

**Selected citations for field-evolved Bt resistance in U.S. corn pests**

**Updated March 2025**

These publications are the basis for the resistance ratings in the Handy Bt Trait Table. Lepidopteran species are listed first, followed by corn rootworm species.

<b>LEIDOPTERAN (CATERPILLAR) SPECIES</b>	<b>Bt protein</b>	<b>Crop Location(s)</b>	<b>Source/Citation for more information</b>
<b>corn earworm (CEW)</b>  <i>Helicoverpa zea</i>	Cry1Ab	Sweet corn Maryland	<ul style="list-style-type: none"> <li>Dively et al. 2016. Field-evolved resistance in corn earworm to Cry proteins expressed by transgenic sweet corn. PLOS ONE 11(12)</li> </ul>
	Cry1A.105 x Cry2Ab2	Sweet corn Maryland	<ul style="list-style-type: none"> <li>Dively et al. 2016. Field-evolved resistance in corn earworm to Cry proteins expressed by transgenic sweet corn. PLOS ONE 11(12)</li> </ul>
	Cry1A.105  Cry2Ab2  Cry1A.105 x Cry2Ab2 pyramids	Field corn  Carolinas Louisiana Texas Southeast US	<ul style="list-style-type: none"> <li>Bilbo et al. 2019. Susceptibility of Corn Earworm to Cry1A.105 and Cry2Ab2 in North &amp; South Carolina. J. Econ.Ent. 112(4): 1845-1857</li> <li>Kaur et al. 2019. Field-evolved resistance of <i>Helicoverpa zea</i> (Boddie) to transgenic maize expressing pyramided Cry1A.105/ Cry2Ab2 proteins in NE Louisiana. J. Invert. Pathol. 163: 11-20.</li> <li>Yang et al. 2019. Occurrence and ear damage of <i>Helicoverpa zea</i> on transgenic <i>Bacillus thuringiensis</i> maize in the field in Texas, U.S. and its susceptibility to Vip3A protein. Toxins 11(2), 102. doi.org/10.3390/toxins11020102</li> <li>Yu et al. 2021. Extended investigation of the field-evolved resistance of the corn earworm to <i>Bacillus thuringiensis</i> Cry1A.105 and Cry2Ab2 proteins in the southeastern United States. J. Invert. Pathol. 183. doi: 10.1016/j.jip.2021.107560</li> </ul>
<b>European corn borer (ECB)</b>  <i>Ostrinia nubilalis</i>	Cry1Fa	Field corn, Potato, Millet  Manitoba Nova Scotia Quebec	<ul style="list-style-type: none"> <li>Smith et al. 2019. Practical resistance of <i>Ostrinia nubilalis</i> to Cry1F <i>Bacillus thuringiensis</i> maize discovered in Nova Scotia. Nature Sci Rep 9, Article #18247</li> <li>Smith &amp; Farhan. 2023. Monitoring resistance of <i>Ostrinia nubilalis</i> in Canada to Cry toxins produced by Bt corn. J. Econ.Ent. <a href="https://doi.org/10.1093/jee/toad046">https://doi.org/10.1093/jee/toad046</a></li> <li>Farhan et al. 2023. Genetic mutations linked to field-evolved Cry1Fa-resistance in the European corn borer, <i>Ostrinia nubilalis</i>. Sci Rep 13, 8081. <a href="https://doi.org/10.1038/s41598-023-35252-y">https://doi.org/10.1038/s41598-023-35252-y</a></li> </ul>
	Cry1Ab	corn Manitoba Nova Scotia  Connecticut	<ul style="list-style-type: none"> <li>Smith &amp; Farhan. 2023. Monitoring resistance of <i>Ostrinia nubilalis</i> in Canada to Cry toxins produced by Bt corn. J. Econ.Ent. <a href="https://doi.org/10.1093/jee/toad046">https://doi.org/10.1093/jee/toad046</a></li> <li>Data presented by K. Fisher, University of Connecticut, at the NC246 Meeting in 2024 and 2025. Manuscript in Preparation.</li> </ul>
	Cry1A.105	corn Nova Scotia PEI Quebec  Connecticut	<ul style="list-style-type: none"> <li>Smith &amp; Farhan. 2023. Monitoring resistance of <i>Ostrinia nubilalis</i> in Canada to Cry toxins produced by Bt corn. J. Econ.Ent. <a href="https://doi.org/10.1093/jee/toad046">https://doi.org/10.1093/jee/toad046</a></li> <li>Data presented by K. Fisher, University of Connecticut, at the NC246 Meeting in 2024 and 2025. Manuscript in Preparation.</li> </ul>
	Cry2Ab	corn Nova Scotia Quebec  Connecticut	<ul style="list-style-type: none"> <li>Smith &amp; Farhan. 2023. Monitoring resistance of <i>Ostrinia nubilalis</i> in Canada to Cry toxins produced by Bt corn. J. Econ.Ent. <a href="https://doi.org/10.1093/jee/toad046">https://doi.org/10.1093/jee/toad046</a></li> <li>Data presented by K. Fisher, University of Connecticut, at the NC246 Meeting in 2024 and 2025. Manuscript in Preparation.</li> </ul>
<b>fall armyworm (FAW)</b>  <i>Spodoptera frugiperda</i>	Cry1F	Field corn  Florida North Carolina Puerto Rico	<ul style="list-style-type: none"> <li>Storer et al. 2010. Discovery and characterization of field resistance to Bt maize: <i>Spodoptera frugiperda</i> in Puerto Rico. J. Econ. Entomol. 103: 1031–1038.</li> <li>Huang et al. 2014. Cry1F Resistance in fall armyworm <i>Spodoptera frugiperda</i>: Single gene versus pyramided Bt maize. PLOS ONE 9(11).</li> <li>Li et al. 2016. Frequency of Cry1F non-recessive resistance alleles in Carolina field populations of <i>Spodoptera frugiperda</i>. PLOS ONE 11(4).</li> </ul>

