GENETIC BASIS OF PEST RESISTANCE IN WHEAT-RYE AND TRITICALE STOCKS

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This review describes eight genes and 21 loci for resistance to pests localized in rye chromosomes of wheat-rye and triticale genetic stocks. Detailed information is given for the rye chromosome donor, the type of tchromatin inserted, the molecular marker, if present, and resulting wheat and/or triticale lines for deployment of the resistance in breeding. The main insect resistance factors are determined in chromosome 1R, followed by 6R, in the form of wheat-rye chromosome translocations or substitutions. Most of the genes provide resistance to Russian wheat aphid and Hessian fly. The recorded geneticstocks can efficiently serve as important bridges for wheat and triticale improvement. The data thus provided will help researchers to competently use resistances of rye chromatin through classical and marker-assisted breeding.

Key words: *Pests resistance, rye chromosomes, wheat-rye hybrids, triticale stocks.*

ГЕНЕТИЧНА ОСНОВА СТІЙКОСТІ ФОНДІВ ГІБРИДІВ ПШЕНИЦІ Й ЖИТА ТА ТРИТИКАЛЕ ДО ШКІДНИКІВ

У цьому огляді описано вісім генів та 21 локус стійкості до шкідників, локалізованих у хромосомах генетичних фондів гібридів жита й пшениці та тритикале. Представлено детальну інформацію щодо донора хромосоми жита, типу вставленого t-хроматину, молекулярного маркера (за його наявності) та отриманих ліній пшениці та/або тритикале для впровадження стійкості при розведенні. Визначено основні фактори стійкості до комах у хромосомі 1R, а потім в 6R, у формі хромосомних транслокацій або замін у гібридах пшениці й жита. Більшість генів забезпечує стійкість до російської пшеничної попелиці та гессенської мухи. Зареєстровані генетичні фонди можуть ефективно слугувати важливими засобами для вдосконалення пшениці та тритикале. Представлені дані допоможуть дослідникам компетентно використовувати стійкість хроматину жита в класичній та маркерній селекції.

Ключові слова: стійкість до шкідників, хромосоми жита, гібриди пшениці й жита, генетичні фонди тритикале.

REFERENCES

Aguirre-Rojas LM, Khalaf LK, Garcés-Carrera S, Sinha DK, Chuang Wen-Po, Smith CM (2017) Resistance to wheat curl mite in arthropod-resistant rye-wheat translocation lines. Agronomy 4:74. https://doi.org/10.3390/agronomy7040074.

Anderson GR, Papa D, Peng J, Tahir M, Lapitan NLV (2003) Genetic mapping of *Dn7*, a rye gene conferring resistance to the Russian wheat aphid in wheat. Theor Appl Genet 107:1297–1303. https://doi.org/10.1007/s00122-003-1358-1.

Andersson SC, Johansson E, Baum M, Rihawi F, El Bouhssini M (2015) New resistance sources to Russian wheat aphid (*Diuraphis noxia*) in Swedish wheat substitution and translocation lines with rye (*Secale cereale*) and *Leymus mollis.* Czech J Genet Plant Breed 51:162–165. https://doi.org/10.17221/72/2015-CJGPB.

Asiedu R, Fisher JM, Driscoll CJ (1990) Resistance to *Heterodera avenae* in the rye genome of triticale. Theor Appl Genet 79:331–336. https://doi.org/10.1007/BF01186075

Bakala HS, Mandahal KS, Ankita Sarao LK, Srivastava P (2022) Breeding wheat for biotic stress resistance: achievements, challenges, and prospects, In: Ansari MR (ed) Current Trends in Wheat Research, IntechOpen, p. 1–30 https://doi.org/10.5772/intechopen.97359.

Berzonsky WA, Ding H, Haley SD, Harris MO, Lamb RJ, McKenzie RIH, Ohm HW, Patterson FL, Peairs FB, Porter DR, Ratcliffe RH, Shanower TG (2003) Breeding wheat for resistance to insects. Plant Breed Rev 22:221–296.

