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Uma Mahesh Bhutharaju
Department of Plant Breeding and Genetics, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author
Uma Mahesh Bhutharaju
Department of Plant Breeding and Genetics, Lovely Professional University, Phagwara, Punjab, India

Role of rye in wheat improvement

Uma Mahesh Bhutharaju

Abstract
Wheat is a cereal crop that is vital for consumption and is used throughout the world as a food source and so it is declared as staple food crop. As the human population is rising there is need to increase the production of wheat by various new molecular breeding techniques or the old plant breeding techniques to meet the food demand. There are also dangers to the production of wheat from climate, pests, diseases and various negative constituents of soils etc. so there is very much need to improve wheat in terms of tolerating the abiotic and biotic stresses. So rye is considered to be the solution in eradicating various stresses in wheat. As rye consists of various desirable genes that help wheat in its genetic improvement. Rye chromatin introgressions are reported to induce good agro-morphological features, pests resistance, disease resistance and also tolerance to various abiotic stresses. In this review a brief information on genes and translocations of rye that induce resistance against abiotic and biotic stress in wheat are included.

Keywords: rye, wheat improvement, abiotic and biotic stresses

Introduction
Common wheat (*Triticum aestivum* L.) is one of the important staple food crops of the world. Common wheat carries allohexaploid genome (AABBDD) which is derived from three ancestor species. Each genome set is composed of seven chromosomes. Wheat is cultivated from the equator to the Arctic Circle (Vetriventhan *et al.* 2016) [44]. But the most suitable conditions for wheat cultivation are at the latitudes 30º–60º N and 27º–40◦ S (Nuttonson *et al.* 1955) [36]. Green Revolution played a very vital role in enhancing wheat production and its yield. Although it contributed to increase in production and yield it has also made the wheat genome less diverse for various reasons (Kaur *et al.* 2016) [18] and also its demand for production is very high as it is consumed by all the people of the world. So it is necessary to improve wheat not only in terms of yield but also other traits that contribute to yield.

Transfer of rye chromatin into wheat
Secale cereale (Rye) originated in the East and is diploid in nature (2n=2x=14). The chromosomes of wheat 1,2,3,4,5,6 are homoeologous with the chromosomes of rye 1R,2R,3R,4R,5R,6R. 4 and 7 chromosomes of wheat have partial reciprocal homeology with the 4R and 7R chromosomes of rye (Baum *et al.* 2015) [4]. Rye is said to have many desirable traits that can improve wheat in terms of tolerating abiotic stress and biotic stress and also for improving its agro-morphological traits.
Wheat is allopolyploid and so it is able to resist various changes in its genome. When rye chromatin is introduced into wheat, wheat becomes resistant to various diseases, pests etc. and even resistant to abiotic stresses. Wheat tolerating genetic changes in its genome paved a way for development of telocentric lines, monosomic lines, deletion and nullisomic lines. These lines are said to have vital importance in terms of research (Sourdille *et al.* 2004) [42] and (Lukaszewski *et al.* 2015) [31].

Creation of translocation lines
Crossing
For transfer of rye chromosomes into wheat, an aneuploid wheat line is selected and is crossed with rye or to a amphidiploid developed in prior. Wheat alien substitution lines are often used as connecting links for making wheat-rye translocation lines (Faris *et al.* 2002) [11]; (Lukaszewski *et al.* 2015) [31]; (Jiang *et al.* 1993) [16].

Centromeric breakage

One of the strategies for development of random wheat-rye translocation lines is that they can be formed due to centromeric breakage. This happens during meiotic metaphase-1 where chromosomes break at the centromere and telocentrics are formed which again fuse and this results in exchange of chromosome segments (Jiang *et al.* 1994); (Lukaszewski *et al.* 1983) [32].

Radiation method

Through irradiation method wheat rye translocations can be obtained when there is absence of homeologous pairing in the substitution lines. But the method is laborious has harmful effects on the plant (Jauhar *et al.* 1999) [15]. Amigo, a winter wheat cultivar was developed using this method (Sebesta *et al.* 1978) [41].