<b>LEIDOPTERAN (CATERPILLAR) SPECIES</b>	<b>Bt protein</b>	<b>Crop Location(s)</b>	<b>Source/Citation for more information</b>
<b>Southwestern corn borer</b>  <i>Diatraea grandiosella</i>	Cry1F	Field Corn  Arizona New Mexico	<ul style="list-style-type: none"> <li>Arizona Pest Management Center. Posted 1 Feb 2017. Chlorpyrifos use in Arizona and New Mexico. Public comment submitted to EPA, ID Docket EPA-HQ-OPP-2015-0653-0654.</li> <li>Data presented by Texas A&amp;M at the NC246 Meeting in 2024 &amp; 2025</li> </ul>
	Cry1Ab	Field Corn New Mexico	<ul style="list-style-type: none"> <li>Data presented by Texas A&amp;M at the NC246 Meeting in 2025</li> </ul>
	Cry1A.105	Field Corn New Mexico	<ul style="list-style-type: none"> <li>Data presented by Texas A&amp;M at the NC246 Meeting in 2025</li> </ul>
	Cry2Ab	Field Corn New Mexico	<ul style="list-style-type: none"> <li>Data presented by Texas A&amp;M at the NC246 Meeting in 2025</li> </ul>
<b>Western bean cutworm (WBC)</b> <i>Striacosta albicosta</i>	Cry1F	Field Corn  Western corn belt Great Lakes Ontario	<ul style="list-style-type: none"> <li>Ostrem et al. 2016. Monitoring susceptibility of western bean cutworm field populations to <i>Bacillus thuringiensis</i> Cry1F protein, J. Econ. Entomol. 109(2) 847–853.</li> <li>Smith et al. 2017. Evidence for field-evolved resistance of <i>Striacosta albicosta</i> to Cry1F <i>Bacillus thuringiensis</i> protein and transgenic corn hybrids in Ontario, Canada. J. Econ. Entomol. 110: 2217-2228.</li> </ul>

