Historical changes in grain yield and quality of spring wheat varieties cultivated in Siberia from 1900 to 2010

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Mateo Vargas[8], and Jose Crossa[8]

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Morgounov, A. I., Belan, I., Zelenskiy, Y., Roseeva, L., Tömösközi, S., Békés, F., Abugalieva, A., Cakmak, I., Vargas, M. and Crossa, J. 2013. **Historical changes in grain yield and quality of spring wheat varieties cultivated in Siberia from 1900 to 2010**. Can. J. Plant Sci. **93**: 425–433. This study focusses on changes in yield, protein content, micronutrient composition and bread-making quality of 32 historical bread wheat varieties. The germplasm was divided into four groups: viz. 1: bred before 1935; 2: bred 1955–1975; 3: bred 1976–1985; 4: bred after 1985. Yield genetic gain was 0.59% per year. The last three periods scored significantly higher for protein, gluten content and alveograph W values, compared with the first group, but did not differ significantly from each other. The physical dough properties of varieties developed between 1976 and 1985 were superior, as reflected by the W value, farinograph mixing time and degree of softening. Loaf volume was highest for the 1950–1975 group, representing a 15.6% superiority. There were significant and gradual reductions between the earliest and latest groups for protein (7.6%) and wet gluten (7.7%) contents. No changes in zinc and iron contents, important in determining grain nutritional value, were detected. Generally, modern germplasm had superior physical dough quality and stability. This improvement was not clearly associated with changes in the frequencies of high- and low-molecular weight glutenin alleles. Sustaining the genetic gains for yield and quality will require investigation of the effects and interactions of genes controlling adaptation and end-use quality of spring wheat in Siberia.

Key words: Genetic gain, grain quality, glutenin composition

Morgounov, A. I., Belan, I., Zelenskiy, Y., Roseeva, L., Tömösközi, S., Békés, F., Abugalieva, A., Cakmak, I., Vargas, M. et Crossa, J. 2013. **Évolution historique du rendement grainier et de la qualité du grain chez les variétés de blé de printemps cultivées en Sibérie de 1900 à 2010**. Can. J. Plant Sci. **93**: 425–433. L'étude portait sur les changements subis par le rendement, la teneur en protéines, le profil des oligoéléments et la qualité à la panification de trente-deux variétés de blé panifiable historiques. Le matériel génétique a été réparti en quatre groupes : groupe 1 : hybridé avant 1935; groupe 2 : hybridé entre 1955 et 1975; groupe 3 : hybridé entre 1976 et 1985; groupe 4 : hybridé après 1985. Le gain génétique sur le plan du rendement s'élève à 0,59 % par année. Les groupes des trois dernières périodes enregistrent une cote sensiblement plus élevée que le premier groupe pour la teneur en protéines, la concentration de gluten et la valeur W à l'alvéographe. Toutefois, ils ne varient pas significativement entre eux. La pâte des variétés développées entre 1976 et 1985 présente des propriétés physiques supérieures, comme le démontrent la valeur W, la durée du pétrissage au farinographe et l'importance de l'amollissement. Le pain atteint son plus haut volume avec les variétés du groupe 1950–1975, l'écart étant de 15,6 %. On observe des réductions importantes et graduelles entre le premier et le dernier groupe au niveau de la teneur en protéines (7,6 %) et en gluten humide (7,7 %). Aucune variation n'a pu être décelée pour la concentration de zinc et de fer, deux paramètres importants qui déterminent la valeur nutritive du grain. En général, le matériel génétique contemporain donne une pâte d'une qualité physique et d'une stabilité supérieures. On n'a pu associer clairement cette amélioration à une modification de la fréquence des allèles de la gluténine à haut et à faible poids moléculaire. Pour confirmer les gains génétiques réalisés sur le plan du rendement et de la qualité du grain, on devra étudier les effets et les interactions des gènes qui commandent l'adaptation et la qualité à l'usage final du blé de printemps en Sibérie.

Mots clés: Gain génétique, qualité du grain, composition de la gluténine

Wheat is an important crop in the Russian Federation, occupying around 25 million ha with an average yield of 2.0–2.3 t/ha (Morgounov et al. 2001). There are two major spring wheat production zones: the Volga region, from east of Moscow to the Ural Mountains, and western Siberia, from the Ural Mountains to the taiga forests of Novosibirsk. The Siberian region located 45–50° north is characterized by long cold winters with a short summer growing season of 90–110 d. Annual precipitation varies between 300 and 450 mm with equal distribution throughout the year. The environment is similar to the spring wheat production areas of Canada.