Cárcamo HA, Beres BL, Clarke F, Byers RJ, Mündel HH, May K, Depauw R (2005) Influence of plant host quality on fitness and sex ratio of the wheat stem sawfly (Hymenoptera: Cephidae). Environ Entomol 34:1579–1592. https://doi.org/10.1603/0046-225X-34.6.1579.

Cárcamo H, Beres B, Wu X, Larson T, Schwinghamer T (2020) Effect of plant density on wheat stem sawfly sex ratio. Front Agronomy 2(4):1–10. https://doi.org/10.3389/fagro.2020.00004.

Cox TS, Bockus WW, Gill BS, Sears RG, Harvey TL, Leath S, Brown-Guedira GL (1999) Registration of KS96WGRC40 hard red winter wheat germplasm resistant to wheat curl mite, *Stagonospora* leaf blotch and *Septoria* leaf blotch. Crop Sci 39(2):597.

Crespo-Herrera LA, Smith CM, Singh RP, Ehman I (2013) Resistance to multiple cereal aphids in wheat–alien substitution and translocation lines. Arthropod Plant Interact 7:535–545. https://doi.org/10.1007/s11829-013-9267-y.

Crespo-Herrera LA, Akhunov E, Garkava-Gustavsson L, Jordan KW, Smith CM, Singh RP, Ehman I (2014) Mapping resistance to the bird cherry-oat aphid and the greenbug in wheat using sequence-based genotyping. Theor Appl Genet 127:1963–1973. https://doi.org/10.1007/s00122-014-2352-5.

Crespo-Herrera LA, Singh RP, Ehman I (2015) Field population development of bird cherry-oat aphid and greenbug (Hemiptera: Aphididae) on wheat-alien substitution and translocation lines. Euphytica 203:249–260. https://doi.org/10.1007/s10681-014-1244-8.

Crespo-Herrera LA, Garkava-Gustavsson L, Ehman I (2017) A systematic review of rye (*Secale cereale* L.) as a source of resistance to pathogens and pests in wheat (*Triticum aestivum* L.). Hereditas 154:14. https://doi.org/10.1186/s41065-017-0033-5.

Crespo-Herrera LA, Singh RP, Sabraoui A, El-Bouhssini M (2019) Resistance to insect pests in wheat-rye and *Aegilops speltoides* Tausch translocation and substitution lines. Euphytica 215:123. https://doi.org/10.1007/s10681-019-2449-7.

Cui L, Gao X, Wang X, Jian H, Tang Wen-Hua, Li Hong-Lian, Li H-J (2012) Characterization of interaction between wheat roots with different resistance and *Heterodera filipjevi*. Acta Agron Sinica 38:1009–1017. http://www.cnki.net/kcms/detail/11.1809.S.20120329.1115.001.html.

Daskalova N, Spetsov P (2020) Taxonomic relationships and genetic variability of wild *Secale* L. species as a source for valued traits in rye, wheat, and triticale breeding. Cytol Genet 54:71–81. https://doi.org/10.3103/S0095452720010041.

Dundas IS, Frappell DE, Crack DM, Fisher JM (2001) Deletion mapping of a nematode resistance gene on rye chromosome 6R in wheat. Crop Sci 41:1771–1778.

El Bouhssini M, Ogbonnaya FC, Chen M et al (2013) Sources of resistance in primary synthetic hexaploid wheat (*Triticum aestivum* L.) to insect pests: Hessian fly, Russian wheat aphid and Sunn pest in the Fertile Crescent. Genet Resour Crop Evol 60:621–627. https://doi.org/10.1007/s10722-012-9861-3.

Ferrahi M, Friebe B, Hatchett JH, Brown-Guedira GL, Gill BS (2017) Two step transfer of rye-derived Hessian fly *H21* to durum wheat by compensating Robertsonian translocation and induced homoeologous recombination. Int J Adv Res 5:262–270. https://doi.org/10.21474/IJAR01/5529.

Fisher JM (1982) Towards a consistent laboratory assay for resistance to *Heterodera avenae*. EPPO Bulletin 12:445–449.

