Breeding strategies to improve grain yield and quality of short-season spring wheat for the steppe of Kazakhstan and Siberia

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INTRODUCTION

The region of Northern Kazakhstan and Siberia represents relatively uniform region growing close to 20 mln ha of spring wheat. The growing season is short from mid-May till the end of August or early September. Precipitation varies between 300-450 mm per year. The dominating cropping system is fallow followed by 3-4 years of continuous wheat. Average wheat yield is 1.0-1.5 t/ha depending on the year. Though spring wheat has been cultivated in the region for more than 100 years the region gained real importance in the 1950s and 1960s when the virgin lands were turned into arable wheat production areas (Morgounov, Trethowan, 2008). The area under wheat reached its maximum in Kazakhstan in 1980s (over 20 mln ha) and then drastically reduced to 10-11 mln ha in 1990s due to the overall economic crisis. In 2000s the yield was gradually improving and the demand for wheat resulted in slight expansion of the area. The wheat producers in the region are very diverse varying from small private farmers owning 1,000-2,000 ha to small or average size cooperatives (up to 10,000-15,000 ha) or big grain companies operating up to 100,000 ha or even more.

The improved profitability of the grain production over the last 3-5 years resulted in higher demand for varieties and technologies. Producers have been replacing the field machinery and looking for more profitable production options. They also became much more interested in spring wheat varieties they chose for their fields. The demand for the new and better varieties is driven by the desire to obtain the highest possible yield with as little penalty for stresses as possible on one hand. On the other hand the grain quality shall meet the requirements of at least the 3rd Quality Grade not to pay penalty for poor grain. Spring wheat variety development in Kazakhstan and Western Siberia is primarily done by the public research and breeding institutions.

The majority of the varieties grown in the region are of local origin. Since 1999 when CIMMYT established its program in the region new cooperative activities were initiated. Kazakhstan-Siberia Network on Spring Wheat Improvement (KASIB) was established in 2000 uniting 18 programs of the region in germplasm and communication exchange. Shuttle breeding program between KASIB and CIMMYT-Mexico was established to integrate resistance to rusts into local germplasm (Trethowan et al, 2006). Several joint experiments were conducted. The results from all these research and breeding activities were analysed to formulate the components of spring wheat breeding strategy for this region.

THE MAIN ABIOTIC AND BIOTIC STRESSES IN KAZAKHSTAN AND SIBERIA AND ADAPTATION OF LOCAL VARIETIES

The major abiotic stress affecting wheat production in the region is lack of moisture. It was believed that wheat suffers from drought in the region on average two years out of three (Morgounov et al, 2001). In dry years average yield would be in a range of 0.4-0.8 t/ha. June is the month when the rainfall is minimal and it also coincides with the critical wheat development stages. For this reason most of the varieties grown in the region have relatively long tillering period so that the stem elongation and booting stage take place when the rains are more likely in late June and early July. There are indications that the climate change may be beneficial for Kazakhstan as no drought was observed in the country since 1998.

For high-latitude short season spring wheat there are two major genetic systems affecting the adaptation: Rht and Ppd. The height and sensitivity to the day length play very important role for adaptation and, hence, agronomic performance. The high-latitude short-season spring wheat belt has global distribution from the region described here to Northern China in the East, Volga region in the European Russia and Scandinavian countries in the West. It is also present in Northern USA and Canada. Experiments conducted in 2002-2004 included 30 varieties from similar latitude breeding programs of China, USA, Canada and Kazakhstan/Siberia. They were tested in trials for yield and other traits across 7-8 global locations in the countries mentioned above (Trethowan et al, 2006b). The results of the trials are presented in Table 1.

Obviously, the Kazakhstan/Siberian material represents more extensive taller types of wheat while the germplasm from similar regions of USA and Canada evolved into shorter almost semi-dwarf types. The experiments with extended day-length also demonstrated that the Kazakh/Siberian varieties possess strong requirements to long day and delay substantially flowering under the short day while once again the germplasm from USA and Canada is less sensitive. How these differences are reflected in the grain yield? It turns out that taller and later Kazakhstan/Siberian material is quite competitive in grain yield not only in its own region but also outside competing with Canadian varieties in Canada and US varieties in USA. Several attempts to introduce the modern Canadian varieties into Northern Kazakhstan are challenged by their lower yields compared to currently grown varieties. It can be concluded that the current types of spring wheat are probably most suitable from the point of view of maximizing the grain yield in the environment of 1.5-2.5 t/ha.