Tissue-culture Technique

According to Lapitan *et al*. wheat-rye hybrids are transferred into auxin containing tissue culture media for callus formation. The then obtained recovered plants are treated with colchicine to diuble the chromosomes. 4DL.1RS, 2BS.2RL and 2BL.3R translocations are present in the lines that are produced through this technique (Lapitan *et al.* 1984) [23]; (Friebe *et al.* 1990) [12].

Ph1B Mutants

The Ph1B allele in wheat inhibits homoeologous pairing between wheat and alien chromosomes. Its mutation i.e. in Ph1B mutant homoeologous pairing occurs and so the amount of genetic material to be induced into the wheat can be reduced (Faris *et al.* 2002) [11]; (Jiang *et al.* 1994).

Okadaic Acid

Okadaic acid is also used for the development of wheat-rye translocations. It induces homoeologous pairing when wheat tillers are exposed to okadaic acid before they enter meiosis. The speciality is that though ph1 allele is present when okadaic acid is used in optimal concentration homoeologous pairing happens between wheat and rye (Knight *et al.* 2010) [20].

Kr Genes

Many Chinese wheat varieties have Kr genes that make them crossable with rye. This method has been used in the very recent times for developing 1BL.1RS translocation lines (Ren *et al.* 2012) [39] and (McIntosh *et al.* 2013) [34].

Rye as a source to biotic stresses in wheat

Rye is said to have various desirable traits of resistances against various pests and pathogens of wheat. Most of these resistance genes have been found out to be present in 1R chromosome of rye. 7R chromosome do not have any resistance conferring genes and 5R chromosome has aphid resistance conferring genes and 5R chromosome has aphid resistance gene (Andersson *et al.* 2015) [2].

If many resistance genes against various pests and diseases are present in the chromosome of interest of rye this can be inherited into the progeny when crosses are made in the wheat and rye.

The rye chromatin may also confer undesirable traits when introduced into wheat. Therefore, it is necessary to minimize the rye chromatin being introduced into wheat.

Resistance to Diseases

Petkus rye was said to have many resistance genes against several diseases and hence it was used for transfer of its chromatin into wheat since 1960’s. 1R chromosome of this rye has genes Lr26, Yr9, Sr31 and Pm8 genes that confer resistance against leaf rust, yellow rust, stem rust and powdery mildew respectively. Sr31 gene of petkus rye conferred resistance against stem rust for about 30 years. In 1999 it was reported that in Uganda its resistance was defeated for the first time (Pretorius *et al.* 2000) [37].

Insave rye chromatin is introduced into winter wheat Amigo which is of 1AL.1RS translocation which carries Sr1RSAmigo gene which is resistant to stem rust and also Pm17 gene which is resistant to powdery mildew. Imperial rye has stem rust resistant gene called as Sr50/SrR. New attempts are being made to transfer yellow rust resistance from rye sources like dwarf rye R12 which a gene called as YrR212, which is a 1BL.1RS translocation which confers recessive yellow rust resistance. New breeding lines and cultivars with 1RS translocations derived from petkus rye, consists of new genes called as YrCn17 and PmCn17 additional to Pm8 and Yr9 (Ren *et al.* 2012) [40].

2R chromosome of rye also consists of some genes that confer disease resistance. Eg: Lr25 and Lr45 genes confer leaf rust resistance and Sr59 gene confers stem rust resistance which is also resistant to Ug99. In 2R chromosome there are genes like Pm7.Lr25 and Pm7 that are derived from rosen rye which confer powdery mildew resistance. In imperial rye in the 3R chromosome a gene called as Sr27 is present which confers stem rust resistance. Powdery mildew resistance genes are present in 4R, 6R chromosomes in Kustro and German white rye and also in the chromosome 6R in prolific rye a gene called Pm20 also confers powdery mildew resistance (Rahmatov *et al.* 2016) [38].

All these genes of rye are able to confer resistance but do not get expressed because of suppressors present in the genome of wheat. Leaf rust resistant genes are being suppressed by suppressors present in all the 3 genomes of 6X wheat (Kolmer *et al.* 1996) [21].

Resistance to Pests

Gb2 gene confer resistance against *Schizaphis graminum* races. It was present in the 1R chromosome of Insave rye and also in Amigo winter wheat. It was reported to be the first insect resistance transferred from rye to wheat. The Gb2 gene confers resistance against B, C, and J biotypes of *Schizaphis graminum*. Also another gene Gb6 which confers resistance against E and I biotypes of *Schizaphis graminum*. It was also present in the 1R chromosome of Insave rye (Burd *et al.* 2006) [6]; (Lu *et al.* 2010) [24] and (Weng *et al.* 2010) [47].