Friebe B, Hatchett JH, Sears RG, Gill BS (1990) Transfer of Hessian fly resistance from 'Chaupon' rye to hexaploid wheat via a 2BS/2RL wheat-rye chromosome translocation. Theor Appl Genet 79:385–389.

Friebe B, Jiang J, Raupp WJ, McIntosh RA, Gill BS (1996) Characterization of wheat- alien translocations conferring resistance to diseases and pests: current status. Euphytica 91:59–87. https://doi.org/10.1007/BF00035277.

Friebe B, Kynast RG, Hatchett JH, Sears RG, Wilson DL, Gill BS (1999) Transfer ofwheat-rye translocation chromosomes conferring resistance to Hessian fly from bread wheat into durum wheat. Crop Sci 39:1692–1696. https://doi.org/10.2135/cropsci1999.3961692x.

Fritz AK, Caldwell S, Worrall WD (1999) Molecular mapping of Russian wheat aphidresistance from triticale accession PI 386156. Crop Sci 39(6):1707-1710. https://doi.org/10.2135/cropsci1999.3961707x.

Geiger HH, Miedaner T (2009) Rye breeding, in *Cereals*. In: Carena MJ (ed) Handbook of Plant Breeding, vol. 3. Springer US, New York, NY, p 157–181. https://doi.org/10.1007/978-0-387-72297-9.

Haley SD, Peairs FB, Walker CB et al (2004) Occurrence of a new Russian wheat aphid biotype in Colorado. Crop Sci 44(5):1589–1592. https://doi.org/10.2135/ cropsci2004.1589.

Harvey TL, Seifers DL, Martin TJ, Brown-Guedira GL, Gill BS (1999) Survival of wheat curl mites on different sources of resistance in wheat. Crop Sci 39:1887–1889. https://doi.org/10.2135/cropsci1999.3961887x.

Hatchett JH, Sears RG, Cox TS (1993) Inheritance of resistance to Hessian fly in rye and in wheat-rye translocation lines. Crop Sci 33:730–734. https://doi.org/10.2135/cropsci1993.0011183X003300040019x.

Hesler LS (2005) Resistance to *Rhopalosiphum padi* (Homoptera: Aphididae) in three triticaleaccessions. J Econ Entomol 98(2):603–610.

Hesler LS, Haley SD, Nkongolo KK, Peairs FB (2007) Resistance to *Rhopalosiphum padi* (Homoptera: Aphididae) in triticale and triticale-derived wheat lines resistant to *Diuraphis noxia* (Homoptera: Aphididae). J Entomol Sci 42:217–227. https://doi.org/10.18474/0749-8004-42.2.217.

Hu XS, Liu YJ, Wang Y-H, Wang Z, Yu X, Wang B, Zhang G-S, Liu X-F, Hu Z-Q, Zhao H-Y, Liu T-X (2016) Resistance of wheat accessions to the English grain aphid *Sitobion avenae*. PLoS ONE 11(6):e0156158. https://doi.org/10.1371/ journal.pone.0156158.

Johansson E, Henriksson T, Prieto-Linde ML, Andersson S, Ashraf R, Rahmatov M (2020) Diverse wheat-alien introgression lines as a basis for durable resistance and quality characteristics in bread wheat. Front Plant Sci 11:1067. https://doi.org/10.3389/fpls.2020.01067.

Karelov AV, Pylypenko LA, Kozub NA, Sozinov IA, Blume YaB (2019) Genetic background of the resistance against parasitic nematodes in wheat. Cytol Genet 53(4):315-320. https://doi.org/10.3103/S0095452719040066.

Khalaf L, Chuang W-P, Aguirre-Rojas LM, Klein P, Smith CM (2019) Differences in *Aceria tosichella* population responses to wheat resistance genes and wheat virus transmission. Arthropod Plant Interact 13:807–818. https://doi.org/10.1007/s11829-019-09717-9.

Kim W, Johnson JW, Baenziger PS, Gaines CS (2004) Agronomic effect of wheat-rye translocation carrying rye chromatin (1R) from different sources. Crop Sci 44:1254–1258. https://doi.org/10.2135/cropsci2004.1254.