<b>CORN ROOTWORM SPECIES</b>	<b>Bt protein</b>	<b>Crop Location(s)</b>	<b>• Source/Citation for more information</b>
<b>Northern corn rootworm (NCR)</b>  <i>Diabrotica barberi</i>	Cry3Bb1	Field Corn  North Dakota	<ul style="list-style-type: none"> <li>Calles-Torrez et al. 2019. Field-evolved resistance of northern and western corn rootworm populations to corn hybrids expressing single and pyramided Cry3Bb1 &amp; Cry34/35Ab1 Bt proteins in North Dakota. J Econ Entomol. 112(4): 1875-1886.</li> </ul>
	Cry34/35Ab1 (now Gpp34Ab1/ Tpp35Ab1)	Field Corn  North Dakota	<ul style="list-style-type: none"> <li>Calles-Torrez et al. 2019. Field-evolved resistance of northern and western corn rootworm populations to corn hybrids expressing single and pyramided Cry3Bb1 &amp; Cry34/35Ab1 Bt proteins in North Dakota. J Econ Entomol. 112(4):1875-1886.</li> </ul>
<b>Western corn rootworm (WCR)</b>  <i>Diabrotica virgifera virgifera</i>	Cry3Bb1	Field Corn  Illinois Iowa Minnesota Nebraska North Dakota	<ul style="list-style-type: none"> <li>Gassmann et al. 2011. Field-Evolved Resistance to Bt maize by western corn rootworm. PLOS ONE 6(7).</li> <li>Gassmann et al. 2012. Western corn rootworm and Bt maize: Challenges of pest resistance in the field. GM Crops &amp; Food: Biotech in Ag and the Food Chain 3(3) 1-10.</li> <li>Gassmann et al. 2012. Field-evolved resistance to Bt maize by western corn rootworm: Predictions from the laboratory and effects in the field. J. Invert Pathology 110:287-293.</li> <li>Wangila et al. 2015. Susceptibility of Nebraska western corn rootworm populations to Bt corn events. J. Econ. Entomol. 108: 742-751.</li> <li>Zukoff et al. 2016. Multiple assays indicate varying levels of cross resistance in Cry3Bb1-selected field populations of the western corn rootworm to mCry3A, eCry3.1Ab, Cry34/35Ab1. J. Econ. Entomol. 109(3): 1387-1398.</li> <li>Schrader et al. 2017. Evaluation of adult emergence and larval root injury for Cry3Bb1-resistant populations of the western corn rootworm. J. Appl. Entomol. 141: 41-52.</li> <li>Ludwick et al. 2017. Minnesota field population of western corn rootworm shows incomplete resistance to Cry34Ab1/ Cry35Ab1 and Cry3Bb1. J. Appl. Entomol. 141: 28-40.</li> <li>Calles-Torrez et al. 2019. Field-evolved resistance of northern and western corn rootworm populations to corn hybrids expressing single and pyramided Cry3Bb1 &amp; Cry34/35Ab1 Bt proteins in North Dakota. J Econ Entomol. 112(4): 1875-1886.</li> </ul>

