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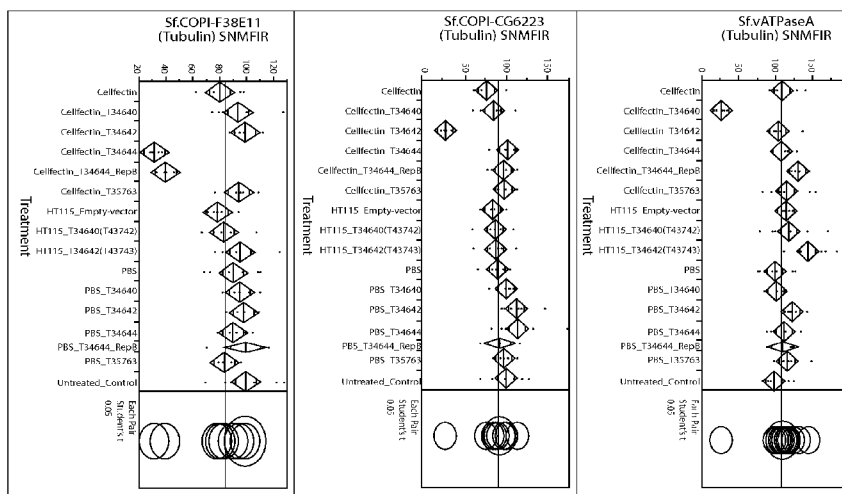
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(54) **Title:** COMPOSITIONS AND METHODS FOR CONTROLLING INSECT PESTS

Figure 1



(57) **Abstract:** Disclosed herein are methods of controlling insect pests which infest crop plants, in particular *Spodoptera frugiperda* (fall armyworm), *Lygus hesperus* (western tarnished plant bug), *Euschistus heros* (neotropical brown stink bug), and *Plutella xylostella* (diamondback moth), and methods of providing plants resistant to such pests. Also disclosed are polynucleotides and recombinant DNA molecules and constructs useful in such methods, insecticidal compositions such as topical sprays containing insecticidal double-stranded RNAs, and plants with improved resistance to infestation by these insects. Further disclosed are methods of selecting target genes for RNAi-mediated silencing and control of these insect pests.

## COMPOSITIONS AND METHODS FOR CONTROLLING INSECT PESTS

### CROSS-REFERENCE TO RELATED APPLICATIONS AND INCORPORATION OF SEQUENCE LISTINGS

[0001] This application claims priority to U. S. Provisional Patent Application No. 61/973,484 filed 1 April 2014, which is incorporated by reference in its entirety herein. The sequence listing contained in the file “40-21\_70001\_0000\_US\_ST25.txt” (49 kilobytes, created on 1 April 2014, filed with U. S. Provisional Patent Application No. 61/973,484 on 1 April 2014), and the replacement sequence listing contained in the file “40-21\_70001\_0000\_US\_ST25.txt” (49 kilobytes, created on 4 April 2014, filed as a replacement sequence listing on 4 April 2014 solely to correct the listing of inventors), are incorporated by in their entirety herein. The sequence listing contained in the file “40-21\_70001\_0000\_WO\_ST25.txt” (70 kilobytes, created on 13 March 2015) is filed herewith and is incorporated by reference in its entirety herein.

### FIELD OF THE INVENTION

[0002] Disclosed herein are methods for controlling invertebrate pest infestations, particularly in plants, and compositions and polynucleotides useful in such methods. More specifically, this invention is related to polynucleotides and methods of use thereof for modifying the expression of genes in an invertebrate pest, particularly through RNA interference. Pest species of interest include insects that infest crop plants, *e. g.*, *Plutella xylostella* (diamondback moth), *Spodoptera frugiperda* (fall armyworm), *Lygus hesperus* (western tarnished plant bug), and *Euschistus heros* (neotropical brown stink bug).

### BACKGROUND OF THE INVENTION

[0003] Commercial crops are often the targets of attack by invertebrate pests such as insects. Compositions for controlling insect infestations in plants have typically been in the form of chemical insecticides. However, there are several disadvantages to using chemical insecticides. For example, chemical insecticides are generally not selective, and applications of chemical insecticides intended to control insect pests in crop plants can exert their effects on non-target insects and other invertebrates as well. Chemical insecticides often persist in the environment and can be slow to degrade, thus potentially accumulating in the food chain. Furthermore the use of persistent chemical insecticides can result in the development of resistance in the target insect species. Thus there has been a long felt need for more environmentally friendly methods for controlling or eradicating insect infestation on or in plants, *i. e.*, methods which are species-selective, environmentally inert, non-persistent, and biodegradable, and that fit well into pest resistance management schemes.

[0004] Insecticidal compositions that include *Bacillus thuringiensis* (“Bt”) bacteria have been commercially available and used as environmentally safe and acceptable insecticides for more than thirty years. The effectiveness of these compositions is due to insecticidal proteins that are produced

exclusively by Bt bacteria. The insecticidal Bt proteins do not persist in the environment, are highly selective as to the target species affected, exert their effects only upon ingestion by a target insect, and have been shown to be harmless to plants and other non-targeted organisms, including humans and other vertebrates. Transgenic plants containing one or more recombinant genes encoding insecticidal Bt proteins are also available in the art and are resistant to insect pest infestation. One positive environmental result of the use of transgenic plants expressing Bt proteins is a decrease in the amount of chemical insecticides that are applied to control pest infestation in such transgenic crop fields, resulting in decreased contamination of soil and waters by non-degraded or excess chemical insecticides. In addition, there has been a noticeable increase in the numbers of beneficial insects in fields in which Bt protein-expressing transgenic crop plants are grown because of the decrease in the use of non-selective chemical insecticides.

**[0005]** RNA interference (RNAi, RNA-mediated gene suppression) is another approach used for pest control. In invertebrates RNAi-based gene suppression was first demonstrated in nematodes (Fire *et al.*, (1998) *Nature*, 391:806–811; Timmons & Fire (1998) *Nature*, 395:854). Subsequently, RNAi-based suppression of invertebrate genes using recombinant nucleic acid techniques has been reported in a number of species, including agriculturally or economically important pests from various insect and nematode taxa, such as: root-knot nematodes (*Meloidogyne* spp.), see Huang *et al.* (2006) *Proc. Natl. Acad. Sci. USA*, 103:14302–14306, doi:10.1073/pnas.0604698103); cotton bollworm (*Helicoverpa armigera*), see Mao *et al.* (2007) *Nature Biotechnol.*, 25:1307–1313, doi:10.1038/nbt1352; Western corn rootworm (*Diabrotica virgifera* LeConte), see Baum *et al.* (2007) *Nature Biotechnol.*, 25:1322–1326, doi:10.1038/nbt1359; sugar beet cyst nematode (*Heterodera schachtii*), see Sindhu *et al.* (2008) *J. Exp. Botany*, 60:315–324, doi:10.1093/jxb/ern289; mosquito (*Aedes aegypti*), see Pridgeon *et al.* (2008) *J. Med. Entomol.*, 45:414–420, doi: full/10.1603/0022-2585%282008%2945%5B414%3ATAADRK%5D2.0.CO%3B2 fruit flies (*Drosophila melanogaster*), flour beetles (*Tribolium castaneum*), pea aphids (*Acyrtosiphon pisum*), and tobacco hornworms (*Manduca sexta*), see Whyard *et al.* (2009) *Insect Biochem. Mol. Biol.*, 39:824–832, doi:10.1016/j.ibmb.2009.09.00; diamondback moth (*Plutella xylostella*), see Gong *et al.* (2011) *Pest Manag. Sci.*, 67: 514–520, doi:10.1002/ps.2086; green peach aphid (*Myzus persicae*), see Pitino *et al.* (2011) *PLoS ONE*, 6:e25709, doi:10.1371/journal.pone.0025709; brown planthopper (*Nilaparvata lugens*), see Li *et al.* (2011) *Pest Manag. Sci.*, 67:852–859, doi:10.1002/ps.2124; and whitefly (*Bemisia tabaci*), see Upadhyay *et al.* (2011) *J. Biosci.*, 36:153–161, doi:10.1007/s12038-011-9009-1.

**[0006]** This invention is related to methods of controlling insect pests, in particular insects which infest crop plants and have previously been found to be recalcitrant to RNA-mediated gene suppression methods, *e. g.*, *Plutella xylostella* (diamondback moth), *Spodoptera frugiperda* (fall armyworm), *Lygus hesperus* (western tarnished plant bug), and *Euschistus heros* (neotropical brown stink bug). Double-stranded RNA (dsRNA) trigger sequences have been identified for testing on the recalcitrant insect species *Plutella xylostella* (diamondback moth, DBM), *Spodoptera frugiperda* (fall

armyworm, FAW), *Lygus hesperus* (western tarnished plant bug, WTPB), and *Euschistus heros* (neotropical brown stink bug, NBSB). These triggers are designed to suppress novel target genes that are putative orthologues of genes previously demonstrated to be efficacious targets for RNAi-mediated mortality in Western corn rootworm (*Diabrotica virgifera*).

[0007] This invention is further related to polynucleotides and recombinant DNA molecules and constructs useful in methods of controlling insect pests. This invention is further related to insecticidal compositions, as well as to transgenic plants resistant to infestation by insect pests. This invention is also related to methods of identifying efficacious double-stranded RNA triggers for controlling insect pests, and methods for identifying target genes that are likely to represent essential functions, making these genes preferred targets for RNAi-mediated silencing and control of insect pests.

