Recent Developments in Triticale Breeding Research and Production - An Overview

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ABSTRACT

This paper reflects an overview and collates possibly new information about current triticale status in Poland and elsewhere. There will be considerable production, breeding research, biology, and agronomy of triticale. Considerable improvements were made in modern triticale cultivars with respect to agronomic performance, resistance to biotic and abiotic stresses and nutritional quality, in particular for human consumption and wider adoption as a viable commercial crop. In the past decades, new breeding tools and enabling technologies (doubled haploid, marker assisted selection, genomics selection, transgenic, functional genomics, and targeted genome editing) have been refined or developed anew and are successfully exploited in triticale improvement. Through, the integration of these tools and technologies with conventional plant breeding approaches, triticale biological potential has been enhanced to make this small grain species an economically successful crop.

Keywords: Triticale, breeding, biotechnology, resistance, somaclonal, androgenic variation, grain production

Triticale past

History of triticale dates back to XIXth century when hybrids between wheat and rye after spontaneous or intentional crossings were observed (Wilson 1876). Since then, almost over a century, triticale was considered as a scientific and/or breeding novelty. On the turn of XIX and XX centuries, many attempts were made to cross wheat and rye, but majority of them were ended with sterile triticale offspring. Such situation lasted until breeding techniques were elaborated and introduced to produce fertile hybrid plants called triticale. According to bibliographic data, in 1930's the name ‘triticale’ was coined combining Triticum and Secale, the Latin names of wheat and rye.

Crosses of durum wheat [Triticum durum (4x - AABB)] with rye [Secale cereale (2x - RR)] produced triploid embryo ABR F₁ (3x). After going through embryo rescue and chromosome doubling with colchicines (Pilch 2001) fertile hexaploid plants of primary triticale were obtained. For a better understanding, the simplified scheme is being shown in figure 1. Most often, the production of variety is much more complex. After a completion of crossing work, selection work is carried out in breeding plots to identify the high yielding genotypes.

It is known from numerous reports on triticale breeding research, that various types of primary triticale could be synthesized with different chromosomal constitutions after crossing different species of wheat with rye, e.g. crossings of Triticum turgidum (AABB) or Triticum aestivum (AABBDD) with rye produced either hexaploid (AABBRR) or octoploid (AABBDDRR) triticale, respectively. It is to indicate, that wheat is the mother plant and rye serves as the pollinator. It also has been tried to make the reversed crosses when rye served as mother plant and wheat as pollinator. The final product was called Secalotricum, but such attempts were unsuccessful so far. Secondary triticales
have been produced by crossing two differently composed primary triticales. The diversity of triticle lines can be enlarged by production of substitution triticales. In such a cross soft, hexaploid wheat with a genome AABBD serves as mother plant, pollinator is secondary, hexaploid triticle with a genome AABBRR to give in a progeny substitution hexaploid triticle with a genome AABBRR or AABBD.

It needs to be emphasized, that among various types of triticales, hexaploid triticle (durum × rye) has commercially been the most successful because of showing superior vigour and reproductive stability. The octoploid triticle type was produced by crossing common wheat × rye. Unfortunately, in comparison to hexaploid type the latter one suffers from greater genetic instability and associated floret sterility (Mergoum et al., 2009).

**Contribution of biotechnological methods into triticle breeding.**

The cross-incompatibility barrier between (4x) wheat and rye has limited the genetic base for triticle breeding. To overcome this problem, biotechnological methods like embryo culture technique, somatic embryogenesis, androgenesis (doubled haploid technology), molecular markers, and genetic engineering have been used in breeding of the crop. It is to underline that since very beginning, triticle has been difficult to obtain as in vivo crosses except through rescue of embryo culture. According to Zimny and Loerz (1996), the production of haploid triticle plants was described for the first time by Ya-Ying in 1973. So far, microspore and anther culture have been most widely used and incorporated into triticale breeding programs (Ahmed & Allam, 2003, Arseniuk and Walczewski 2014). These provided an opportunity to create haploid and doubled haploid plants within a single season, thereby reducing the time and cost of cultivar development. So far, 12 sustainable and highly productive triticle cultivars have been released on the basis of anther culture technology in Poland (Table 1).