Koch KG, Chapman K, Louis J, Heng-Moss T, Sarath G (2016) Plant tolerance: a unique approach to control Hemipteran pests. Front Plant Sci 7:1363. https://doi.org/10.3389/fpls.2016.01363.

Kumlay AM, Baenziger PS, Gill KS, Shelton DR, Graybosch RA, Lukaszewski AJ, Wesenberg DM (2003) Understanding the effect of rye chromatin in bread wheat. Crop Sci 43:1643–1651.

Lapitan NLV, Peng J, Sharma V (2007) A high-density map and PCR markers for Russian wheat aphid resistance gene *Dn7* on chromosome 1RS/1BL. Crop Sci 47:811–820. https://doi.org/10.2135/cropsci2006.08.0529.

Li G, Wang Y, Chen MS et al (2015) Precisely mapping a major gene conferring resistance to Hessian fly in bread wheat using genotyping-by-sequencing. BMC Genom 16:108. https://doi.org/10.1186/s12864-0151297-7.

Liu XM, Brown-Guedira GL, Hatchett JH, Owuoche JO, Chen MS (2005) Genetic characterization and molecular mapping of a Hessian fly-resistance gene transferred from *T. turgidum* ssp. *dicoccum* to common wheat. Theor Appl Genet 111:1308–1315. https://doi.org/10.1007/s00122-005-0059-3.

Liu S, Rudd JC, Bai G, Haley SD, Ibrahim AMH, Xue Q, Hays DB, Graybosch RA, Devkota RN, Amand PSt (2014) Molecular markers linked to important genes in hard winter wheat. Crop Sci 54:1304–1321. https://doi.org/10.2135/cropsci2013.08.0564.

Liu XL, Lu BY, Wang CY, Wang YJ, Zhang H, Tian ZR, Ji WQ (2018) Identification of *Sitobion avenae* F. resistance and genetic diversity of wheat landraces from Qinling Mountains, China. Cereal Res Commun 46:104–113. https://doi.org/10.1556/0806.45.2017.071.

Lu H, Rudd JC, Burd JD, Weng Y (2010) Molecular mapping of greenbug resistance genes *Gb2* and *Gb6* in T1AL.1RS wheat-rye translocations. Plant Breed 129(5):472–476. https://doi.org/10.1111/j.1439-0523.2009.01722.x.

Lukaszewski AJ (1997) Further manipulation by centric misdivision of the 1RS.1BL translocation in wheat. Euphytica 94:257–261. https://doi.org/10.1023/A:1002916323085.

Lukaszewski AJ (2000) Manipulation of the 1RS.1BL translocation in wheat by induced homoeologous recombination. Crop Sci 40:216–225.

Lukaszewski AJ (2006) Cytogenetically engineered rye chromosomes 1R to improve bread- making quality of hexaploid triticale. Crop Sci 46:2183–2194. https://doi.org/10.2135/cropsci2006.03.0135.

Lukaszewski AJ (2015) Introgressions between wheat and rye, in *Alien introgression in wheat, cytogenetics, molecular biology, genomics.* In: Molnár-Láng M, Ceoloni C, Doležel J (eds) International Publishing Switzerland, Springer, Cham, p 163–189. https://doi.org/10.1007/978-3-319-23494-6_7.

Lukaszewski AJ, Porter DR, Baker CA, Rybka K, Lapinski B (2001) Attempts to transfer Russian wheat aphid resistance from a rye chromosome in Russian triticales to wheat. Crop Sci 41:1743–1749. https://doi.org/10.2135/cropsci2001.1743.

Malik R, Brown-Guedira GL, Smith CM, Harvey TL, Gill BS (2003) Genetic mapping of wheat curl mite resistance genes *Cmc3* and *Cmc4* in common wheat. Crop Sci 43:644–650.

Marais GF, Horn M, Du Toit F (1994) Intergeneric transfer (rye to wheat) of gene(s) for Russian wheat aphid resistance. Plant Breed 113:265–271. https://doi.org/10.1111/j.1439-0523.1994.tb00735.x.