#### SUMMARY OF THE INVENTION

[0008] This invention is related to control of insect species, especially those that are economically or agriculturally important pests. The compositions and methods of this invention include recombinant polynucleotide molecules, such as recombinant DNA constructs for making transgenic plants resistant to infestation by insect species and RNA “triggers” that are useful, *e. g.*, as topically applied agents for causing RNAi-mediated suppression of a target gene in a insect species and thus controlling or preventing infestation by that insect species. Another utility of this invention is a polynucleotide-containing composition (*e. g.*, a composition containing a dsRNA trigger for suppressing a target gene) that is topically applied to an insect species or to a plant, plant part, or seed to be protected from infestation by an insect species. This invention is further related to methods for selecting preferred insect target genes that are more likely to be effective targets for RNAi-mediated control of an insect species.

[0009] In one aspect, this invention provides a method for controlling an insect infestation of a plant including contacting with a dsRNA an insect that infests a plant, wherein the dsRNA includes at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% complementarity with a fragment of a target gene of the insect, and wherein the target gene has a DNA sequence selected from the group consisting of **SEQ ID NOS:1 – 12 and 43 – 44**. In embodiments, the dsRNA includes an RNA strand with a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOS:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the dsRNA includes an RNA strand with a sequence selected from the group consisting of **SEQ ID NOS:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the dsRNA trigger suppresses a gene in the insect and stunts or kills the insect.

[0010] In another aspect, this invention provides a method of causing mortality or stunting in an insect, including providing in the diet of an insect at least one recombinant RNA including at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID**

**NOs:1 – 12 and 43 – 44**, and wherein ingestion of the recombinant RNA by the insect results in mortality or stunting in the insect. In embodiments, the silencing element includes an RNA strand with a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the silencing element includes an RNA strand with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0011] In another aspect, this invention provides an insecticidal composition including an insecticidally effective amount of a recombinant RNA molecule, wherein the recombinant RNA molecule includes at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% complementarity with a fragment of a target gene of an insect that infests a plant, and wherein the target gene has a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**. In embodiments, the recombinant RNA molecule is dsRNA. In embodiments, the recombinant RNA molecule includes at least one segment (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the recombinant RNA molecule includes at least one segment (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0012] In another aspect, this invention provides a method of providing a plant having improved resistance to an insect, including expressing in the plant a recombinant DNA construct including DNA encoding at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**, and wherein ingestion of the recombinant RNA by the insect results in mortality or stunting in the insect. In embodiments, the silencing element is ssRNA. In other embodiments, the silencing element is dsRNA. In embodiments, the silencing element includes RNA (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the silencing element includes RNA (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0013] In another aspect, this invention provides a recombinant DNA construct including a heterologous promoter, such as a heterologous promoter functional in a bacterial cell or in a eukaryotic cell (*e. g.*, a plant cell or an insect cell), operably linked to DNA encoding an RNA transcript including a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the RNA transcript is ssRNA. In other embodiments, the RNA transcript is dsRNA. In embodiments, the silencing element includes RNA (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence of

about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In embodiments, the silencing element includes RNA (*e. g.*, an RNA strand or segment of an RNA strand) with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0014] In related aspects, this invention provides man-made compositions including the polynucleotide or trigger of this invention, such as dsRNA formulations useful for topical application to a plant or substance in need of protection from an insect infestation, recombinant constructs and vectors useful for making transgenic plant cells and transgenic plants, formulations and coatings useful for treating plants (including plant seeds or propagatable parts such as tubers), plant seeds or propagatable parts such as tubers treated with or containing a polynucleotide of this invention as well as commodity products and foodstuffs produced from such plants, seeds, or propagatable parts (especially commodity products and foodstuffs having a detectable amount of a polynucleotide of this invention). A further aspect of this invention are polyclonal or monoclonal antibodies that bind a peptide or protein encoded by a sequence or a fragment of a sequence selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**; another aspect of this invention are polyclonal or monoclonal antibodies that bind a peptide or protein encoded by a sequence or a fragment of a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46** or the complement thereof. Such antibodies are made by routine methods as known to one of ordinary skill in the art.

[0015] Other aspects and specific embodiments of this invention are disclosed in the following detailed description and working Examples.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0016] **Figure 1** depicts the results of the transfection experiments described in **Example 2** for the dsRNA triggers (TOP PANEL) T34640 (**SEQ ID NO:17**, targeting V-ATPase A subunit), (MIDDLE PANEL) T34642 (**SEQ ID NO:18**, targeting COPI coatomer beta subunit), or (BOTTOM PANEL) T34644 (**SEQ ID NO:19**, targeting COPI coatomer beta prime subunit) in *Spodoptera frugiperda* (fall armyworm, FAW) SF9 cells.

[0017] **Figure 2** depicts the results of the transfection experiments described in **Example 2** for the dsRNA triggers (TOP PANEL) T42017 (**SEQ ID NO:21**, targeting V-ATPase subunit A), (TOP PANEL) T33310 (**SEQ ID NO:29**, targeting V-ATPase subunit A), (MIDDLE PANEL) T32938 (**SEQ ID NO:28**, targeting COPI coatomer beta subunit), and (BOTTOM PANEL) T32937 (**SEQ ID NO:13**, targeting COPI coatomer beta prime subunit) in *Plutella xylostella* (diamondback moth, DBM) cells.

#### **DETAILED DESCRIPTION OF THE INVENTION**

[0018] Unless defined otherwise, all technical and scientific terms used have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Generally, the nomenclature used and the manufacturing or laboratory procedures described below are well known and commonly employed in the art. Conventional methods are used for these procedures, such as those

provided in the art and various general references. Where a term is provided in the singular, the inventors also contemplate aspects of the invention described by the plural of that term. Where there are discrepancies in terms and definitions used in references that are incorporated by reference, the terms used in this application shall have the definitions given. Other technical terms used have their ordinary meaning in the art in which they are used, as exemplified by various art-specific dictionaries, for example, "The American Heritage® Science Dictionary" (Editors of the American Heritage Dictionaries, 2011, Houghton Mifflin Harcourt, Boston and New York), the "McGraw-Hill Dictionary of Scientific and Technical Terms" (6<sup>th</sup> edition, 2002, McGraw-Hill, New York), or the "Oxford Dictionary of Biology" (6<sup>th</sup> edition, 2008, Oxford University Press, Oxford and New York). The inventors do not intend to be limited to a mechanism or mode of action. Reference thereto is provided for illustrative purposes only.

**[0019]** Unless otherwise stated, nucleic acid sequences in the text of this specification are given, when read from left to right, in the 5' to 3' direction. One of skill in the art would be aware that a given DNA sequence is understood to define a corresponding RNA sequence which is identical to the DNA sequence except for replacement of the thymine (T) nucleotides of the DNA with uracil (U) nucleotides. Thus, providing a specific DNA sequence is understood to define the exact RNA equivalent. A given first polynucleotide sequence, whether DNA or RNA, further defines the sequence of its exact complement (which can be DNA or RNA), *i. e.*, a second polynucleotide that hybridizes perfectly to the first polynucleotide by forming Watson-Crick base-pairs. By "essentially identical" or "essentially complementary" to a target gene or a fragment of a target gene is meant that a polynucleotide strand (or at least one strand of a double-stranded polynucleotide) is designed to hybridize (generally under physiological conditions such as those found in a living plant or animal cell) to a target gene or to a fragment of a target gene or to the transcript of the target gene or the fragment of a target gene; one of skill in the art would understand that such hybridization does not necessarily require 100% sequence identity or complementarity. A first nucleic acid sequence is "operably" connected or "linked" with a second nucleic acid sequence when the first nucleic acid sequence is placed in a functional relationship with the second nucleic acid sequence. For example, a promoter sequence is "operably linked" to DNA if the promoter provides for transcription or expression of the DNA. Generally, operably linked DNA sequences are contiguous.