Dn7 gene present in the 1R chromosome of Turkey77 rye confers resistance against *Diuraphis noxia* (Mordivilko) (Haley *et al.* 2004) [13]. Dn7 gene of all the Dn genes it is the only gene that is resistant against biotype 2 of *Diuraphis noxia*. Recntly biotype 3 variant was discovered to which no known Dn genes are resistant (Burd *et al.* 2006) [7] and (Weiland *et al.* 2008).

Lukaszewski *et al.* 1995 [26]; Lukaszewski *et al.* 1993 [25]; Lukaszewski *et al.* 1997 [27]; Lukaszewski *et al.* 2000 [28]; Lukaszewski *et al.* 2006 [29] and Lukaszewski *et al.* 2008 [30], Lukaszewski *et al.* 2004 [33] and Zhang *et al.* 2001 [48] utilised and exploited centromeric breakage fusion and Ph1 mutants to examine different substitution, translocation and recombinant lines of various rye resources using the spring cultivar Pavon F76 as a genetic background. Out of 61 lines of 1R or 1RS translocation lines, triticale species Presto and Panda have shown seedling resistance against aphids like *Rhopalosiphum padi* and *Sitobion avenae*.1 line with 1RS translocation of Amigo wheat have shown resistance against *Sitobion avenae* at both seedling and adult stages of plant life.

Cmc3 gene of 1AL.1RS translocation of rye in Amigo wheat is resistant to mite *Aceria tosichell*. Resistance to *Mayetiola destructor* the cecidomyid was found in 2RL and 6RL translocations and the genes contributing to resistance are H21 and H25. Nematodes like *Heterodera filipjevi* (Madzhidov) and *Heterodera avenae* were reported to be controlled by using resistant genes in 6R chromosome of rye in 6X wheat (Crespo-Herrera *et al.* 2017) [10].

Rye as a source to Abiotic stress in wheat

Transferring abiotic stress resistance from rye into wheat not only allows positive effects but also negative effects on growth and development of wheat. The 1RS translocation of rye in wheat promoted increase in root biomass (Hoffman *et al.* 2008) [14]; (Waines and Ehdaie *et al.* 2007) [45].

The 1BL.1RS translocation withholds moisture stress better than 1AL.1RS and 1DL.1RS translocation (Karki *et al.* 2014) [17]. The 1BL.1RS translocation inhibits the yield parameter in wheat when it is grown in rainfed conditions and under heat stress. It is because of presence of suppressors in wheat (Monneveux *et al.* 2003) [35]. Pavon F76 spring wheat cultivar, in its genetic background 1R of rye was tested to find out which 1RS translocated need to be incorporated into wheat. Irrespective of its introgression into whichever chromosome, the translocation should induce positive effects in wheat. But 1RS in wheat confers negative effect in baking quality. So 1AL.1RS are preferred over 1BL.1RS and 1DL.1RS. (Kim *et al.* 2004) [19] and (Kumlay *et al.* 2003) [22].

Rye has tolerance to withstand excess aluminium in soil and also acidic condition of soil. It was reported that the chromosomes 3R, 4R, and 6R consists of genes that tolerate these adverse conditions. But these genes do not get expressed completely because of presence of suppressors in wheat (Carver *et al.* 1995) [9].

It was also reported that uptake of Zinc by wheat can be enhanced by some loci present on chromosomes 1R and 7R (Cakmak *et al.* 1997) [8] and also copper uptake was increased with loci present on 5RL (Velasco *et al.* 2007) [43]. The 1R and 2R substitutions of rye in wheat confer allelopathic effects against some weeds (Bertholdsson *et al.* 2012) [5].

Conclusion

Plant scientists are always finding out new resources from which new resistant genes can be introgressed into wheat genome for its improvement. However, some genes do not get expressed due to presence of suppressors in wheat genome. The information presented above can be useful in combining the genes and introjecting them into wheat genome that way the present rye sources can be used. With these resources new introgression lines can be developed which can be useful for future breeding programmes.

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