Mondal S, Rutkoski JE, Velu G et al (2016) Harnessing diversity in wheat to enhance grain yield, climate resilience, disease and insect pest resistance and nutrition through conventional and modern breeding approaches. Front Plant Sci 7:991. https://doi.org/10.3389/fpls.2016.00991.

Mookiah S, Sivasubramaniam B, Thangaraj T, Govindaraj S (2021) Host Plant Resistance. In: Omkar (ed) Molecular Approaches for Sustainable Insect Pest Management, Springer, Singapore, p 1–56. https://doi.org/10.1007/978-981-16-3591-5.

Moskal K, Kowalik S, Podyma W, Łapiński B, Boczkowska M (2021) The pros and cons of rye chromatin introgression into wheat genome. Agronomy 11(3):456. https://doi.org/10.3390/agronomy11030456.

Newell MA, Butler TJ (2013) Forage rye improvement in the Southern United States: a review. Crop Sci 53:38–47. https://doi.org/10.2135/cropsci2012.05.0319.

Nkongolo KK, Lapitan NLV, Quick JS (1996) Genetic and cytogenetic analyses of Russian wheat aphid resistance in triticale × wheat hybrids and progenies. Crop Sci 36(5):1114–1119. https://doi.org/10.2135/cropsci1996.0011183X003600050007x.

Nkongolo KK, Haley SD, Kim NS, Michael P, Fedak G, Quick JS, Peairs FB (2009) Molecular cytogenetic and agronomic characterization of advanced generations of wheat x triticale hybrids resistant to *Diuraphis noxia* (Mordvilko): application of GISH and microsatellite markers. Genome 52(4):353–360. https://doi.org/10.1139/G09-010.

Nkongolo KK, Scott D, Haley SD, Quick JS, Peairs FB (2011) Registration of six wheat- rye addition li-nes resistant to the Russian wheat aphid. J Plant Regist 5(3):426-429. https://doi.org/10.3198/jpr2010.11.0637crgs.

Özberk I, Atlı A, Yücel A, Özberk F, Coşkun Y (2005) Wheat stem sawfly (*Cephus pygmaeus* L.) damage; impacts on grain yield, quality and marketing prices in Anatolia. Crop Protect 24:1054–1060. https://doi.org/10.1016/j.cropro.2005.03.006.

Peng J, Wang H, Haley SD, Peairs FB, Lapitan NLV (2007) Molecular mapping of the Russian wheat aphid resistance gene *Dn2414* in wheat. Crop Sci 47:2418–2429. https://doi.org/10.2135/cropsci2007.03.0137.

Puterka GJ, Xu X, Li G, Carver BF, Guo P (2020) Mechanisms of resistance of new wheat gene *Dn10* in comparison with other *Dn* genes resistant to Russian wheat aphid. Crop Sci 60:1782–1788. https://doi.org/10.1002/csc2.20051.

Qiao F, Kong L-A, Peng H, Huang W-K, Wu D-K, Liu S-M, Clarke JL, Qiu D-W, Peng D-L (2019) Transcriptional profiling of wheat (*Triticum aestivum* L.) during a compatible interaction with the cereal cyst nematode *Heterodera avenae*. Sci Rep 9(2184). https://doi.org/10.1038/s41598-018-37824-9.

Rabinovich SV (1998) Importance of wheat-rye translocations for breeding modern cultivars of *Triticum aestivum* L. Euphytica 100:323–340. https://doi.org/10.1023/A:1018361819215.

Rakoczy-Trojanowska M, Bolibok-Brągoszewska H, Myśkyw B, Dzięgielewska M, Stojałowski S, Grądzielewska A, Boczkowska M, Moskal K (2021) Genetics and genomics of stress tolerance. In: Rabanus- Wallace MT, Stein N (eds) The Rye Genome, Compendium of Plant Genomes, Springer Nature Switzerland AG, p 213–236. https://doi.org/10.1007/978-3-030-83383-1_11.