**[0020]** The term "polynucleotide" commonly refers to a DNA or RNA molecule containing multiple nucleotides and generally refers both to "oligonucleotides" (a polynucleotide molecule of 18-25 nucleotides in length) and longer polynucleotides of 26 or more nucleotides. Polynucleotides also include molecules containing multiple nucleotides including non-canonical nucleotides or chemically modified nucleotides as commonly practiced in the art; see, *e. g.*, chemical modifications disclosed in the technical manual "RNA Interference (RNAi) and DsiRNAs", 2011 (Integrated DNA Technologies Coralville, IA). Generally, polynucleotides or triggers of this invention, whether DNA or RNA or both, and whether single- or double-stranded, include at least one segment of 18 or more contiguous

nucleotides (or, in the case of double-stranded polynucleotides, at least 18 contiguous base-pairs) that are essentially identical or complementary to a fragment of equivalent size of the DNA of a target gene or the target gene's RNA transcript. Throughout this disclosure, "at least 18 contiguous" means "from about 18 to about 10,000, including every whole number point in between". Thus, embodiments of this invention include compositions including oligonucleotides having a length of 18-25 nucleotides (18-mers, 19-mers, 20-mers, 21-mers, 22-mers, 23-mers, 24-mers, or 25-mers), or medium-length polynucleotides having a length of 26 or more nucleotides (polynucleotides of 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, about 65, about 70, about 75, about 80, about 85, about 90, about 95, about 100, about 110, about 120, about 130, about 140, about 150, about 160, about 170, about 180, about 190, about 200, about 210, about 220, about 230, about 240, about 250, about 260, about 270, about 280, about 290, or about 300 nucleotides), or long polynucleotides having a length greater than about 300 nucleotides (*e. g.*, polynucleotides of between about 300 to about 400 nucleotides, between about 400 to about 500 nucleotides, between about 500 to about 600 nucleotides, between about 600 to about 700 nucleotides, between about 700 to about 800 nucleotides, between about 800 to about 900 nucleotides, between about 900 to about 1000 nucleotides, between about 300 to about 500 nucleotides, between about 300 to about 600 nucleotides, between about 300 to about 700 nucleotides, between about 300 to about 800 nucleotides, between about 300 to about 900 nucleotides, or about 1000 nucleotides in length, or even greater than about 1000 nucleotides in length, for example up to the entire length of a target gene including coding or non-coding or both coding and non-coding portions of the target gene). Where a polynucleotide is double-stranded, such as the dsRNA triggers described in the working Examples, its length can be similarly described in terms of base pairs. Double-stranded polynucleotides, such as the dsRNA triggers described in the working examples, can further be described in terms of one or more of the single-stranded components.

[0021] The polynucleotides or triggers of this invention are generally designed to suppress or silence one or more genes ("target genes"). The term "gene" refers to any portion of a nucleic acid that provides for expression of a transcript or encodes a transcript. A "gene" can include, but is not limited to, a promoter region, 5' untranslated regions, transcript encoding regions that can include intronic regions, 3' untranslated regions, or combinations of these regions. In embodiments, the target genes can include coding or non-coding sequence or both. In other embodiments, the target gene has a sequence identical to or complementary to a messenger RNA, *e. g.*, in embodiments the target gene is a cDNA.

#### **CONTROLLING INSECT INFESTATIONS OF A PLANT BY CONTACTING WITH A DSRNA**

[0022] A first aspect of this invention provides a method for controlling an insect infestation of a plant including contacting with a double-stranded RNA (dsRNA) an insect that infests a plant, wherein the dsRNA includes at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) complementarity with a fragment of a target gene of the insect, and wherein the target gene has a DNA

sequence selected from the group consisting of **SEQ ID NOs:1 – 12** and **43 – 44**. In this context “controlling” includes inducement of a physiological or behavioural change in an insect (adult or larvae or nymphs) such as, but not limited to, growth stunting, increased mortality, decrease in reproductive capacity, decrease in or cessation of feeding behavior or movement, or decrease in or cessation of metamorphosis stage development. “Double-stranded” refers to the base-pairing that occurs between sufficiently complementary, anti-parallel nucleic acid strands to form a double-stranded nucleic acid structure, generally under physiologically relevant conditions.

**[0023]** In various embodiments, the insect is selected from the group consisting of *Spodoptera* spp., *Lygus* spp., *Euschistus* spp., and *Plutella* spp. Insects of particular interest include *Spodoptera frugiperda* (fall armyworm), *Lygus hesperus* (western tarnished plant bug), *Euschistus heros* (neotropical brown stink bug), and *Plutella xylostella* (diamondback moth).

**[0024]** Various embodiments of the method include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 3**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:4 – 7, 43, and 44**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:8 – 9**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**. Other embodiments of the method include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the dsRNA includes a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the dsRNA includes a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the dsRNA includes a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the dsRNA includes a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**. Other embodiments include those where the dsRNA has a sequence modified as described in **Example 5** to eliminate matches to non-target organisms, such as the modified sequences (**SEQ ID NOs:30 – 42**) disclosed in **Table 6**.

**[0025]** The plant can be any plant that is subject to infestation by an insect that can be controlled by the polynucleotides disclosed herein. Plants of particular interest include commercially important plants, including row crop plants, vegetables, and fruits, and other plants of agricultural or decorative use. Examples of suitable plants are provided under the heading “Plants”.

**[0026]** In embodiments of the method, the dsRNA includes multiple segments each of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) complementarity with a fragment of a target gene of the insect. For example, the dsRNA can include segments corresponding to different regions of the target gene, or can include multiple copies of a segment. In other embodiments of the method, the dsRNA

includes multiple segments, each of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) complementarity with a fragment of a different target gene; in this way multiple target genes, or multiple insect species, can be suppressed.

[0027] In embodiments of the method, the dsRNA is blunt-ended. In other embodiments, the dsRNA has an overhang at one or both ends (termini); the overhang can be a single nucleotide or 2, 3, 4, 5, 6, or more nucleotides, and can be located on the 5' end or on the 3' end of a strand. The dsRNA can be chemically synthesized, or can be produced by expression in a microorganism, by expression in a plant cell, or by microbial fermentation. The dsRNA can be chemically modified, *e. g.*, to improve stability or efficacy.

[0028] In some embodiments of the method, the contacting includes application of a composition including the dsRNA to a surface of the insect or to a surface of the plant infested by the insect. The composition can include or be in the form of a solid, liquid, powder, suspension, emulsion, spray, encapsulation, microbeads, carrier particulates, film, matrix, or seed treatment. In embodiments, the composition can be applied to a seed, *e. g.*, by soaking the seed in a liquid composition including the dsRNA, wherein the seed imbibes or takes up the dsRNA into the seed interior or seed endosperm in an effective amount to provide improved resistance to the insect pest by the seed or a plant or seedling grown from the seed. In embodiments, the contacting includes providing the dsRNA in a composition that further includes one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator. In embodiments, the contacting includes providing the dsRNA in a composition that further includes at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporus* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.

[0029] In some embodiments of the method, the contacting includes providing the dsRNA in a composition that is ingested by the insect, such as in a liquid, emulsion, or powder applied to a plant on which the insect feeds, or in the form of bait. Such compositions can further include one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator. Such compositions can further include at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporus* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein. In embodiments, the combination of the dsRNA and the pesticidal agent

provides a level of insect control that is synergistic, *i. e.*, greater than the sum of the effects of the dsRNA and the pesticidal agent components if tested separately.

#### METHODS OF CAUSING MORTALITY OR STUNTING IN AN INSECT

[0030] Another aspect of this invention provides a method of causing mortality or stunting in an insect, including providing in the diet of an insect at least one recombinant RNA including at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12** and **43 – 44**, and wherein ingestion of the recombinant RNA by the insect results in mortality or stunting in the insect. The method is applicable to insects at various life stages. In embodiments, the method causes mortality or stunting in an insect larva or nymph. In other embodiments, the method causes mortality in adult insects.

[0031] In embodiments of the method the recombinant RNA includes at least one RNA strand having a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. Embodiments of the method include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 3**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:4 – 7, 43, and 44**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:8 – 9**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**. Other embodiments of the method include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the silencing element includes a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the silencing element includes a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the silencing element includes a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the silencing element includes a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**. Other embodiments include those where the recombinant RNA has a sequence modified as described in **Example 5** to eliminate matches to non-target organisms, such as the modified sequences (**SEQ ID NOs:30 – 42**) disclosed in **Table 6**.

[0032] In embodiments of the method, the recombinant RNA is dsRNA. In these embodiments, the dsRNA can be blunt-ended dsRNA, or can be dsRNA with an overhang at one or both ends (termini); the overhang can be a single nucleotide or 2, 3, 4, 5, 6, or more nucleotides, and can be located on the 5' end or on the 3' end of a strand. The dsRNA can be chemically synthesized, or can be

produced by expression in a microorganism, by expression in a plant cell, or by microbial fermentation. The dsRNA can be chemically modified, *e. g.*, to improve stability or efficacy. In embodiments of the method where the recombinant RNA is dsRNA, the dsRNA includes at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0033] In some embodiments of the method, the recombinant RNA is provided in the insect's diet in the form of an ingestible composition, such as in a liquid, emulsion, or powder applied to a plant on which the insect feeds, or in the form of bait. Such ingestible compositions can further include one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator. Such ingestible compositions can further include at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein. In embodiments, the combination of the recombinant RNA and the pesticidal agent provides a level of insect stunting or mortality that is synergistic, *i. e.*, greater than the sum of the effects of the recombinant RNA and the pesticidal agent components if tested separately.

#### INSECTICIDAL COMPOSITIONS

[0034] Another aspect of the invention provides an insecticidal composition including an insecticidally effective amount of a recombinant RNA molecule, wherein the recombinant RNA molecule includes at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) complementarity with a fragment of a target gene of an insect that infests a plant, and wherein the target gene has a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**. By "insecticidally effective" is meant effective in inducing a physiological or behavioural change in an insect (adult or larvae or nymphs) that infests a plant such as, but not limited to, growth stunting, increased mortality, decrease in reproductive capacity or decreased fecundity, decrease in or cessation of feeding behavior or movement, or decrease in or cessation of metamorphosis stage development; in embodiments, application of an insecticidally effective amount of the recombinant RNA molecule to a plant improves the plant's resistance to infestation by the insect.