There are several public breeding programs developing new varieties for the region. The Siberian Research Institute of Agriculture (SRIA) in Omsk conducted a study of genetic gains in yield among an historical set of 47 spring wheat varieties in the period 2002–2008 (Morgounov et al. 2010). The study indicated an average yield increase of 0.7% during the past 100 yr. The genetic gain in yield was attributed to higher numbers of grains per unit area as well as higher 1000-grain weight. Unlike other spring wheat production regions of the world, Siberian germplasm does not possess *Rht* genes and therefore maintains tall stature. The conclusion was that the yield gains were achieved through the accumulation of minor favorable alleles. The study did not include an analysis of bread-making quality, as there were not sufficient data. A subset of 32 of the 47 varieties was studied between 2003 and 2010, with a primary objective of analyzing changes in bread making quality.

Analyses of genetic gains in yield and associated changes in agronomic traits in wheat are commonly used to develop breeding strategies and to prioritize traits for enhancement. Araus et al. (2008) reviewed studies on genetic gains in cereals grown under favorable and stressed environments. Depending on the crop and target environment, genetic gains in yield varied from 0.5 to 1.5% per year. Historical changes in end-use quality of wheat grain are less studied and are not clear. Since protein influences bread-making quality, the relationship between genetic gains in grain yield and protein content is fundamental to understanding the evolution of quality traits. Wang et al. (2003) compared recent Canadian spring wheat varieties with Neepawa and Marquis and concluded that the newer cultivars had significantly more grain nitrogen than the older cultivars, and significantly less non-grain nitrogen. The nitrogen harvest index for the newer cultivars was significantly higher than that of the older cultivars. In another study of Canadian spring wheat, DePauw et al. (2007) found that grain yield increased without loss of grain protein concentration. The negative correlation between grain yield and protein concentration had shifted rather than broken. In yet another Canadian study by Iqbal et al. (2007) grain protein content exhibited a negative genetic correlation with grain yield in spring wheat. However, higher-yielding lines with medium maturity and higher grain protein content were identified. Protein content in an historical set of US hard red spring wheat varieties declined significantly over time (Souza et al. 1993). These studies in high latitude spring wheat in the United States of America and Canada (similar to Siberia) indicated that changes in protein content accompanying yield increase can occur in both directions.

Most of the studies on genetic gains in grain quality parameters agree on the intrinsic improvement of bread making quality, both for dough physical properties and loaf characteristics. This was demonstrated for winter wheat in the United States of America (Cox et al. 1989), Belarus (Koleda et al. 2007), Spain (Gomez et al. 2009) and Bulgaria (Tsenov et al. 2011), and for spring wheat in the United States of America (Souza et al. 1993). A study on winter wheat in Slovakia found that breeding progress in grain yield was compensated by decreased parameters of quality (Uzik et al. 2009). High- and low-molecular weight glutenins play an important role in determining bread-making quality (Cornish et al. 2006) and variation in high- and low-molecular weight glutenin composition of wheat germplasm from different geographic regions has been well documented (Jin et al. 2011). However, changes in glutenin allelic variation in studies of the historical varietal sets have rarely been addressed.

There is growing evidence of the effect of mineral composition in wheat grain on nutritional quality (Cakmak 2008). This is especially important for iron and zinc. Garvin et al. (2006) studied a set of US hard red winter wheat for micronutrient concentration and showed that genetic gains in grain yield tended to reduce iron and zinc concentration. In another study (Murphy et al. 2008) 63 historical and modern wheat cultivars were evaluated for grain yield and concentrations of calcium, copper, iron, magnesium, manganese, phosphorus, selenium, and zinc. Whereas grain yield had increased over time, the concentrations of all of the minerals, except calcium, decreased. In a United Kingdom winter wheat study, Fan et al. (2008) evaluated changes in the mineral concentration of wheat to establish whether trends were due to plant factors (e.g., cultivar, yield) or changes in soil nutrient concentration. The mineral concentrations of archived wheat grain and soil samples from the Broadbalk Wheat Experiment (established in 1843 at Rothamsted, UK) were determined and trends over time in relation to cultivar, yield, and harvest index were examined. The concentrations of zinc, iron, copper and magnesium remained stable between 1845 and the mid-1960s, after which they significantly decreased, coinciding with the introduction of semi-dwarf, high-yielding cultivars. In comparison, concentrations in soil either increased or remained stable. Multiple regression analysis showed that both increasing yield and harvest index were highly significant factors in the downward trend in grain mineral concentrations.

The objective of the current study was to evaluate the genetic gains in bread-making quality and mineral composition in the grain of spring wheat varieties cultivated in Siberia from 1900 until 2010 and their association with yield increase.