Riedell WE, Kieckhefer RW, Langham MAC, Hesler LS (2003) Root and shoot responses to bird cherry-oat aphids and *Barley yellow dwarf virus* in spring wheat. Crop Sci 43(4):1380–1386.

Royer TA, Pendleton BB, Elliott NC, Giles KL (2015) Greenbug (Hemiptera: Aphididae) Biology, ecology, and management in wheat and sorghum. J Integ Pest Mngmt 6(1):19. https://doi.org/10.1093/jipm/pmv018.

Sandhu S, Kang M (2017) Advances in Breeding for Resistance to Insects, in *Breeding Insect Resistant Crops for Sustainable Agriculture*. In: Arora R, Sandhu S (eds) Springer, Singapore, p 67–99. https://doi.org/10.1007/978-981-10-6056-4_3.

Schlegel R, Melz G, Mettin D (1986) Rye cytology, cytogenetics and genetics – Current status. Theor Appl Genet 72:721–734. https://doi.org/10.1007/BF00266535.

Sebesta EE, Wood EA, Porter DR, Webster JA, Smith EL (1994) Registration of Gaucho Greenbug-Resistant Triticale Germplasm. Crop Sci 34(5).

Sebesta EE, Wood EA, Porter DR, Webster JA, Smith EL (1995) Registration of Amigo wheat germplasm resistant to greenbug. Crop Sci 35:293. https://doi.org/10.2135/cropsci1995.0011183X003500010074x.

Singh B, Simon A, Halsey K, Kurup S, Clark S, Aradottir GI (2020) Characterisation of bird cherry-oat aphid (*Rhopalosiphum padi* L.) behaviour and aphid host preference in relation to partially resistant and susceptible wheat landraces. Ann Appl Biol 177:184–194. https://doi.org/10.1111/aab.12616.

Singh B, Jasrotia P, Crespo-Herrera L (2022) Breeding for aphid resistance in wheat: Status and future prospects. In: Kashyap PL, Gupta V, Gupta OP, Sendhil R, Gopalareddy K, Jasrotia P, Singh GP (eds) New Horizons in Wheat and Barley Research, Crop Protection and Resource Management. Springer Singapore, p 381–399. https://doi.org/10.1007/978-981-16-4134-3.

Spetsov P, Daskalova N (2022) Resistance to pathogens in wheat-rye and triticale genetic stocks. J Plant Pathol 104:99–114. https://doi.org/10.1007/s42161-021-01019-5.

Taylor C, Shepherd KW, Langridge P (1998) A molecular genetic map of the long arm ofchromosome 6R of rye incorporating the cereal cyst nematode resistance gene. CreR Theor Appl Genet 97:1000–1012. https://doi.org/10.1007/s001220050984.

Tyrka M, Chełkowski J (2004) Enhancing the resistance of triticale by using genes from wheat and rye. J Appl Genet 45:283–295. https://doi.org/jag.igr.poznan.pl.

Varella AC, Weaver DK, Sherman JD, Black NK, Heo H-Y, Kalous J, Chao J, Hofland ML, Martin JM, Kephart KD, Talbert LE (2015) Association analysis of stem solidness and wheat stem sawfly resistance in a panel of North American spring wheat germplasm. Crop Sci 55:2046–2055. https://doi.org/10.2135/cropsci2014.12.0852.

Wang D, Liu D, Shi X, Yang Y, Zhang N, Shang Z (2020) Transcriptome profiling revealed potentially important roles of defensive gene expression in the divergence of insect biotypes: a case study with the

cereal aphid *Sitobion avenae*. BMC Genom 21:546. https://doi.org/10.1186/s12864-020-06950-y.
Ward S, van Helden M, Heddle T, Ridland PM, Pirtle E, Umina PA (2020) Biology, ecology, and management of *Diuraphis noxia* (Hemiptera: Aphididae) in Australia. Austral Entomol 59:238–252. https://doi.org/10.1111/aen.12453.
Webster JA (1990) Resistance in triticale to the Russian wheat aphid (Homoptera: Aphididae). J Econ Entomol 83:1091–1095. https://doi.org/10.1093/jee/83.3.1091.

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