

Genetic Improvement of Natural Enemies and Microbial Biocontrol Agents: Emerging Tools for Sustainable Pest Management

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Biological control is an important component of sustainable agriculture and Integrated Pest Management (IPM). Natural enemies such as predators, parasitoids, pathogens, and entomopathogenic microorganisms help suppress insect pest populations without causing major environmental pollution. However, the effectiveness of natural enemies in the field is sometimes limited due to environmental stress, slow action, narrow host range, or low persistence. To overcome these limitations, scientists use genetic improvement techniques including selective breeding, mutation, tissue culture, recombinant DNA technology, and molecular biology approaches. These techniques improve the virulence, environmental tolerance, reproductive capacity, and host specificity of beneficial organisms.

Table 1. Genetic Improvement of Predators

Gene/Target Trait	Natural Enemy Used	Source	Against	Scientist (Year)
Flightless trait	<i>Harmonia axyridis</i>	Selective breeding	Aphids	Seko and Miura (2013)
Hsp70	<i>Adalia bipunctata</i>	Insect genome	Aphids	Sørensen <i>et al.</i> , (2003)
Cytochrome P450	<i>Harmonia axyridis</i>	Insect genome	Aphids	Pan <i>et al.</i> , (2014)
Esterase gene	<i>Coccinella septempunctata</i>	Insect genome	Resistant aphids	Ferrari <i>et al.</i> , (2001)
Vitellogenin gene	<i>Harmonia axyridis</i>	Insect genome	Aphids	Osawa (2000)
Odorant receptor gene	<i>Harmonia axyridis</i>	Insect genome	Aphids & whiteflies	Zhang <i>et al.</i> , (2011)
Antifreeze protein gene	Ladybird beetles	Arctic insects	Aphids	Duman (2001)
Trehalase gene	<i>Chrysoperla carnea</i>	Insect genome	Soft-bodied pests	Li <i>et al.</i> , (2013)

Table 2. Genetic Improvement of Parasitoids

Gene/Target Trait	Natural Enemy Used	Source	Against	Scientist
Venom protein genes	<i>Nasonia vitripennis</i>	Parasitoid genome	Lepidopteran larvae	Werren <i>et al.</i> (2010)
RNAi technology	<i>Nasonia vitripennis</i>	dsRNA constructs	Functional gene studies	Lynch & Desplan (2006)
Wolbachia-associated genes	<i>Trichogramma kaykai</i>	<i>Wolbachia</i>	Fruit flies	Zabalou <i>et al.</i> (2004)
Odorant receptor genes	<i>Trichogramma chilonis</i>	Insect genome	Lepidopteran eggs	Fatouros <i>et al.</i> (2008)

Gene/Target Trait	Natural Enemy Used	Source	Against	Scientist
Desaturase genes	<i>Trichogramma brassicae</i>	Insect genome	Host location	Wajnberg <i>et al.</i> (2012)
Vitellogenin gene	<i>Nasonia vitripennis</i>	Insect genome	Improved reproduction	Lynch <i>et al.</i> (2015)
DNA methylation genes	<i>Nasonia vitripennis</i>	Insect genome	Epigenetic improvement	Werren <i>et al.</i> (2010)
Immune-related genes	<i>Nasonia vitripennis</i>	Insect genome	Pathogen resistance	Sackton <i>et al.</i> (2013)

Table 3. Genetic Improvement of Baculoviruses

Gene/Target Trait	Baculovirus Used	Source	Against (Target Pest)	Scientist
AaIT scorpion toxin gene	<i>Autographa californica</i> MNPV (AcMNPV)	Scorpion <i>Androctonus australis</i>	<i>Helicoverpa zea</i> , <i>Spodoptera</i> spp.	Stewart <i>et al.</i> , (1991)
LqhIT2 toxin gene	AcMNPV	Scorpion <i>Leiurus quinquestriatus</i>	Lepidopteran larvae	McCutchen <i>et al.</i> , (1991)
TxP-I toxin gene	AcMNPV	Scorpion <i>Buthus occitanus</i>	<i>Heliothis virescens</i>	Carbonell <i>et al.</i> , (1988)
Juvenile hormone esterase (JHE) gene	AcMNPV	<i>Heliothis virescens</i>	Tobacco budworm	Hammock <i>et al.</i> , (1990)
Diuretic hormone gene	AcMNPV	<i>Manduca sexta</i>	Lepidopteran pests	Maeda (1989)
Insect-selective neurotoxin gene	AcMNPV	Mite <i>Pyemotes tritici</i>	Armyworms and caterpillars	Tomalski and Miller (1991)
Ecdysteroid UDP-glucosyltransferase (EGT) deletion	AcMNPV	Viral genome modification	Various lepidopteran pests	O'Reilly and Miller (1991)
Cry1Ac gene	AcMNPV	<i>Bacillus thuringiensis</i>	<i>Helicoverpa armigera</i>	Martens <i>et al.</i> , (1995)
Cry1Ab gene	AcMNPV	<i>Bacillus thuringiensis</i>	Armyworms	Merryweather <i>et al.</i> , (1990)