MATERIALS AND METHODS

Thirty-two spring bread wheat varieties were chosen based on two main criteria: (a) only varieties officially released in the western Siberian region of the Russian Federation were considered, with the exception of old varieties that predated the formal release system; (b) varieties that occupied an area of at least 100 000 ha and therefore a proven contribution to production. The germplasm was divided into four groups, with eight varieties in each group according to the breeding period (Table 1).

Table 1. Grain yield and quality parameters of a historical set of western Siberian spring wheat varieties cultivated from 1900 to 2008, Omsk, average data for 2003 to 2010

Breeding period	Variety no.	Variety name	Pedigree	Year of selection	Maximum area (m ha^{-1})	Grain yield (t ha^{-1})	1000 grain weight (g)	Test weight (g L^{-1})	% grain protein content	Gluten content (%)	Alveograph W value	Farinograph mixing value	Loaf volume (mL)
Before 1930	1	Noe	Selection from local French variety	1891	–	1.88	29.30	747	17.88	36.10	239	60.1	767
	2	Smena	Selection from local Siberian variety	1919	–	2.20	30.45	764	17.41	35.25	191	55.0	782
	3	Lutescens 956	Selection from local Siberian variety	1919	–	2.09	29.90	744	17.83	35.63	195	53.7	802
	4	Marquis	Hard Red Calcutta/Red Fife	1911	–	2.89	33.55	740	16.75	33.59	332	63.5	956
	5	Albidum 3700	Selection from local Siberian variety	1925	–	2.22	31.65	751	17.06	34.18	237	58.6	836
	6	Milturum 321	Selection from local Siberian variety	1913	–	2.10	29.93	741	17.10	33.87	221	58.7	842
	7	Cesium 94	Caesium 117/Western Polba	1923	–	2.37	29.03	746	17.02	33.31	272	53.9	822
	8	Milturum 553	Milturum 321/Kitchener (Canada)	1927	2.5	2.16	30.10	749	16.78	33.61	282	63.5	940
1950–1975	9	Irtyshanka 10	Skala/Saratovskaya 36	1964	1.5	2.30	32.91	737	17.30	33.00	306	58.7	945
	10	Omskaya 12	Lade (Norway)/FKN 25 (USA)	1970	0.5	2.34	32.34	734	16.90	33.79	254	59.9	755
	11	Saratovskaya 29	Lutescens 91/Sarroza//Lutescens 55-11	1948	12.0	2.82	35.16	750	16.13	32.20	403	55.2	1007
	12	Sybakovskaya 3	Bezostaya 1/Saratovskaya 29	1965	1.0	3.03	38.03	767	15.63	31.15	346	59.4	922
	13	Omskaya 17	Lutescens 1138-166/Red River 68 (USA)	1972	0.5	3.03	35.16	770	16.20	31.81	439	62.5	1054
	14	Omskaya 19	Lutescens 1138-70/Lutescens 1210	1973	1.5	2.96	35.76	765	16.52	33.19	453	63.9	1059
	15	Omskaya 9	Bezostaya 1/Saratovskaya 29	1954	3.0	2.75	33.75	753	15.83	31.51	363	59.4	1031
	16	Omskaya 18	Omskaya 11/Heynes (WW) (USA)	1974	2.5	3.74	34.49	766	15.64	31.30	343	59.6	999
1976–1985	17	Rosinka	Physical mutant from Sibakovskay 3	1979	0.5	2.74	32.63	735	17.07	34.33	291	62.2	776
	18	Altayskaya 92	Novosibirskaya 67/Lutescens 4029	1981	1.5	2.46	33.26	763	16.70	32.95	458	64.9	943
	19	Shernyava 13	OmSHI 6/ANK 17//OmSHI 6	1985	0.5	3.79	39.29	766	15.76	31.19	296	59.1	905
	20	Omskaya 20	Irtyshanka 10//Graecum 114/Kavkaz	1980	1.0	3.42	34.40	733	16.12	31.65	416	65.4	1014
	21	Rosinka 2	Chemical mutant from Tselinnaya 21	1984	0.5	3.06	36.03	757	16.35	31.93	468	63.4	989
	22	Omskaya 24	Lutescens 1594/Sibiryashka 8//Krasnodarskaya 39	1977	0.5	3.25	37.84	749	15.85	31.64	465	69.4	1089
	23	Tertsiya	Saratovskaya 36/I 428010 (Canada)	1980	1.0	3.07	35.05	758	16.00	31.78	374	61.9	991
	24	Omskaya 28	Lutescens 19/Hybrid (Canada)	1985	1.5	3.90	36.18	777	15.33	30.58	375	60.0	1028
After 1986	25	Omskaya 32	Lutescens 162-84-1/Chris (USA)	1989	0.5	3.38	36.61	745	15.94	32.09	428	61.1	943
	26	Kazanskaya yubileynaya	Omskaya 20/Lutescens 204-80-1//Lutescens 3-86-6	1992	0.1	4.11	39.53	751	15.76	31.26	436	57.0	956
	27	Sonata	Tselinnaya 20/Tertsiya	1986	1.0	3.68	35.86	770	16.51	32.84	304	58.2	825
	28	Omskaya 29	Lutescens 204-80-1/Lutescens 99-80-1	1987	1.0	3.74	39.13	746	15.84	31.44	434	63.9	975
	29	Tuleevskaya	Olivatseva/Vendel//Lutescens 105 (WW)	1989	1.0	3.92	34.69	776	16.26	32.46	348	56.1	892
	30	Omskaya 30	Omskaya 20/Lutescens 204-80-1	1986	1.0	4.21	38.93	762	15.01	30.24	343	60.6	951
	31	Omskaya 33	Lutescens 137-87-39/Omskaya 28	1992	1.0	3.22	35.33	768	16.12	32.35	341	55.6	979
	32	Omskaya 35	Omskaya 29/Omskaya 30	1994	0.5	4.02	38.81	746	15.84	31.50	381	64.2	980