Table 1. Mean grain yield and plant height of high latitude spring wheat varieties, 2002-2004 (Trethowan, et al. 2006b)

Genotype Origin Group	Countries where the trials were sown:				
	Canada	USA	China	KAZ/SIB	Mexico
Grain yield, t/ha					
Canada	3.10a[1]	3.98ab	3.79c	1.99ab	2.30b
China	2.79b	3.38b	4.44a	1.64b	2.07b
KAZ/SIB	3.10a	4.16a	4.23ab	2.36a	1.14c
Mexico	2.91a	4.04a	3.93bc	2.09ab	3.44a
USA	2.82b	3.78ab	3.94bc	1.80b	2.29b
Plant height, cm					
Canada	75.5b	-	81.0ab	59.6bc	88.1d
China	76.8b	-	87.2b	54.2c	93.4c
KAZ/SIB	92.3a	-	97.9a	74.8a	100.0a
Mexico	68.7c	-	79.6d	54.9c	88.5d
USA	78.4b	-	84.7bc	62.1b	96.7b

[1] Means followed by the same letter within each column not significantly different at P<0.05

The role of biotic stresses and rust diseases in particular is frequently underestimated by both the producers and unfortunately the breeding community. Leaf rust being a major pathogen normally occurs during favourable years with precipitation when the farmers obtain yield higher than average. However, they do not realize the losses of 10-30% occurring in their fields. Over the last 10 years leaf rust occurred annually throughout the regions or in substantial areas. The review of the leaf rust work in Kazakhstan and Siberia and related breeding is given by Morgounov et.al. (2007). By 2000 there was hardly any variety resistant to leaf rust grown in the region. This situation coupled with increased precipitation resulted in widespread leaf rust. Observation on the trap nurseries based on Thatcher isogenic lines demonstrated that every year the genes *Lr9, Lr28* and *Lr36* provided complete resistance. The genes *Lr19, Lr 24, Lr25* and *Lr37* were resistant or moderately resistant depending on the year. Some genes (*Lr12, Lr29, Lr30*) seem to have slow rusting effect with moderately susceptible reaction type but rust severity not exceeding 50%.

Starting from mid-1990s CIMMYT initiated broad germplasm exchange and cooperative breeding efforts with the region to enhance leaf rust resistance while maintaining the general adaptation and grain quality. Testing of CIMMYT germplasm showed that its resistance effective in Mexico was also effective in Northern Kazakhstan and Siberia. The spring wheat varieties from similar environments in Canada and USA also demonstrated good resistance in Kazakhstan. Crossing program based on local varieties crossed with Mexican, USA and Canadian rust resistant germplasm proves beneficial for combination of adaptation and disease resistance.

Such a crossing program was initiated in the framework of so called "shuttle breeding" (Trethowan et al., 2006). The crosses between Kazakh and Mexican germplasm are made in Mexico and developed until F4-F5 generations under continuous leaf rust pressure. Frequently, top crosses or three-way crosses are made utilizing the best parents from USA and Canada. The resulting populations are sent to the region to be selected for adaptation, leaf rust resistance and other traits. The best lines identified are advanced in the breeding program, utilized in the crosses and also sent back to Mexico for the next cycle of crosses. The first crosses were made in 2000 and by 2008 the program produced lines combining leaf rust resistance with high yield. The lines originating from crosses AKMOLA 2/PASTOR**,** AKMOLA3//3/TRAP#1/YACO//BAV92, KAZACHSTANSKAYA10 //PASTOR1/YACO/3/BAV 92, TSELINNAYA 24//HXL7573/2*BAU exceed the yield of the local check by 10-20% while demonstrating high degree of resistance to leaf rust. It appears that incorporation of leaf rust resistance into locally adapted germplasm would be an important strategy to improve grain yield in favorable years when the production suffers from the pathogen