Table 4. Genetic Improvement of *Bacillus thuringiensis*

Gene/Target Trait	<i>Bacillus thuringiensis</i> Strain	Source	Against (Target Pest)	Scientist
Cry1Ac gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i> subsp. <i>kurstaki</i>	<i>Helicoverpa armigera</i>	Schnepf <i>et al.</i> , (1998)
Cry1Ab gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	European corn borer (<i>Ostrinia nubilalis</i>)	Höfte & Whiteley (1989)
Cry1C gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	<i>Spodoptera litura</i>	Visser <i>et al.</i> , (1990)
Cry2Aa gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	Cotton bollworm	Widner & Whiteley (1990)
Cry2Ab gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	Lepidopteran pests	Perlak <i>et al.</i> , (1991)
Cry3A gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i> subsp. <i>tenebrionis</i>	Colorado potato beetle	Donovan <i>et al.</i> , (1988)
Cry3Bb1 gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	Corn rootworm	Vaughn <i>et al.</i> , (2005)

Gene/Target Trait	<i>Bacillus thuringiensis</i> Strain	Source	Against (Target Pest)	Scientist
Cry9C gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i>	Corn pests	Lambert <i>et al.</i> , (1996)
Cyt1Aa gene	Recombinant <i>Bt</i>	<i>B. thuringiensis</i> subsp. <i>israelensis</i>	Mosquito larvae	Crickmore <i>et al.</i> , (1995)
Vip3A gene	Recombinant <i>Bt</i>	Vegetative insecticidal protein-producing <i>Bt</i>	<i>Helicoverpa armigera</i> , <i>Spodoptera</i> spp.	Estruch <i>et al.</i> , (1996)

Table 5. Genetic Improvement of Entomopathogenic Fungi

Gene/Target Trait	Entomopathogenic Fungus Used	Source	Against (Target Pest)	Scientist (Year)
Scorpion toxin (AaIT) gene	<i>Metarhizium anisopliae</i>	Scorpion <i>Androctonus australis</i>	<i>Manduca sexta</i> , caterpillars	Wang & St. Leger (2007)
Hybrid toxin (Hybrid) gene	<i>Metarhizium anisopliae</i>	Spider + scorpion toxin	Termites, caterpillars	Wang <i>et al.</i> (2012)
Chitinase (chi2) gene	<i>Beauveria bassiana</i>	Fungal genome	Whiteflies, aphids	Fang <i>et al.</i> (2005)
Pr1 protease gene	<i>Metarhizium anisopliae</i>	Fungal genome	Various insect pests	St. Leger <i>et al.</i> (1996)
Cat1 catalase gene	<i>Metarhizium anisopliae</i>	Fungal genome	Stress tolerance during infection	Wang <i>et al.</i> (2013)
GFP marker gene	<i>Beauveria bassiana</i>	<i>Aequorea victoria</i>	Monitoring infection process	Fan <i>et al.</i> (2007)
Trypsin gene	<i>Metarhizium anisopliae</i>	Fungal genome	Lepidopteran larvae	Joshi <i>et al.</i> (1997)
Bbsmr1 transporter gene	<i>Beauveria bassiana</i>	Fungal genome	Insect virulence enhancement	Song <i>et al.</i> (2016)
Superoxide dismutase (SOD) gene	<i>Beauveria bassiana</i>	Fungal genome	Increased oxidative stress tolerance	Xie <i>et al.</i> (2010)
Destruxin biosynthesis genes	<i>Metarhizium robertsii</i>	Fungal genome	Broad-spectrum insect pests	Wang <i>et al.</i> (2012)

Conclusion

The genetic improvement of natural enemies, including baculoviruses, *Bacillus thuringiensis* (Bt), and entomopathogenic fungi, represents a critical advancement in sustainable agriculture and Integrated Pest Management (IPM). By utilizing techniques such as selective breeding and molecular biology, researchers have overcome traditional limitations like slow action and environmental sensitivity, developing superior strains of parasitoids like *Trichogramma chilonis* that exhibit significantly higher fecundity and insecticide tolerance. Innovations such as the use of CRISPR-Cas9 to enhance the virulence of fungi like *Beauveria bassiana* and the engineering of "rapid action" baculoviruses with scorpion neurotoxins allow for faster pest suppression and more reliable field performance. Ultimately, these genetic enhancements provide a more robust and lethal alternative to chemical pesticides, ensuring effective pest control while reducing environmental pollution.

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