The first period before 1930 primarily represented selections from landraces and the first hybrid derivatives. This was followed by 20 to 25 yr of decline in the development of varieties due to various reasons, including World War II. The second period from 1950 to 1975 was characterized by the first wave of productive crosses and selections including spring × winter crosses. During the third period from 1976 to 1985, breeding programs were supported by the development of greenhouse and laboratory facilities and a more interdisciplinary approach to breeding. Foreign germplasm became available and contributed to the development of new varieties. The fourth period, from 1986 to 1997, reflected modern breeding with a better knowledge of varietal performance, wider access to germplasm sources and a broader range of methodologies utilized in breeding. Varieties from SRIA as well as varieties from other breeding programs in western Siberia and outside the region were included in the study. The variety Marquis from Canada was part of the study, as it was an important parental variety in the region during early breeding efforts.

The present work was conducted between 2003 and 2010 at SRIA, located near Omsk. The soil was a chernozem with an organic matter content of 4–5%. The preceding season was summer fallow representing the regular fallow–wheat rotation used in the breeding program. Planting was conducted between May 10 and 20 when conditions were favorable. Harvesting took place between Aug. 20 and Sep. 10, depending on the year. Fertilizers were not applied. Commercial herbicide Dialen Super (2,4-D + dicamba) was applied to control weeds following production recommendations. No fungicides were applied. The trial design (RCBD) consisted of a border plot to protect against environment effects and randomization of cultivars within maturity groups. Each variety was planted in a 30 m^2 plot with three replications. Grain yield was measured after harvesting and adjusted to 14% moisture. The Kjeldahl test was used to determine the nitrogen and protein contents. Grain quality parameters were defined using standard equipment. Macro- and micronutrients concentrations were determined in 2006, 2007 and 2008 using inductively coupled plasma optical emission spectrometry (ICP-OES) (Vista-Pro Axial, Varian Pty Ltd, Mulgrave, Australia) after acid-digestion in a closed-vessel microwave system (MarsExpress; CEM Corp., Matthews, NC). The presence of high- and low-molecular weight glutenin subunits was determined by RP-HPLC analysis. The presence of the 1B.1R translocation in lines was predicted by association with *Glu-B3j* (Gupta and Shepherd 1992). ANOVA was performed for all traits using SAS software. Tukey's Studentized Range (HSD) Test was used to evaluate the significance of differences between the varietal groups. Genotype × year interaction and stability analysis were performed using SREG biplot analysis as described by Cornelius et al. (1996) and Crossa and Cornelius (1997). Mean genetic gains were determined as the quotients of the b values from linear regression of the traits on years of development of the genotypes over the mean values for all genotypes.

Soil moisture availability in April and precipitation in May–July are primarily determinants of grain yield under western Siberian conditions (Morgounov et al. 2001). The long-term average annual precipitation in Omsk is 325 mm and the long-term average precipitation for May–July is 144 mm. Seasonal (May–July) rainfall over the 8 yr of experimentation varied from 114 mm in 2004 to 313 mm in 2007. Overall, the diverse combinations of the moisture and temperature were typical of western Siberian conditions.