CORN ROOTWORM SPECIES	Bt protein	Crop Location(s)	• Source/Citation for more information
western corn rootworm (WCR)  continued			<ul style="list-style-type: none"> <li>• Gassmann et al. 2020. Field evolved resistance by western corn rootworm to Cry34/35Ab1 and other <i>Bacillus thuringiensis</i> traits in transgenic maize. <i>Pest Manag Sci</i> 76:268–276.</li> <li>• Reinders et al. 2022. Evidence of western corn rootworm field-evolved resistance to Cry3Bb1 + Cry34/35Ab1 maize in Nebraska. <i>Pest Manag. Sci.</i> 78(4): 1356-1366.</li> </ul>
	mCry3A	Field Corn  Iowa Minnesota Nebraska Texas	<ul style="list-style-type: none"> <li>• Gassmann et al. 2014. Field-evolved resistance by western corn rootworm to multiple <i>Bacillus thuringiensis</i> toxins in transgenic maize. <i>PNAS</i> 111(14). 5141–5146.</li> <li>• Wangila et al. 2015. Susceptibility of Nebraska western corn rootworm populations to Bt corn events. <i>J. Econ. Entomol.</i> 108: 742-751.</li> <li>• Zukoff et al. 2016. Multiple assays indicate varying levels of cross resistance in Cry3Bb1-selected field populations of the western corn rootworm to mCry3A, eCry3.1Ab &amp; Cry34/35Ab1. <i>J Econ Entomol</i> 109(3): 1387-1398.</li> </ul>
	eCry3.1Ab	Field Corn  Iowa Minnesota	<ul style="list-style-type: none"> <li>• Jakka et al. 2016. Broad-spectrum resistance to <i>Bacillus thuringiensis</i> toxins by western corn rootworm. <i>Nature Scientific Reports</i> 6, 27860; doi: 10.1038/srep27860.</li> <li>• Zukoff et al. 2016. Multiple assays indicate varying levels of cross resistance in Cry3Bb1-selected field populations of the western corn rootworm to mCry3A, eCry3.1Ab &amp; Cry34/35Ab1. <i>J Econ Entomol</i> 109(3): 1387-1398.</li> </ul>
	Cry34/35Ab1 (now Gpp34Ab1/ Tpp35Ab1)	Field Corn  Iowa Minnesota Nebraska	<ul style="list-style-type: none"> <li>• Zukoff et al. 2016. Multiple assays indicate varying levels of cross resistance in Cry3Bb1-selected field populations of the western corn rootworm to mCry3A, eCry3.1Ab &amp; Cry34/35Ab1. <i>J Econ Entomol</i> 109(3): 1387-1398.</li> <li>• Gassmann et al. 2016. Evidence of resistance to Cry34/35Ab1 corn by western corn rootworm: Root injury in the field and larval survival in plant-based Bioassays. <i>J Econ Entomol</i> 109(4): 1872–1880</li> <li>• Ludwick et al. 2017. Minnesota field population of western corn rootworm shows incomplete resistance to Cry34Ab1/ Cry35Ab1 and Cry3Bb1. <i>J. Appl. Entomol.</i> 141: 28-40.</li> <li>• Gassmann et al. 2020. Field evolved resistance by western corn rootworm to Cry34/35Ab1 and other <i>Bacillus thuringiensis</i> traits in transgenic maize. <i>Pest Manag Sci</i> 76:268–276.</li> <li>• Reinders &amp; Meinke. 2022. Reduced susceptibility of western corn rootworm populations to Cry34/35Ab1-expressing maize in northeast Nebraska. <i>Nature Sci. Rpts.</i> (2022) 12: 19221.</li> </ul>
	Cry3 x Cry34/35Ab1 pyramid	Field Corn  Iowa Nebraska North Dakota	<ul style="list-style-type: none"> <li>• Calles-Torrez et al. 2019. Field-evolved resistance of northern and western corn rootworm populations to corn hybrids expressing single and pyramided Cry3Bb1 &amp; Cry34/35Ab1 Bt proteins in North Dakota. <i>J Econ Entomol.</i> 112(4): 1875-1886.</li> <li>• Gassmann et al. 2020. Field evolved resistance by western corn rootworm to Cry34/35Ab1 and other <i>Bacillus thuringiensis</i> traits in transgenic maize. <i>Pest Manag Sci</i> 76: 268–276.</li> <li>• Reinders et al. 2022. Evidence of western corn rootworm field-evolved resistance to Cry3Bb1 + Cry34/35Ab1 maize in Nebraska. <i>Pest Manag. Sci.</i> 78(4): 1356-1366.</li> </ul>