GENOTYPE X ENVIRONMENT INTERACTION IN KAZAKHSTAN-SIBERIA WHEAT NETWORK

Kazakhstan-Siberia Network on Spring Wheat Improvement (KASIB) was established in 2000 and since then annually conducts cooperative yield trails in all 15-18 participating programs. Each breeding and research program submits 2-3 new varieties or breeding lines to the trial which is conducted for two years in a row. After two years new varieties/lines are submitted for testing. The data from the KASIB trials represents quite a unique tool for analysis of the genotype x environment interaction as well as identification of the best genotypes based on mutlilocational data. ANOVA of the yield data of 40 genotypes in 22 environments in 2003 and 2004 demonstrated that the variation due to environment dominated in the contribution to the overall yield variation followed by genotype x environment interaction and by genotypes (Gomez-Becerra, et al, 2007). However, the role of genotypes is much more pronounced within one year and in more limited geographical area. There is a clear role of maturity group in contribution to G x E variation. Traditionally, the cultivated varieties are assigned to three major maturity groups: early; medium and late. The average difference between the groups in heading date and maturity is 5-7 days. Depending on the weather conditions and dates of planting the yield of different maturity groups varies substantially. It is recommended that producers grow varieties belonging at least to two maturity groups to reduce the risks. In fact, division of the breeding germplasm into maturity groups and comparing the genotypes within the same group is an important component of the breeding strategy for the region. The KASIB G x E interaction once again proved the importance of leaf rust resistance, The highest yielding genotypes in the absence of the pathogen demonstrated poor yield performance when the leaf rust infection readings reached 30-50%.

The important consideration for the breeding strategy is wide adaptation versus specific adaptation of the varieties targeted for the region. So far the production in the region was dominated by the so-called mega-varieties each occupying the area of 1-3 mln ha (Morgounov et al, 2001). In the past, area under some varieties like a landmark Saratov 29 occupied 10-12 mln ha. KASIB data represents excellent tool to show if any variety could be utilized throughout the region or there is a tendency of one variety being more specifically adapted to geographically limited area. Analysis by Gomez-Becerra et al (2007) of the performance of 40 genotypes across 22 environments showed that the most widely adapted variety Lutescence 54 was in top five highest yielding in 13 environments out of 22. The importance of recommending right variety for each environment is emphasized. An improvement of 0.89 t/ha can be achieved if only the dominant variety for each environment is grown.

VARIATION IN GRAIN QUALITY AND STRATEGIES TO IMPROVE IT

The KASIB trails also served as an instrument to study the G x E for grain quality characteristics (Gomez-Becerra, personal communication). A major quality constrain detected was low flour strength, which can be attributed in part to low glutenin content (low glu/gli ratio). Important associations among quality traits were found, of which, the strong positive correlations between gliadin content and grain micronutrient concentrations (especially with Zn), and the positive associations of Fe-grain content with stability time, water absorption and valorimeter are notable. Higher concentrations of Fe and Zn were found to affect negatively only two quality characteristics: flour color (whiteness) and glutenin content, to a lesser extent. However, these negative effects appear to be minimal in comparison with the expected large positive nutritional benefits and the positive associations with flour strength related traits. Based on G x E interaction breeding scenarios including three locations with two replicates are suited for most of the quality traits. Nevertheless, faster improvement of flour strength could be achieved if a larger number of locations were contemplated. Also, for the improvement of glutenin content, increasing diversity by introducing genotypes with higher glutenin content (or higher glu/gli ratio, which seems to be more genotypic dependent) would be desirable.

In 2007 cooperative efforts of the scientists from Australia, Hungary and Kazakhstan evaluated grain quality parameters of a large number of diverse germplasm from the region. The overall results confirm that the bread-making quality of the grain from the region can be improved for Kazakhstan to play sufficiently significant role as a grain exporter. The variation in high- and low-molecular weight glutenins was quite diverse and also can be improved to enhance the quality. Surprisingly, relatively high frequency of 1B.1R translocation was detected. The grain quality of introduced Canadian varieties was better compared to local germplasm but their yield was lower.

The strategies of improving the grain yield of the new varieties should take into account possible compromise with the bread-making grain quality.

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