RESULTS

Average grain yield and quality parameters for all varieties used in the study are presented in Table 1. Average yield across all varieties and years exceeded 3 t ha^{-1}. The highest yielding variety, Omskaya 30 (4.21 t ha^{-1}), yielded twice that of older varieties grown 100 yr ago. The genetic gain over all time period was 0.59% per year while it increased to 0.95% per year in the three latest breeding periods starting from 1948 (Fig. 1). The average protein content exceeded 16%, which is high compared with wheat produced in Europe or the United States of America. The Russian system of variety classification based on grain quality comprises a combination of grain, flour and dough traits. The superior

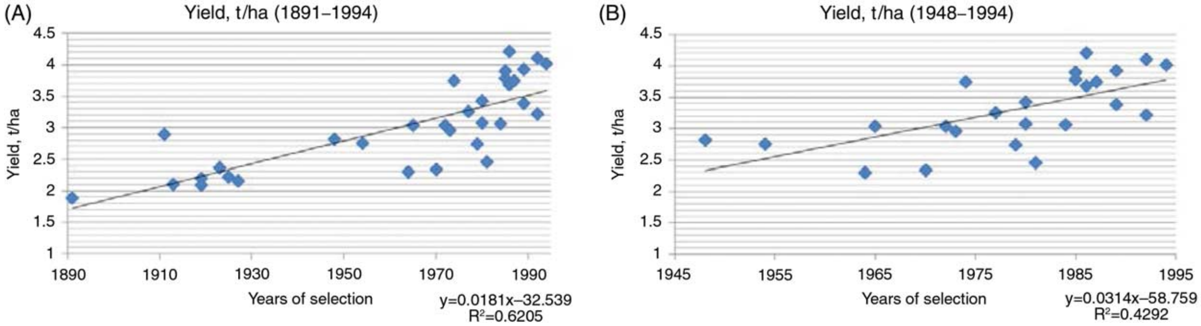

Fig. 1. Genetic gain of an historical set of spring wheat varieties grown in western Siberia: (A) all 32 varieties selected in 1891–1994; (B) varieties selected in 1948–1994.

(or strong) grade has a protein content exceeding 14%, gluten content exceeding 32%, and an alveograph W value of more than 280 units (Belousova 1990). The majority of varieties developed after 1976 meet the criteria for the superior quality grade. Spring wheat varieties Omskaya 20, Omskaya 28, Omskaya 29, Omskaya 35 and Kazanskaya Yubileynaya combined high yield with strong gluten and high loaf volume. ANOVA results (Table 2) demonstrated highly significant effects of years, breeding periods and genotypes for almost all traits. Average values of the traits per breeding period are presented in Table 3. For grain yield, the second and third breeding periods were significantly higher than the first period, and lower than the last period. The modern varieties group developed after 1986 was 68.4% higher yielding than the old varieties grown at the beginning of the last century. Significant and continuous increases were observed for 1000-grain weight (22.4%). For protein, gluten content and alveograph W value, the last three breeding periods were significantly higher than the old varieties, but did not differ significantly between each other. Average alveograph W value for the fourth breeding period was 52.0% higher than the old varieties group. Dough physical properties were also better than for varieties developed between 1976 and 1985, as reflected by W value and farinograph mixing time and softening degree. Loaf volume was highest for the 1950–1975 group, representing a 15.6% increase; however, it gradually declined in modern germplasm. There was a significant and gradual reduction in protein (7.6%) and wet gluten (7.7%) contents between the earliest and latest varietal groups. The 8 yr of data allowed analysis of genotype × environment interaction for the main agronomic and quality traits. SREG graphs for grain yield, 1000-grain weight, protein content and alveograph W value (Fig. 2) demonstrated that modern varieties had higher stability across years, when compared with the old germplasm. Genetic gains for these traits (with the exception of protein content) were accompanied by improved and stable performance under diverse weather conditions.

Table 2. Significance of differences based on ANOVA for grain yield and quality parameters in a historical set of spring wheat varieties, Omsk, Russia, 2003–2010

	Probability $>F$ values for treatments and interactions		
Trait	Year	Breeding period	Variety
Grain yield	<0.0001	<0.0001	<0.0001
1000 grain weight	<0.0001	<0.0001	<0.0001
Test weight	<0.0001	0.003	<0.0001
Protein content	<0.0001	<0.0001	<0.0001
Wet gluten	<0.0001	<0.0001	<0.0001
Alveograph, W	<0.0001	<0.0001	<0.0001
Mixing time	<0.0001	<0.0001	<0.0001
Softening degree	<0.0001	<0.0001	0.0211
Loaf volume	<0.0001	<0.0001	<0.0001