[0035] In embodiments of the insecticidal composition, the recombinant RNA molecule includes at least one RNA strand having a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In specific embodiments, the recombinant RNA molecule is a dsRNA including an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In

embodiments, the recombinant RNA molecule is a dsRNA of at least 50 base pairs in length. In embodiments of the method, the recombinant RNA molecule is dsRNA. In embodiments, the recombinant RNA molecule is a dsRNA which can be blunt-ended dsRNA, or can be dsRNA with an overhang at one or both ends (termini); the overhang can be a single nucleotide or 2, 3, 4, 5, 6, or more nucleotides, and can be located on the 5' end or on the 3' end of a strand. In embodiments, the recombinant RNA molecule is a dsRNA which can be chemically synthesized, or can be produced by expression in a microorganism, by expression in a plant cell, or by microbial fermentation. In embodiments, the recombinant RNA molecule is a dsRNA of a length greater than that which is typical of naturally occurring regulatory small RNAs (such as endogenously produced siRNAs and mature miRNAs), *i. e.*, the polynucleotide is double-stranded RNA of at least about 30 contiguous base-pairs in length. In embodiments, the recombinant RNA molecule is a dsRNA with a length of between about 50 to about 500 base-pairs.

[0036] Embodiments of the insecticidal composition include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 3**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:4 – 7, 43, and 44**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:8 – 9**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the target gene includes a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**. Other embodiments of the insecticidal composition include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the recombinant RNA molecule includes at least one RNA strand having a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and the recombinant RNA molecule includes at least one RNA strand having a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and the recombinant RNA molecule includes at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; and wherein the insect is *Plutella xylostella* (diamondback moth) and the recombinant RNA molecule includes at least one RNA strand having a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**. Specific embodiments of the insecticidal composition include those wherein the insect is *Spodoptera frugiperda* (fall armyworm) and the recombinant RNA molecule is a dsRNA including an RNA strand having a sequence selected from the group consisting of **SEQ ID**

**NOs:17 – 19**; wherein the insect is *Lygus hesperus* (western tarnished plant bug) and recombinant RNA molecule is a dsRNA including an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**; wherein the insect is *Euschistus heros* (neotropical brown stink bug) and recombinant RNA molecule is a dsRNA including an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; and wherein the insect is *Plutella xylostella* (diamondback moth) and recombinant RNA molecule is a dsRNA including an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**. Other embodiments of the insecticidal composition include those where the recombinant RNA molecule has a sequence modified as described in **Example 5** to eliminate matches to non-target organisms, such as the modified sequences (**SEQ ID NOs:30 – 42**) disclosed in **Table 6**.

**[0037]** In various embodiments the insecticidal composition includes an insecticidally effective amount of a recombinant RNA molecule that consists of naturally occurring ribonucleotides, such as those found in naturally occurring RNA. In certain embodiments, the polynucleotide is a combination of ribonucleotides and deoxyribonucleotides, for example, synthetic polynucleotides consisting mainly of ribonucleotides but with one or more terminal deoxyribonucleotides or one or more terminal dideoxyribonucleotides. In certain embodiments, the polynucleotide includes non-canonical nucleotides such as inosine, thiouridine, or pseudouridine. In certain embodiments, the polynucleotide includes chemically modified nucleotides. Examples of chemically modified oligonucleotides or polynucleotides are well known in the art; see, for example, U.S. Patent Publication 2011/0171287, U.S. Patent Publication 2011/0171176, U.S. Patent Publication 2011/0152353, U.S. Patent Publication 2011/0152346, and U.S. Patent Publication 2011/0160082, which are herein incorporated by reference. Illustrative examples include, but are not limited to, the naturally occurring phosphodiester backbone of an oligonucleotide or polynucleotide which can be partially or completely modified with phosphorothioate, phosphorodithioate, or methylphosphonate internucleotide linkage modifications, modified nucleoside bases or modified sugars can be used in oligonucleotide or polynucleotide synthesis, and oligonucleotides or polynucleotides can be labeled with a fluorescent moiety (*e. g.*, fluorescein or rhodamine) or other label (*e. g.*, biotin).

**[0038]** The recombinant RNA molecule of is provided by suitable means known to one in the art. Embodiments include those wherein the recombinant RNA molecule is chemically synthesized (*e. g.*, by *in vitro* transcription, such as transcription using a T7 polymerase or other polymerase), produced by expression in a microorganism or in cell culture (such as plant or insect cells grown in culture), produced by expression in a plant cell, or produced by microbial fermentation.

**[0039]** In embodiments the recombinant RNA molecule of use in this method is provided as an isolated RNA fragment (not part of an expression construct, *i. e.*, lacking additional elements such as a promoter or terminator sequences). Such recombinant RNA molecules can be relatively short, such as single- or double-stranded RNA molecules of between about 18 to about 300 or between about 50 to about 500 nucleotides (for single-stranded polynucleotides) or between about 18 to about 300 or between

about 50 to about 500 base-pairs (for double-stranded polynucleotides). Embodiments include those in which the polynucleotide is a dsRNA including a segment having a sequence selected from the group consisting of SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46.

[0040] In embodiments, the insecticidal composition is in a form selected from the group consisting of a solid, liquid, powder, suspension, emulsion, spray, encapsulation, microbeads, carrier particulates, film, matrix, soil drench, insect diet or insect bait, and seed treatment. In embodiments, the insecticidal composition can be applied to a seed, *e. g.*, by soaking the seed in a liquid insecticidal composition including the dsRNA, wherein the seed imbibes or takes up the dsRNA into the seed interior or seed endosperm in an effective amount to provide improved resistance to the insect pest by the seed or a plant or seedling grown from the seed. In some embodiments, the insecticidal composition is provided in a form that is ingested by the insect, such as in a liquid, emulsion, or powder applied to a plant on which the insect feeds, or in the form of bait. The insecticidal compositions can further include one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator. The insecticidal compositions can further include at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein. In embodiments, the combination of the recombinant RNA molecule and the pesticidal agent provides a level of insect control that is synergistic, *i. e.*, greater than the sum of the effects of the recombinant RNA molecule and the pesticidal agent components if tested separately.

[0041] A related aspect of the invention is a plant treated with an insecticidal composition as described herein, or a seed of the treated plant, wherein the plant exhibits improved resistance to the insect. In embodiments, the plant exhibiting improved resistance to the insect is characterized by improved yield, when compared to a plant not treated with the insecticidal composition.

#### METHODS OF PROVIDING PLANTS WITH IMPROVED INSECT RESISTANCE

[0042] Another aspect of the invention provides a method of providing a plant having improved resistance to an insect, including expressing in the plant a recombinant DNA construct including DNA encoding RNA that includes at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of SEQ ID NOs:1 – 12 and 43 – 44, and wherein ingestion of the RNA by the insect results in mortality or stunting in the insect.

[0043] In embodiments of the method, the silencing element has a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of SEQ ID NOs:13 – 26, 28 – 29, 45, and 46. In specific embodiments, the silencing element is RNA that forms double-stranded RNA

from two separate, essentially complementary strands, wherein at least one RNA strand includes a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 45, and 46**. In other embodiments, the silencing element is RNA that forms double-stranded RNA from a single self-hybridizing hairpin transcript, wherein one “arm” of the hairpin includes a sequence of about 95% to about 100% (*e. g.*, about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 45, and 46**. Other embodiments include those where the silencing element has a sequence modified as described in **Example 5** to eliminate matches to non-target organisms, such as the modified sequences (**SEQ ID NOs:30 – 42**) disclosed in **Table 6**.

[0044] In embodiments of the method, the recombinant DNA construct further includes a heterologous promoter operably linked to the DNA encoding RNA that includes at least one silencing element, wherein the heterologous promoter is functional in a plant cell. Promoters functional in a plant cell include those listed under the heading “Promoters”.

[0045] In embodiments of the method, the recombinant DNA construct is expressed in the plant by means of transgenic expression or transient expression. In some embodiments, the method further includes expression in the plant of at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein. The pesticidal agent can be expressed from the same recombinant DNA construct that includes the DNA encoding at least one silencing element, or from a different recombinant DNA construct.

[0046] A related aspect of the invention is a plant having improved resistance to an insect, or the seed of such a plant, wherein the plant is provided by the method including expressing in the plant a recombinant DNA construct including DNA encoding RNA that includes at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**, and wherein ingestion of the RNA by the insect results in mortality or stunting in the insect. In embodiments, the plant exhibiting improved resistance to the insect is characterized by improved yield, when compared to a plant not treated with the insecticidal composition. Also encompassed by the invention are fruit, seed, or propagatable parts of the plant provided by this method and exhibiting improved resistance to the insect.

[0047] A related aspect of the invention is a plant or seedling having improved resistance to an insect, wherein the plant or seedling is grown from a seed treated with a recombinant DNA construct including DNA encoding RNA that includes at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**; alternatively the

plant is grown from a seed directly treated with the RNA that includes at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of the insect, wherein the target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**. In embodiments, the recombinant DNA construct (or the encoded RNA that includes at least one silencing element) is applied by soaking the seed in a liquid composition including the recombinant DNA construct (or the encoded RNA that includes at least one silencing element), wherein the seed imbibes or takes up the DNA or encoded RNA into the seed interior or seed endosperm in an effective amount to provide improved resistance to the insect pest by a plant or seedling grown from the seed.