Despite the fact, conventional triticale breeding focuses on the selection of superior progeny from segregating populations, and selection is mostly based on phenotypic characters. The breeders are looking for new approaches and tools to reduce the environmental effect on the selection of appropriate triticale genotype, since there is a confounding impact of environmental factors on phenotype. Breeding of new variety, takes up to 15-20 years and the release of an improved variety is not really guaranteed and it depends on the utilization of the best parental combination. So, this is the reason that the recent approaches in triticale and cereal breeding have been focusing on application of molecular marker techniques and DNA technology.

The application of molecular markers in triticale breeding research is quite extensive and its main uses include:

- **Assessment of genetic diversity and characterization of germplasm collections** (Niedziela et al., 2016; Kang et al., 2016);
- **Variety fingerprinting for identification, accelerating the development of individuals that combine favourable alleles, contributing to hybrid performance prediction, establishment the distinctiveness of new cultivars prior to registration and protection** (Ma and Gustafson, 2006);
- **Estimation of genetic distances between populations, inbreds and breeding material** (Niedziela et al., 2016);
- **Facilitation of the introgression of chromosomal segments from alien species and even tagging of specific genes** (Hakeem et al., 2016);
- **Detection of monogenic and qualitative trait loci (QTLs)**(Reszka et al., 2007);
- **Purity and stability of the seed and plant material** (Góral et al., 2005);
- **Identification of sequences of useful candidate genes, etc.** (Hakeem et al., 2016).

**Response to biotic and abiotic stresses**

Triticale was developed with a hope that in addition to the high yield potential and good grain quality of wheat, it will combine the resistance/tolerance to the biotic and abiotic stresses of rye. Initially, diseases did not appear to reduce triticale yields greatly. This could be explained by limited triticale acreage worldwide. At early stages, the area of triticale was insufficient for pathogens to adapt to the crop to cause serious outbreaks of diseases. The importance of diseases started to increase, as the amount of land planted with the small grain species has been steadily expanded in majority of triticale producing countries. Among adverse factors, at the beginning, like stem rust, ergot, *Fusarium* head blight (FHB), and leaf spots were recognized (Arseniuk 1996). Other adverse factors that downgraded triticale grain quantity and quality for end users included its late maturity than wheat, preharvest sprouting and pedoclimatic conditions. All these adverse factors contributed to lower triticale feed classifications and have reduced economic returns. On the other hand, lack of crop insurance coverage in quite a number of countries, inadequate research investment, lack of production technology, perception about triticale end-uses, lack of good-quality pedigreed seed, limited marketing options for farmers resulted in increases of economic risks to produce triticale.
It is to indicate, that triticale is a crop on which pathogens of wheat and rye meet, but there is evidence that on triticale embedded more so called “wheat pathogens”, than rye ones. For such a notable example many server races of *Puccinia recondita*, the causal agent of leaf rust. In the latter respect, triticale also appears to bridge direct contacts for a number of pathogens e.g. between physiological forms of the most important cereal rusts. Such contacts stimulate somatic hybridization on a triticale plant and may finally result in new pathogenicities and virulence factors. Such new emerged forms, are able to attack triticale, wheat and rye. In such cases, resistance genes are becoming ineffective. The first disease which occurred on this cereal in epidemic proportions was stem rust (*Puccinia graminis* f. sp. *tritici*) in Australia.