The concentrations of macro- and micronutrients in the grain of varieties developed over the past 100 yr were not significantly different for K, P, S, Mg, Fe, Mn, Cu and Zn (Table 4). The oldest varietials group had significantly higher concentrations of calcium relative to 1950s varieties. Among the mineral nutrients, zinc and iron are the main nutrients that play a significant nutritional role in human health at a global level and are currently subject to breeding efforts worldwide (Cakmak 2008). In general, the concentrations of these two micronutrients in the grain were high compared with other environments and this was probably due to the generally high protein contents and lower grain yields. Varieties with average zinc concentrations exceeding 40 mg kg^{-1} over 3 yr of trials included Noe, Albidum 3700, Irtyshanka 10, Omskaya 12 and Rosinka. The same varieties had the highest iron concentrations. However, all belonged to the old varieties group or were bred before 1986. Depending on the year, the coefficient of correlation between protein content and zinc concentration varied from 0.25 to 0.57, indicating a weak to medium positive relationship between the two traits. Since there was a tendency for reductions in protein content over time, it was clear that genetic gains in zinc and iron content are unlikely. Progress in yield and changes in dough properties over time did not affect the chemical composition of wheat grain.

Despite the reductions in protein content, improvement of dough physical properties and loaf volume in this historical set could be explained by changes in the composition of high- and low-molecular weight glutenins. For high-molecular weight glutenins, the allelic diversity at the three loci in this historical set was not high, but changed over time (Table 5). The frequency of *Glu-A1c* (Null) was 12.5% in the first breeding period, increased in the second period to 37.5%, completely disappeared in the third breeding period, and 12.5% in the modern group. The frequency of allele *Glu-D1d* (5 + 10) increased from 37.5% in groups 1 and 2 to 62.5% in group 3 and 50% in group 4. The effects of low molecular weight glutenin subunits on grain quality is less well understood than the effects of high molecular weight glutenins. Alleles *Glu-A3b*, *Glu-B3d*, *Glu-B3h* were present in the old varieties, but were not found in more modern germplasm. Alleles *Glu-A3c*, *Glu-B3b* and *Glu-D3b* increased in frequency over time. Only two varieties – one each from groups 3 and 4 – possessed 1B.1R translocation. The effects of glutenin alleles on quality traits did not clearly explain the genetic gains in the Siberian historical set.

DISCUSSION

The current study, which used a subset of historical cultivars and a longer time period, confirmed that genetic gains in grain yield of Siberian varieties were about 0.7% per year (Morgounov et al. 2010). During

Table 3. Grain yield and grain quality parameters of spring wheat varieties from different breeding periods, Omsk, 2003–2010

Period	Grain yield (t ha^{-1})	1000 grain weight (g)	Test weight (g L^{-1})	Protein content (%)	Gluten content (%)	Alveograph value (a.u.)	Farinograph		Loaf volume (mL)
							Mixing time	Soft. degree	
<1935	2.25*c*	30.52*c*	749*b*	17.21*a*	34.42*a*	248*b*	58.5*b*	98.86*a*	843*c*
1950–1975	2.87*b*	34.70*b*	755*ab*	16.27*b*	32.24*b*	365*a*	59.9*b*	89.58*ab*	975*a*
1976–1985	3.21*b*	35.58*b*	755*ab*	16.15*b*	32.00*b*	393*a*	63.3*a*	79.84*b*	967*ab*
>1986	3.79*a*	37.36*a*	758*a*	15.91*b*	31.77*b*	377*a*	59.6*b*	88.75*ab*	938*b*

a–c Different letters in columns indicate significant differences at $P = 0.05$.

the 8 yr of study, varying weather conditions permitted an evaluation of stability of the germplasm for yield and other traits. Again it was demonstrated that genetic gains in yield were accompanied by a more stable performance of the modern varieties. The yield progress was achieved without introduction of *Rht* genes or the 1B.1R translocation through accumulation of minor genes, primarily increasing grain size, grain numbers or grains per unit area (Morgounov et al. 2010). Calderini and Slafer (1999) observed a general decrease in yield stability with genetic gains in yield potential in a number of countries. In Siberia, with low input production and relatively low yields, it was possible to improve both yield and its stability.