#### **RECOMBINANT DNA CONSTRUCTS ENCODING RNA FOR INSECT CONTROL**

[0048] Another aspect of the invention provides a recombinant DNA construct including a heterologous promoter operably linked to DNA encoding an RNA transcript including a sequence of about 95% to about 100% (e. g., about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0049] In specific embodiments, the RNA transcript forms double-stranded RNA from two separate, essentially complementary strands (e. g., where one strand is encoded on a separate DNA construct or where the two strands are encoded on separate sections of the DNA encoding an RNA transcript, and which are separately transcribed or made separate, for example, by the action of a recombinase or nuclease), wherein at least one RNA strand includes a sequence of about 95% to about 100% (e. g., about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In other embodiments, the RNA transcript forms double-stranded RNA from a single self-hybridizing hairpin transcript, wherein one “arm” of the hairpin includes a sequence of about 95% to about 100% (e. g., about 95%, about 96%, about 97%, about 98%, about 99%, or about 100%) identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.

[0050] Embodiments of the recombinant DNA construct include those wherein the heterologous promoter is functional for expression of the RNA transcript in a bacterium. In embodiments where the recombinant DNA construct is to be expressed in a bacterium, the bacterium is selected from the group consisting of *Escherichia coli*, *Bacillus* species, *Pseudomonas* species, *Xenorhabdus* species, or *Photorhabdus* species. In other embodiments, the recombinant DNA construct includes a heterologous promoter that is functional in a plant cell. In embodiments, the recombinant DNA construct is contained in a recombinant vector, such as a recombinant plant virus vector or a recombinant baculovirus vector. In embodiments, the recombinant DNA construct is integrated into a plant chromosome or plastid, e. g., by stable transformation.

[0051] Related aspects of the invention include a transgenic plant cell having in its genome the recombinant DNA construct, and a transgenic plant including such a transgenic plant cell. Transgenic plant cells and plants are made by methods known in the art, such as those described under the heading "Making and Using Transgenic Plant Cells and Transgenic Plants". Further aspects of the invention include a commodity product produced from such a transgenic plant, and transgenic progeny seed or propagatable plant part of the transgenic plant.

## RELATED INFORMATION AND TECHNIQUES

### Plants

[0052] The methods and compositions described herein for treating and protecting plants from insect infestations are useful across a broad range of plants. Suitable plants in which the methods and compositions disclosed herein can be used include, but are not limited to, cereals and forage grasses (rice, maize, wheat, barley, oat, sorghum, pearl millet, finger millet, cool-season forage grasses, and bahiagrass), oilseed crops (soybean, oilseed brassicas including canola and oilseed rape, sunflower, peanut, flax, sesame, and safflower), legume grains and forages (common bean, cowpea, pea, faba bean, lentil, tepary bean, Asiatic beans, pigeonpea, vetch, chickpea, lupine, alfalfa, and clovers), temperate fruits and nuts (apple, pear, peach, plums, berry crops, cherries, grapes, olive, almond, and Persian walnut), tropical and subtropical fruits and nuts (citrus including limes, oranges, and grapefruit; banana and plantain, pineapple, papaya, mango, avocado, kiwifruit, passionfruit, and persimmon), vegetable crops (solanaceous plants including tomato, eggplant, and peppers; vegetable brassicas; radish, carrot, cucurbits, alliums, asparagus, and leafy vegetables), sugar, tuber, and fiber crops (sugarcane, sugar beet, stevia, potato, sweet potato, cassava, and cotton), plantation crops, ornamentals, and turf grasses (tobacco, coffee, cocoa, tea, rubber tree, medicinal plants, ornamentals, and turf grasses), and forest tree species.

### Additional Construct Elements

[0053] Embodiments of the polynucleotides and nucleic acid molecules of this invention can include additional elements, such as promoters, small RNA recognition sites, aptamers or ribozymes, additional and additional expression cassettes for expressing coding sequences (*e. g.*, to express a transgene such as an insecticidal protein or selectable marker) or non-coding sequences (*e. g.*, to express additional suppression elements). For example, an aspect of this invention provides a recombinant DNA construct including a heterologous promoter operably linked to DNA encoding an RNA transcript that includes a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**. In another embodiment, a recombinant DNA construct including a promoter operably linked to DNA encoding: (a) an RNA transcript that includes a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and**

46, and (b) an aptamer, is stably integrated into the plant's genome from where RNA transcripts including the RNA aptamer and the RNA silencing element are expressed in cells of the plant; the aptamer serves to guide the RNA silencing element to a desired location in the cell. In another embodiment, inclusion of one or more recognition sites for binding and cleavage by a small RNA (*e. g.*, by a miRNA or an siRNA that is expressed only in a particular cell or tissue) allows for more precise expression patterns in a plant, wherein the expression of the recombinant DNA construct is suppressed where the small RNA is expressed. Such additional elements are described below.

#### Promoters

[0054] Promoters of use in the invention are functional in the cell in which the construct is intended to be transcribed. Generally these promoters are heterologous promoters, as used in recombinant constructs, *i. e.*, they are not in nature found to be operably linked to the other nucleic elements used in the constructs of this invention. In various embodiments, the promoter is selected from the group consisting of a constitutive promoter, a spatially specific promoter, a temporally specific promoter, a developmentally specific promoter, and an inducible promoter. In many embodiments the promoter is a promoter functional in a plant, for example, a pol II promoter, a pol III promoter, a pol IV promoter, or a pol V promoter.

[0055] Non-constitutive promoters suitable for use with the recombinant DNA constructs of this invention include spatially specific promoters, temporally specific promoters, and inducible promoters. Spatially specific promoters can include organelle-, cell-, tissue-, or organ-specific promoters (*e. g.*, a plastid-specific, a root-specific, a pollen-specific, or a seed-specific promoter for expression in plastids, roots, pollen, or seeds, respectively). In many cases a seed-specific, embryo-specific, aleurone-specific, or endosperm-specific promoter is especially useful. Temporally specific promoters can include promoters that tend to promote expression during certain developmental stages in a plant's growth cycle, or during different times of day or night, or at different seasons in a year. Inducible promoters include promoters induced by chemicals or by environmental conditions such as, but not limited to, biotic or abiotic stress (*e. g.*, water deficit or drought, heat, cold, high or low nutrient or salt levels, high or low light levels, or pest or pathogen infection). MicroRNA promoters are useful, especially those having a temporally specific, spatially specific, or inducible expression pattern; examples of miRNA promoters, as well as methods for identifying miRNA promoters having specific expression patterns, are provided in U. S. Patent Application Publications 2006/0200878, 2007/0199095, and 2007/0300329, which are specifically incorporated herein by reference. An expression-specific promoter can also include promoters that are generally constitutively expressed but at differing degrees or "strengths" of expression, including promoters commonly regarded as "strong promoters" or as "weak promoters".

[0056] Promoters of particular interest include the following examples: an opaline synthase promoter isolated from T-DNA of *Agrobacterium*; a cauliflower mosaic virus 35S promoter; enhanced promoter elements or chimeric promoter elements such as an enhanced cauliflower mosaic virus (CaMV)

35S promoter linked to an enhancer element (an intron from heat shock protein 70 of *Zea mays*); root specific promoters such as those disclosed in U.S. Patents 5,837,848; 6,437,217 and 6,426,446; a maize L3 oleosin promoter disclosed in U.S. Patent 6,433,252; a promoter for a plant nuclear gene encoding a plastid-localized aldolase disclosed in U. S. Patent Application Publication 2004/0216189; cold-inducible promoters disclosed in U.S. Patent 6,084,089; salt-inducible promoters disclosed in U. S. Patent Number 6,140,078; light-inducible promoters disclosed in U.S. Patent 6,294,714; pathogen-inducible promoters disclosed in U.S. Patent 6,252,138; and water deficit-inducible promoters disclosed in U.S. Patent Application Publication 2004/0123347 A1. All of the above-described patents and patent publications disclosing promoters and their use, especially in recombinant DNA constructs functional in plants are incorporated herein by reference.

[0057] Plant vascular- or phloem-specific promoters of interest include a rolC or rolA promoter of *Agrobacterium rhizogenes*, a promoter of a *Agrobacterium tumefaciens* T-DNA gene 5, the rice sucrose synthase RSs1 gene promoter, a Commelina yellow mottle badnavirus promoter, a coconut foliar decay virus promoter, a rice tungro bacilliform virus promoter, the promoter of a pea glutamine synthase GS3A gene, a invCD111 and invCD141 promoters of a potato invertase genes, a promoter isolated from *Arabidopsis* shown to have phloem-specific expression in tobacco by Kertbundit *et al.* (1991) *Proc. Natl. Acad. Sci. U S A.*, 88:5212-5216, a VAHOX1 promoter region, a pea cell wall invertase gene promoter, an acid invertase gene promoter from carrot, a promoter of a sulfate transporter gene Sultr1;3, a promoter of a plant sucrose synthase gene, and a promoter of a plant sucrose transporter gene.

