by higher biomass, more grains per unit area and higher 1000 kernel weight. The current study utilized much broader germplasm covering all the maturity groups and all the important varieties released and grown in the region between 1891 and 1997. This study was also conducted for longer period of time (seven years) to allow evaluation of grain yield stability. The objective of the study was to document the genetic gains in high latitude short season spring wheat grown in Western Siberia and analyze associated changes in the agronomic traits and yield stability.

2. Materials and methods

2.1. Wheat cultivars

Forty-seven spring bread wheat varieties were chosen based on two main criteria: (a) only varieties officially released in Russian Federation for Western Siberia region were considered with the exception of the old varieties when there was no formal release system; (b) the varieties which occupied an area of at least 100,000 ha with proven contribution to wheat production. The germplasm was divided into 12 groups according to the maturity and the breeding period (Table 1). The period of vegetation plays a fundamental role for the short season spring wheats of Russia. The State Variety Testing Commission classifies all the released varieties into three major groups: early maturing (less than 95 days from emergence to maturity); medium maturing (95–100 days) and late maturing (more than 100 days) (Morgounov et al., 2001). In total, there were 16 early, 18 medium and 13 late maturing varieties. The division of

Table 1
The grouping of spring wheat varieties used in the study according to the maturity group and breeding period.

Maturity group	Number of varieties per period of breeding				
	Before 1930	1950–1975	1976–1985	After 1985	Total
Early maturity	3	3	5	5	16
Medium maturity	2	6	5	5	18
Late maturity	3	3	4	3	13
Total	8	12	14	13	47