Increasing the concentration of zinc and iron in wheat grain, from the current 25–30 mg kg^{-1} to 45–50 mg kg^{-1}, represents a major breeding objective of the Harvest Plus program, which specifically targets India and Pakistan

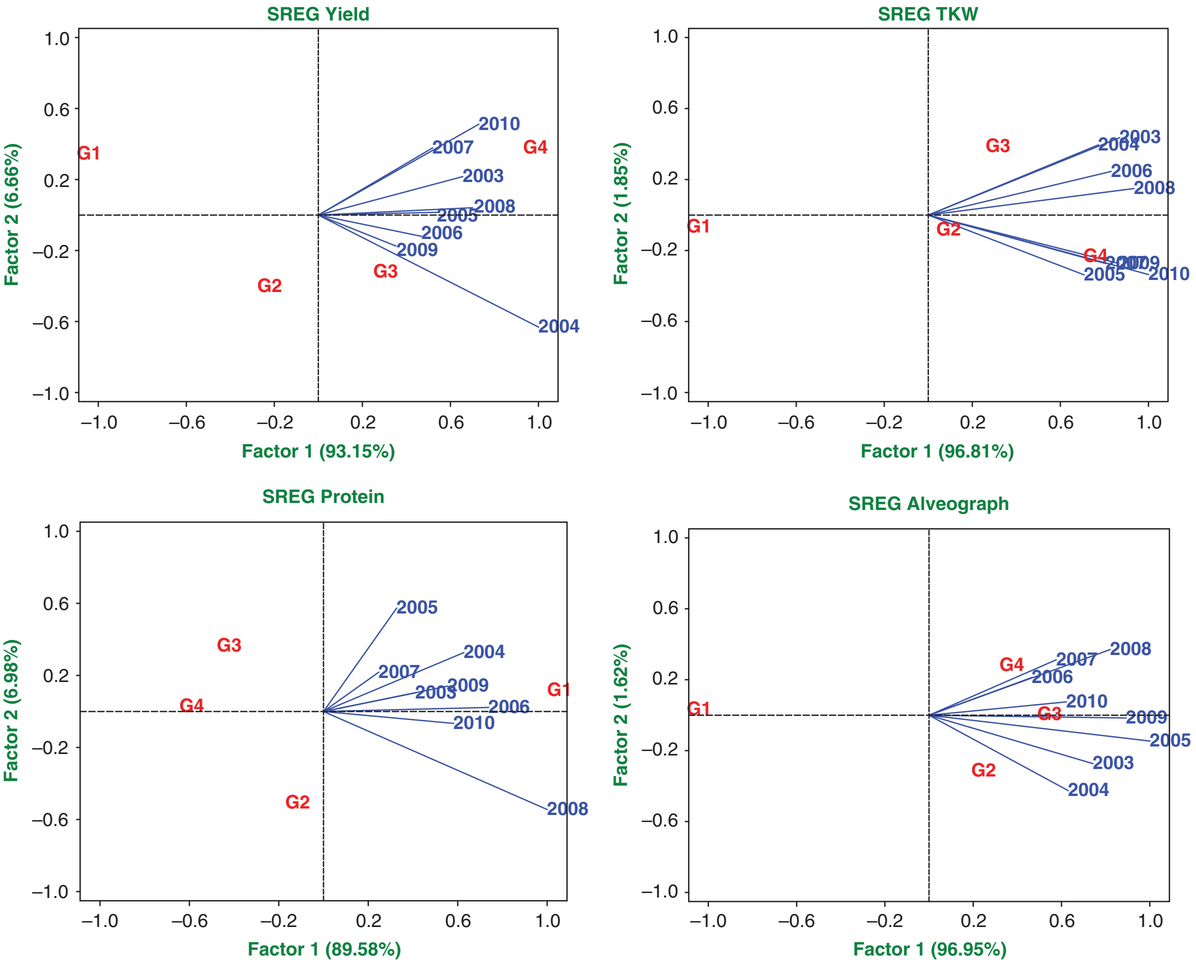

Fig. 2. SREG analysis for grain yield, 1000-grain weight, protein content and alveograph W value in a set of 32 historical spring wheat varieties grown in 2003–2010. G1, varieties cultivated before 1935; G2, 1950–1975; G3, 1976–1985; G4, after 1985.

Table 4. Concentrations of macro- and micronutrients in a historical set of spring wheat varieties grown in western Siberia in 1900–2010, and Omsk, 2006–2008

	%				Concentration (mg kg^{-1})				
Period	K	P	S	Mg	Ca	Fe	Mn	Cu	Zn
<1935	0.41	0.44	0.18	0.14	416*a*	44.9	39.9	2.70	37.0
1950–1975	0.40	0.43	0.18	0.14	370*b*	45.9	39.5	2.77	38.7
1976–1985	0.41	0.43	0.17	0.14	360*b*	43.1	37.8	2.75	35.8
>1986	0.41	0.42	0.17	0.14	360*b*	42.7	37.7	2.72	34.2

a, *b* Different letters in columns indicate significant differences at $P = 0.05$.