[0058] Promoters suitable for use with a recombinant DNA construct or polynucleotide of this invention include polymerase II ("pol II") promoters and polymerase III ("pol III") promoters. RNA polymerase II transcribes structural or catalytic RNAs that are usually shorter than 400 nucleotides in length, and recognizes a simple run of T residues as a termination signal; it has been used to transcribe siRNA duplexes (see, *e. g.*, Lu *et al.* (2004) *Nucleic Acids Res.*, 32:e171). Pol II promoters are therefore preferred in certain embodiments where a short RNA transcript is to be produced from a recombinant DNA construct of this invention. In one embodiment, the recombinant DNA construct includes a pol II promoter to express an RNA transcript flanked by self-cleaving ribozyme sequences (*e. g.*, self-cleaving hammerhead ribozymes), resulting in a processed RNA, such as a single-stranded RNA that binds to the transcript of the *Leptinotarsa* target gene, with defined 5' and 3' ends, free of potentially interfering flanking sequences. An alternative approach uses pol III promoters to generate transcripts with relatively defined 5' and 3' ends, *i. e.*, to transcribe an RNA with minimal 5' and 3' flanking sequences. In some embodiments, Pol III promoters (*e. g.*, U6 or H1 promoters) are preferred for adding a short AT-rich transcription termination site that results in 2 base-pair overhangs (UU) in the transcribed RNA; this is useful, *e. g.*, for expression of siRNA-type constructs. Use of pol III promoters for driving expression of siRNA constructs has been reported; see van de Wetering *et al.* (2003) *EMBO Rep.*, 4: 609-615, and Tuschl (2002) *Nature Biotechnol.*, 20: 446-448. Baculovirus promoters such as baculovirus polyhedrin and p10 promoters are known in the art and commercially available; see, *e. g.*, Invitrogen's "Guide to

Baculovirus Expression Vector Systems (BEVS) and Insect Cell Culture Techniques”, 2002 (Life Technologies, Carlsbad, CA) and F. J. Haines *et al.* “Baculovirus Expression Vectors”, undated (Oxford Expression Technologies, Oxford, UK).

**[0059]** The promoter element can include nucleic acid sequences that are not naturally occurring promoters or promoter elements or homologues thereof but that can regulate expression of a gene. Examples of such “gene independent” regulatory sequences include naturally occurring or artificially designed RNA sequences that include a ligand-binding region or aptamer (see “Aptamers”, below) and a regulatory region (which can be *cis*-acting). See, for example, Isaacs *et al.* (2004) *Nat. Biotechnol.*, 22:841-847, Bayer and Smolke (2005) *Nature Biotechnol.*, 23:337-343, Mandal and Breaker (2004) *Nature Rev. Mol. Cell Biol.*, 5:451-463, Davidson and Ellington (2005) *Trends Biotechnol.*, 23:109-112, Winkler *et al.* (2002) *Nature*, 419:952-956, Sudarsan *et al.* (2003) *RNA*, 9:644-647, and Mandal and Breaker (2004) *Nature Struct. Mol. Biol.*, 11:29-35. Such “riboregulators” could be selected or designed for specific spatial or temporal specificity, for example, to regulate translation of DNA that encodes a silencing element for suppressing a target gene only in the presence (or absence) of a given concentration of the appropriate ligand. One example is a riboregulator that is responsive to an endogenous ligand (*e. g.*, jasmonic acid or salicylic acid) produced by the plant when under stress (*e. g.*, abiotic stress such as water, temperature, or nutrient stress, or biotic stress such as attack by pests or pathogens); under stress, the level of endogenous ligand increases to a level sufficient for the riboregulator to begin transcription of the DNA that encodes a silencing element for suppressing a target gene.

#### Recombinase Sites

**[0060]** In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA encoding one or more site-specific recombinase recognition sites. In one embodiment, the recombinant DNA construct includes at least a pair of loxP sites, wherein site-specific recombination of DNA between the loxP sites is mediated by a Cre recombinase. The position and relative orientation of the loxP sites is selected to achieve the desired recombination; for example, when the loxP sites are in the same orientation, the DNA between the loxP sites is excised in circular form. In another embodiment, the recombinant DNA construct includes DNA encoding one loxP site; in the presence of Cre recombinase and another DNA with a loxP site, the two DNAs are recombined.

#### Aptamers

**[0061]** In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA that is processed to an RNA aptamer, that is, an RNA that binds to a ligand through binding mechanism that is not primarily based on Watson-Crick base-pairing (in contrast, for example, to the base-pairing that occurs between complementary, anti-parallel nucleic acid strands to form a double-stranded nucleic acid structure). See, for example, Ellington and Szostak (1990) *Nature*,

346:818-822. Examples of aptamers can be found, for example, in the public Aptamer Database, available on line at [aptamer.icmb.utexas.edu](http://aptamer.icmb.utexas.edu) (Lee *et al.* (2004) *Nucleic Acids Res.*, 32(1):D95-100). Aptamers useful in the invention can, however, be monovalent (binding a single ligand) or multivalent (binding more than one individual ligand, *e. g.*, binding one unit of two or more different ligands).

[0062] Ligands useful in the invention include any molecule (or part of a molecule) that can be recognized and be bound by a nucleic acid secondary structure by a mechanism not primarily based on Watson-Crick base pairing. In this way, the recognition and binding of ligand and aptamer is analogous to that of antigen and antibody, or of biological effector and receptor. Ligands can include single molecules (or part of a molecule), or a combination of two or more molecules (or parts of a molecule), and can include one or more macromolecular complexes (*e. g.*, polymers, lipid bilayers, liposomes, cellular membranes or other cellular structures, or cell surfaces). Examples of specific ligands include vitamins such as coenzyme B<sub>12</sub> and thiamine pyrophosphate, flavin mononucleotide, guanine, adenosine, *S*-adenosylmethionine, *S*-adenosylhomocysteine, coenzyme A, lysine, tyrosine, dopamine, glucosamine-6-phosphate, caffeine, theophylline, antibiotics such as chloramphenicol and neomycin, herbicides such as glyphosate and dicamba, proteins including viral or phage coat proteins and invertebrate epidermal or digestive tract surface proteins, and RNAs including viral RNA, transfer-RNAs (t-RNAs), ribosomal RNA (rRNA), and RNA polymerases such as RNA-dependent RNA polymerase (RdRP). One class of RNA aptamers useful in the invention are “thermoswitches” that do not bind a ligand but are thermally responsive, that is to say, the aptamer’s conformation is determined by temperature; see, for example, Box 3 in Mandal and Breaker (2004) *Nature Rev. Mol. Cell Biol.*, 5:451-463.

#### Transgene Transcription Units

[0063] In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes a transgene transcription unit. A transgene transcription unit includes DNA sequence encoding a gene of interest, *e. g.*, a natural protein or a heterologous protein. A gene of interest can be any coding or non-coding sequence from any species (including, but not limited to, non-eukaryotes such as bacteria, and viruses; fungi, protists, plants, invertebrates, and vertebrates. Particular genes of interest are genes encoding at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein. The transgene transcription unit can further include 5’ or 3’ sequence or both as required for transcription of the transgene.

#### Introns

[0064] In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA encoding a spliceable intron. By “intron” is generally meant a segment of DNA (or the RNA transcribed from such a segment) that is located between exons (protein-encoding segments

of the DNA or corresponding transcribed RNA), wherein, during maturation of the messenger RNA, the intron present is enzymatically “spliced out” or removed from the RNA strand by a cleavage/ligation process that occurs in the nucleus in eukaryotes. The term “intron” is also applied to non-coding DNA sequences that are transcribed to RNA segments that can be spliced out of a maturing RNA transcript, but are not introns found between protein-coding exons. One example of these are spliceable sequences that have the ability to enhance expression in plants (in some cases, especially in monocots) of a downstream coding sequence; these spliceable sequences are naturally located in the 5’ untranslated region of some plant genes, as well as in some viral genes (*e. g.*, the tobacco mosaic virus 5’ leader sequence or “omega” leader described as enhancing expression in plant genes by Gallie and Walbot (1992) *Nucleic Acids Res.*, 20:4631-4638). These spliceable sequences or “expression-enhancing introns” can be artificially inserted in the 5’ untranslated region of a plant gene between the promoter and any protein-coding exons. Examples of such expression-enhancing introns include, but are not limited to, a maize alcohol dehydrogenase (*Zm-Adh1*), a maize Bronze-1 expression-enhancing intron, a rice actin 1 (*Os-Act1*) intron, a Shrunken-1 (*Sh-1*) intron, a maize sucrose synthase intron, a heat shock protein 18 (*hsp18*) intron, and an 82 kilodalton heat shock protein (*hsp82*) intron. U. S. Patents 5,593,874 and 5,859,347, specifically incorporated by reference herein, describe methods of improving recombinant DNA constructs for use in plants by inclusion of an expression-enhancing intron derived from the 70 kilodalton maize heat shock protein (*hsp70*) in the non-translated leader positioned 3’ from the gene promoter and 5’ from the first protein-coding exon.

#### Ribozymes

[0065] In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA encoding one or more ribozymes. Ribozymes of particular interest include a self-cleaving ribozyme, a hammerhead ribozyme, or a hairpin ribozyme. In one embodiment, the recombinant DNA construct includes DNA encoding one or more ribozymes that serve to cleave the transcribed RNA to provide defined segments of RNA, such as silencing elements for suppressing a *Leptinotarsa* target gene.

#### Gene Suppression Elements

[0066] In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA encoding additional gene suppression element for suppressing a target gene other than a *Leptinotarsa* target gene. The target gene to be suppressed can include coding or non-coding sequence or both.