Leaf and stripe rusts caused, respectively by *P. recondita* f. sp. *tritici* and *P. striiformis*) also have gained importance everywhere in triticale grown areas, and especially in Poland. In recent years, at least in Poland, powdery mildew caused by *Blumeria graminis* occurred in epidemic proportions in quite a number of winter triticale cultivars. Similar phenomena have appeared with a number of other diseases caused by facultative pathogens, such as, the most damaging disease to triticale is the *Paras ofpora* spp. leaf and glume blotch disease complex, *Zymoseptoria tritici* inciting speckled leaf blotch and other pathogens like *Cochliobolus sativus*, *Fusarium culmorum*, and *F. graminearum*, *Microdochium nivale*, *Bipolaris sorokiniana*, *Oculimacula yallundae* (Wallwork & Spooner) Crous & W. Gams) (synonym: *Pseudocercosporella herpotrichoides*), and *Gaeumannomyces graminis* var. *tritici* inciting head, leaf and seedling blights and foot, crown and root rots. In addition to fungal pathogens, triticale is affected by bacteria, viruses, virus-like organisms and nematodes (Arseniuk and Góral, 2015). Research reports have shown that triticale presents broad genetic diversity to abiotic stresses, like drought, frost and cold, pre-harvest sprouting, water logging, lodging, shattering, Al toxicities (Arseniuk and Wálczewski 2014; Blum 2014; Arseniuk 2015). Triticale is also tolerant of low pH (acidic soils), grows well on sodic soils, and tolerates high in boron soils. Its high productivity and resilience to growing conditions become as important as wheat and it is so already in Poland.

**Cultivation and production**

Triticale was originally promoted as a new cereal crop that combines the superior agronomic performance and the end-use qualities of wheat with high resistance/tolerance to biotic and abiotic stresses and adaptability of rye to poorer pedo-climatic conditions. This small grain cereal species is also considered as germplasm resource of improvement genes for resistance to the above mentioned stresses in wheat. Unfortunately, so far, triticale has only been recognized to have potential as a fodder cereal and to some extent as promising cereal for energy supply because of its high biomass and grain yield. The harvested area varies from year to year, but this is steadily increasing. Over about 30 years, the progress in the total harvested area of triticale appeared quite rapid, e.g. in 1985, triticale globally was grown on 232,631 ha and in 2016, on 4,234,298 ha and in 2015, even on 4,559,828 ha. Thus, the growing area over 30 years increased 19.6 times (Figure 2).

On the other hand, in Poland in 1985 triticale was grown solely on 20,000 ha and in 2015 and 2016, cultivated on 1,516,168 ha and 1,373,529 ha, respectively, so over 30 years, the growing triticale area in Poland has been increased 75.8 times (Figure 3)

In 2016, top triticale grain producers were as follows: Poland produced 5.1 million metric tonnes (m. mt) on 1.4 million ha; Germany produced 2.4 m mt. on 396,1 thousands ha (th. ha), Belarus produced 1.6 m mt. on 0.5 m ha, France produced 1.4 m mt. on 334.2 th. ha, Russia produced 0.62 m mt. on 223 th ha and Hungary produced 0.5 m mt. on 139,1 th. ha (FAO Stat). Likewise, the grain tonnage, the growing area is also varying from year to year, but it also is steadily increasing. In 2016, worldwide, 15.2 million metric tons of triticale grain was produced on almost 4.2 million ha (Figure 4).
Table 1. Triticale cultivars developed by Polish breeders on basis of anther culture technology

<table>
<thead>
<tr>
<th>DANKO breeders</th>
<th>Winter triticale</th>
<th>SPRZELCE breeders</th>
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<th>Winter triticale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard's yield</td>
<td>81.1 dt/ha</td>
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<td>Standard's yield</td>
<td>87.7 dt/ha</td>
<td>SPRZELCE breeders</td>
</tr>
<tr>
<td>Rotondo DH</td>
<td>103%</td>
<td>Panteon DH</td>
<td>105%</td>
<td>Dublet DH</td>
<td>102%</td>
<td>SPRZELCE breeders</td>
</tr>
<tr>
<td>Twingo DH</td>
<td>94%</td>
<td>Borowik DH</td>
<td>102%</td>
<td>Sopo DH</td>
<td>105%</td>
<td>SPRZELCE breeders</td>
</tr>
<tr>
<td>Torino DH</td>
<td>103%</td>
<td>Probus DH</td>
<td>112%</td>
<td>Mamut DH</td>
<td>107%</td>
<td>SPRZELCE breeders</td>
</tr>
</tbody>
</table>

Winter wheat

| Standard's yield | 90.3 dt/ha | Mazur DH | 105% |
| Izyda DH | 101% | | |

Figure 2. Triticale, area harvested in world over 1975 – 2016 (Source FAOStat)
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References