where whole meal flour is used for bread preparation (Ortiz-Monasterio 2007). Screening of a wide diversity of wheat germplasm demonstrated that limited progress can be made within the modern gene pool for these traits (Cakmak 2008). Current breeding efforts towards this objective include wide crosses involving *Triticum dicoccum*, *T. dicoccoides*, *T. spelta* and other sources to increase zinc and iron concentration (Rawat et al. 2009; Gomez-Becerra et al. 2010). Recent studies show that the concentrations of these micronutrients are positively correlated with the protein content (Morgounov et al. 2007; Zhang et al. 2010). Improving the nitrogen status in plants (e.g., tissue protein levels) by soil and/or foliar sprays of nitrogenous fertilizers such as urea contribute to root absorption, shoot transport and seed deposition of zinc and iron (Aciksoz et al. 2011). It appears that the nitrogen status of plants has a direct impact on check points that control the uptake, transport and seed deposition of zinc and iron. The current study found no significant genetic gain in concentration of any macro- or micronutrient except calcium, which was highest in the oldest varietal group and then declined in the mid-century and modern germplasm. This decline in calcium concentration in modern germplasm might have important adverse health consequences. Calcium is known to be an important structural nutrient in the human body and is needed for maintaining bone health and prevention of osteoporosis (Whiting 2010). One reason for widespread calcium deficiency in human populations is reduced calcium intake (Broadley and White 2010). Special attention should therefore be paid to the decline in calcium concentration in cereal grains where cereals are major source of daily calorie intake.

Despite decreasing protein and wet gluten contents, significant improvements in key grain quality traits (alveograph W value, mixing time, softening degree and loaf volume) were observed. Tsenov et al. (2011) compared yield and grain quality stability of recent winter wheat varieties in Bulgaria with Bezostaya. The newest varieties had both higher yield and stronger gluten. Several studies have demonstrated that genetic gains in yield were accompanied by improved physical

Table 5. Frequencies of high and low molecular weight glutenins and the 1B.1R translocation in a historical set of spring wheat varieties grown in Western Siberia in 1900–2010

			% of varieties with the *Glu* genes across breeding periods			
Glu locus	Allele	Subunits	<1935	1950–1975	1976–1985	>1986
Glu-A1	*a*	1	12.5	37.5	0	25.0
	b	2*	75.0	25.0	100.0	62.5
	c	Null	12.5	37.5	0	12.5
Glu-B1	*c*	7+9	75.0	100.0	87.5	50.0
	u	7*+8	25.0	0	12.5	50.0
Glu-D1	*a*	2+12	62.5	62.5	37.5	50.0
	d	5+10	37.5	37.5	62.5	50.0
Glu-A3	*b*		12.5	0	0	0
	c		12.5	25.0	62.5	37.5
	d		37.5	12.5	0	12.5
	f		37.5	62.5	37.5	50.0
Glu-B3	*b*		25.0	50.0	62.5	50.0
	d		12.5	0	0	0
	h		12.5	0	0	0
	g		50.0	50.0	25.0	37.5
	j		0	0	12.5	12.5
Glu-D3	*a*		75.0	50.0	37.5	37.5
	b		25.0	50.0	50.0	62.5
	c		0	0	12.5	0
1B.1R			0	0	12.5	12.5

dough properties, despite a tendency for protein content to decrease (Cox et al. 1989; Souza et al. 1993; Gomez et al. 2009). Functional dough properties were evaluated in this study using several parameters. Gluten strength was evaluated by alveograph W value. The strongest gluten was observed in the group of varieties bred between 1976 and 1985, partly due to an increased frequency of *Glu-A3c*, with a large positive effect on this trait. Its frequency decreased in the most recent varietial group, and the W value decreased as well. This does not correspond with the summary of previous reports on the effect of this allele on gluten strength (Cornish et al. 2006). Gluten extensibility, as reflected by farinograph mixing time, was also highest for varieties bred between 1976 and 1985 and was slightly but significantly lower in the most recent group. The number of varieties tested did not allow a statistical comparison of the effects of individual glutenin alleles on bread-making quality parameters.

Overall the study concludes that Siberian spring wheat breeding achieved yield genetic gain of 0.95% since the late 1950s without reduction in height and maintaining day length sensitivity. The progress in yield was accompanied by an increase in 1000-grain weight and test weight as well as improvement of dough physical properties despite the tendency of protein content reduction. Stability of both grain yield and quality also improved over time. The enhancement of grain quality was not clearly associated with the known glutenin alleles. Their effect on end-use quality deserves further investigation. There is no deterioration of grain nutritional quality over time associated with lower content of zinc and iron. Sustaining these genetic gains in the future may require investigation of the role of major adaptation systems (plant height and daylength sensitivity) and combination of adaptive traits on grain yield.

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