[0067] Suitable gene suppression elements are described in detail in U. S. Patent Application Publication 2006/0200878, which disclosure is specifically incorporated herein by reference, and include one or more of:

- (a) DNA that includes at least one anti-sense DNA segment that is anti-sense to at least one segment of the gene to be suppressed;
- (b) DNA that includes multiple copies of at least one anti-sense DNA segment that is anti-sense to at least one segment of the gene to be suppressed;
- (c) DNA that includes at least one sense DNA segment that is at least one segment of the gene to be suppressed;
- (d) DNA that includes multiple copies of at least one sense DNA segment that is at least one segment of the gene to be suppressed;
- (e) DNA that transcribes to RNA for suppressing the gene to be suppressed by forming double-stranded RNA and includes at least one anti-sense DNA segment that is anti-sense to at least one segment of the gene to be suppressed and at least one sense DNA segment that is at least one segment of the gene to be suppressed;
- (f) DNA that transcribes to RNA for suppressing the gene to be suppressed by forming a single double-stranded RNA and includes multiple serial anti-sense DNA segments that are anti-sense to at least one segment of the gene to be suppressed and multiple serial sense DNA segments that are at least one segment of the gene to be suppressed;
- (g) DNA that transcribes to RNA for suppressing the gene to be suppressed by forming multiple double strands of RNA and includes multiple anti-sense DNA segments that are anti-sense to at least one segment of the gene to be suppressed and multiple sense DNA segments that are at least one segment of the gene to be suppressed, and wherein the multiple anti-sense DNA segments and the multiple sense DNA segments are arranged in a series of inverted repeats;
- (h) DNA that includes nucleotides derived from a plant miRNA;
- (i) DNA that includes nucleotides of a siRNA;
- (j) DNA that transcribes to an RNA aptamer capable of binding to a ligand; and
- (k) DNA that transcribes to an RNA aptamer capable of binding to a ligand, and DNA that transcribes to regulatory RNA capable of regulating expression of the gene to be suppressed, wherein the regulation is dependent on the conformation of the regulatory RNA, and the conformation of the regulatory RNA is allosterically affected by the binding state of the RNA aptamer.

**[0068]** In some embodiments, an intron is used to deliver a gene suppression element in the absence of any protein-coding exons (coding sequence). In one example, an intron, such as an expression-enhancing intron (preferred in certain embodiments), is interrupted by embedding within the intron a gene suppression element, wherein, upon transcription, the gene suppression element is excised from the intron. Thus, protein-coding exons are not required to provide the gene suppressing function of the recombinant DNA constructs disclosed herein.

### Transcription Regulatory Elements

[0069] In some embodiments, the recombinant DNA construct or polynucleotide of this invention includes DNA encoding a transcription regulatory element. Transcription regulatory elements include elements that regulate the expression level of the recombinant DNA construct of this invention (relative to its expression in the absence of such regulatory elements). Examples of suitable transcription regulatory elements include riboswitches (*cis*- or *trans*-acting), transcript stabilizing sequences, and miRNA recognition sites, as described in detail in U. S. Patent Application Publication 2006/0200878, specifically incorporated herein by reference.

### Making and Using Transgenic Plant Cells and Transgenic Plants

[0070] Transformation of a plant can include any of several well-known methods and compositions. Suitable methods for plant transformation include virtually any method by which DNA can be introduced into a cell. One method of plant transformation is microprojectile bombardment, for example, as illustrated in U.S. Patents 5,015,580 (soybean), 5,538,880 (maize), 5,550,318 (maize), 5,914,451 (soybean), 6,153,812 (wheat), 6,160,208 (maize), 6,288,312 (rice), 6,365,807 (rice), and 6,399,861 (maize), and 6,403,865 (maize), all of which are incorporated by reference for enabling the production of transgenic plants.

[0071] Another useful method of plant transformation is *Agrobacterium*-mediated transformation by means of *Agrobacterium* containing a binary Ti plasmid system, wherein the *Agrobacterium* carries a first Ti plasmid and a second, chimeric plasmid containing at least one T-DNA border of a wild-type Ti plasmid, a promoter functional in the transformed plant cell and operably linked to a polynucleotide or recombinant DNA construct of this invention. See, for example, the binary system described in U. S. Patent 5,159,135, incorporated by reference. Also see De Framond (1983) *Biotechnology*, 1:262-269; and Hoekema *et al.*, (1983) *Nature*, 303:179. In such a binary system, the smaller plasmid, containing the T-DNA border or borders, can be conveniently constructed and manipulated in a suitable alternative host, such as *E. coli*, and then transferred into *Agrobacterium*.

[0072] Detailed procedures for *Agrobacterium*-mediated transformation of plants, especially crop plants, include procedures disclosed in U. S. Patents 5,004,863, 5,159,135, and 5,518,908 (cotton); 5,416,011, 5,569,834, 5,824,877 and 6,384,301 (soybean); 5,591,616 and 5,981,840 (maize); 5,463,174 (brassicacae including canola), 7,026,528 (wheat), and 6,329,571 (rice), and in U. S. Patent Application Publications 2004/0244075 (maize) and 2001/0042257 A1 (sugar beet), all of which are specifically incorporated by reference for enabling the production of transgenic plants. U. S. Patent Application Publication 2011/0296555 discloses in Example 5 the transformation vectors (including the vector sequences) and detailed protocols for transforming maize, soybean, canola, cotton, and sugarcane) and is specifically incorporated by reference for enabling the production of transgenic plants. Similar methods have been reported for many plant species, both dicots and monocots, including, among others, peanut (Cheng *et al.* (1996) *Plant Cell Rep.*, 15: 653); asparagus (Bytebier *et al.* (1987) *Proc. Natl. Acad. Sci.*

U.S.A., 84:5345); barley (Wan and Lemaux (1994) *Plant Physiol.*, 104:37); rice (Toriyama *et al.* (1988) *Bio/Technology*, 6:10; Zhang *et al.* (1988) *Plant Cell Rep.*, 7:379; wheat (Vasil *et al.* (1992) *Bio/Technology*, 10:667; Becker *et al.* (1994) *Plant J.*, 5:299), alfalfa (Masoud *et al.* (1996) *Transgen. Res.*, 5:313); and tomato (Sun *et al.* (2006) *Plant Cell Physiol.*, 47:426-431). See also a description of vectors, transformation methods, and production of transformed *Arabidopsis thaliana* plants where transcription factors are constitutively expressed by a CaMV35S promoter, in U. S. Patent Application Publication 2003/0167537 A1, incorporated by reference. Transformation methods specifically useful for solanaceous plants are well known in the art. See, for example, publicly described transformation methods for tomato (Sharma *et al.* (2009), *J. Biosci.*, 34:423-433), eggplant (Arpaia *et al.* (1997) *Theor. Appl. Genet.*, 95:329-334), potato (Bannerjee *et al.* (2006) *Plant Sci.*, 170:732-738; Chakravarty *et al.* (2007) *Amer. J. Potato Res.*, 84:301-311; S. Millam "Agrobacterium-mediated transformation of potato." Chapter 19 (pp.257 - 270), "Transgenic Crops of the World: Essential Protocols", Ian S. Curtis (editor), Springer, 2004), and peppers (Li *et al.* (2003) *Plant Cell Reports*, 21: 785-788). Stably transgenic potato, tomato, and eggplant have been commercially introduced in various regions; see, *e. g.*, K. Redenbaugh *et al.* "Safety Assessment of Genetically Engineered Fruits and Vegetables: A Case Study of the FLAVR SAVR™ Tomato", CRC Press, Boca Raton, 1992, and the extensive publicly available documentation of commercial genetically modified crops in the GM Crop Database; see: CERA. (2012). GM Crop Database. Center for Environmental Risk Assessment (CERA), ILSI Research Foundation, Washington D.C., available electronically at [www.cera-gmc.org/?action=gm\\_crop\\_database](http://www.cera-gmc.org/?action=gm_crop_database). Various methods of transformation of other plant species are well known in the art, see, for example, the encyclopedic reference, "Compendium of Transgenic Crop Plants", edited by Chittaranjan Kole and Timothy C. Hall, Blackwell Publishing Ltd., 2008; ISBN 978-1-405-16924-0 (available electronically at [mrw.interscience.wiley.com/emrw/9781405181099/hpt/toc](http://mrw.interscience.wiley.com/emrw/9781405181099/hpt/toc)), which describes transformation procedures for cereals and forage grasses (rice, maize, wheat, barley, oat, sorghum, pearl millet, finger millet, cool-season forage grasses, and bahiagrass), oilseed crops (soybean, oilseed brassicas, sunflower, peanut, flax, sesame, and safflower), legume grains and forages (common bean, cowpea, pea, faba bean, lentil, tepary bean, Asiatic beans, pigeonpea, vetch, chickpea, lupine, alfalfa, and clovers), temperate fruits and nuts (apple, pear, peach, plums, berry crops, cherries, grapes, olive, almond, and Persian walnut), tropical and subtropical fruits and nuts (citrus, grapefruit, banana and plantain, pineapple, papaya, mango, avocado, kiwifruit, passionfruit, and persimmon), vegetable crops (tomato, eggplant, peppers, vegetable brassicas, radish, carrot, cucurbits, alliums, asparagus, and leafy vegetables), sugar, tuber, and fiber crops (sugarcane, sugar beet, stevia, potato, sweet potato, cassava, and cotton), plantation crops, ornamentals, and turf grasses (tobacco, coffee, cocoa, tea, rubber tree, medicinal plants, ornamentals, and turf grasses), and forest tree species.

[0073] Transformation methods to provide transgenic plant cells and transgenic plants containing stably integrated recombinant DNA are preferably practiced in tissue culture on media and in a controlled environment. "Media" refers to the numerous nutrient mixtures that are used to grow cells *in*

*in vitro*, that is, outside of the intact living organism. Recipient cell targets include, but are not limited to, meristem cells, callus, immature embryos or parts of embryos, and gametic cells such as microspores, pollen, sperm, and egg cells. Any cell from which a fertile plant can be regenerated is contemplated as a useful recipient cell for practice of this invention. Callus can be initiated from various tissue sources, including, but not limited to, immature embryos or parts of embryos, seedling apical meristems, microspores, and the like. Those cells which are capable of proliferating as callus can serve as recipient cells for genetic transformation. Practical transformation methods and materials for making transgenic plants of this invention (*e. g.*, various media and recipient target cells, transformation of immature embryos, and subsequent regeneration of fertile transgenic plants) are disclosed, for example, in U. S. Patents 6,194,636 and 6,232,526 and U. S. Patent Application Publication 2004/0216189, which are specifically incorporated by reference.

**[0074]** In general transformation practice, DNA is introduced into only a small percentage of target cells in any one transformation experiment. Marker genes are generally used to provide an efficient system for identification of those cells that are stably transformed by receiving and integrating a transgenic DNA construct into their genomes. Preferred marker genes provide selective markers which confer resistance to a selective agent, such as an antibiotic or herbicide. Any of the antibiotics or herbicides to which a plant cell is resistant can be a useful agent for selection. Potentially transformed cells are exposed to the selective agent. In the population of surviving cells will be those cells where, generally, the resistance-conferring gene is integrated and expressed at sufficient levels to permit cell survival. Cells can be tested further to confirm stable integration of the recombinant DNA. Commonly used selective marker genes include those conferring resistance to antibiotics such as kanamycin or paromomycin (*nptII*), hygromycin B (*aph IV*) and gentamycin (*aac3* and *aacC4*) or resistance to herbicides such as glufosinate (*bar* or *pat*) and glyphosate (EPSPS). Examples of useful selective marker genes and selection agents are illustrated in U. S. Patents 5,550,318, 5,633,435, 5,780,708, and 6,118,047, all of which are specifically incorporated by reference. Screenable markers or reporters, such as markers that provide an ability to visually identify transformants can also be employed. Examples of useful screenable markers include, for example, a gene expressing a protein that produces a detectable color by acting on a chromogenic substrate (*e. g.*, beta glucuronidase (GUS) (*uidA*) or luciferase (*luc*) or that itself is detectable, such as green fluorescent protein (GFP) (*gfp*) or an immunogenic molecule. Those of skill in the art will recognize that many other useful markers or reporters are available for use.

**[0075]** Detecting or measuring transcription of a recombinant DNA construct in a transgenic plant cell can be achieved by any suitable method, including protein detection methods (*e. g.*, western blots, ELISAs, and other immunochemical methods), measurements of enzymatic activity, or nucleic acid detection methods (*e. g.*, Southern blots, northern blots, PCR, RT-PCR, fluorescent *in situ* hybridization).

**[0076]** Other suitable methods for detecting or measuring transcription in a plant cell of a recombinant polynucleotide of this invention targeting an insect target gene include measurement of any other trait that is a direct or proxy indication of the level of expression of the target gene in the insect,

relative to the level of expression observed in the absence of the recombinant polynucleotide, *e. g.*, growth rates, mortality rates, or reproductive or recruitment rates of the insect, or measurements of injury (*e. g.*, root injury) or yield loss in a plant or field of plants infested by the insect. In general, suitable methods for detecting or measuring transcription in a plant cell of a recombinant polynucleotide of interest include, *e. g.*, gross or microscopic morphological traits, growth rates, yield, reproductive or recruitment rates, resistance to pests or pathogens, or resistance to biotic or abiotic stress (*e. g.*, water deficit stress, salt stress, nutrient stress, heat or cold stress). Such methods can use direct measurements of a phenotypic trait or proxy assays (*e. g.*, in plants, these assays include plant part assays such as leaf or root assays to determine tolerance of abiotic stress). Such methods include direct measurements of resistance to an invertebrate pest or pathogen (*e. g.*, damage to plant tissues) or proxy assays (*e. g.*, plant yield assays, or invertebrate pest bioassays such as the Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) larval bioassay described in International Patent Application Publication WO2005/110068 A2 and U. S. Patent Application Publication US 2006/0021087 A1, specifically incorporated by reference, or the soybean cyst nematode bioassay described by Steeves *et al.* (2006) *Funct. Plant Biol.*, 33:991-999, wherein cysts per plant, cysts per gram root, eggs per plant, eggs per gram root, and eggs per cyst are measured, or the bioassays described herein in the working Examples.

[0077] The recombinant DNA constructs of this invention can be stacked with other recombinant DNA for imparting additional traits (*e. g.*, in the case of transformed plants, traits including herbicide resistance, pest resistance, cold germination tolerance, water deficit tolerance, and the like) for example, by expressing or suppressing other genes. Constructs for coordinated decrease and increase of gene expression are disclosed in U.S. Patent Application Publication 2004/0126845 A1, specifically incorporated by reference.

[0078] Seeds of fertile transgenic plants can be harvested and used to grow progeny generations, including hybrid generations, of transgenic plants of this invention that include the recombinant DNA construct in their genome. Thus, in addition to direct transformation of a plant with a recombinant DNA construct of this invention, transgenic plants of this invention can be prepared by crossing a first plant having the recombinant DNA with a second plant lacking the construct. For example, the recombinant DNA can be introduced into a plant line that is amenable to transformation to produce a transgenic plant, which can be crossed with a second plant line to introgress the recombinant DNA into the resulting progeny. A transgenic plant of this invention can be crossed with a plant line having other recombinant DNA that confers one or more additional trait(s) (such as, but not limited to, herbicide resistance, pest or disease resistance, environmental stress resistance, modified nutrient content, and yield improvement) to produce progeny plants having recombinant DNA that confers both the desired target sequence expression behavior and the additional trait(s).

[0079] In such breeding for combining traits the transgenic plant donating the additional trait can be a male line (pollinator) and the transgenic plant carrying the base traits can be the female line. The progeny of this cross segregate such that some of the plant will carry the DNA for both parental traits

and some will carry DNA for one parental trait; such plants can be identified by markers associated with parental recombinant DNA. Progeny plants carrying DNA for both parental traits can be crossed back into the female parent line multiple times, *e. g.*, usually 6 to 8 generations, to produce a homozygous progeny plant with substantially the same genotype as one original transgenic parental line as well as the recombinant DNA of the other transgenic parental line.

[0080] Yet another aspect of this invention is a transgenic plant grown from the transgenic seed of this invention. This invention contemplates transgenic plants grown directly from transgenic seed containing the recombinant DNA as well as progeny generations of plants, including inbred or hybrid plant lines, made by crossing a transgenic plant grown directly from transgenic seed to a second plant not grown from the same transgenic seed. Crossing can include, for example, the following steps:

- (a) plant seeds of the first parent plant (*e. g.*, non-transgenic or a transgenic) and a second parent plant that is transgenic according to the invention;
- (b) grow the seeds of the first and second parent plants into plants that bear flowers;
- (c) pollinate a flower from the first parent with pollen from the second parent; and
- (d) harvest seeds produced on the parent plant bearing the fertilized flower.

[0081] It is often desirable to introgress recombinant DNA into elite varieties, *e. g.*, by backcrossing, to transfer a specific desirable trait from one source to an inbred or other plant that lacks that trait. This can be accomplished, for example, by first crossing a superior inbred (“A”) (recurrent parent) to a donor inbred (“B”) (non-recurrent parent), which carries the appropriate gene(s) for the trait in question, for example, a construct prepared in accordance with the current invention. The progeny of this cross first are selected in the resultant progeny for the desired trait to be transferred from the non-recurrent parent “B”, and then the selected progeny are mated back to the superior recurrent parent “A”. After five or more backcross generations with selection for the desired trait, the progeny can be essentially hemizygous for loci controlling the characteristic being transferred, but are like the superior parent for most or almost all other genes. The last backcross generation would be selfed to give progeny which are pure breeding for the gene(s) being transferred, *i. e.*, one or more transformation events.

[0082] Through a series of breeding manipulations, a selected DNA construct can be moved from one line into an entirely different line without the need for further recombinant manipulation. One can thus produce inbred plants which are true breeding for one or more DNA constructs. By crossing different inbred plants, one can produce a large number of different hybrids with different combinations of DNA constructs. In this way, plants can be produced which have the desirable agronomic properties frequently associated with hybrids (“hybrid vigor”), as well as the desirable characteristics imparted by one or more DNA constructs.

[0083] In certain transgenic plant cells and transgenic plants of this invention, it is sometimes desirable to concurrently express a gene of interest while also modulating expression of a *Leptinotarsa* target gene. Thus, in some embodiments, the transgenic plant contains recombinant DNA further including a gene expression element for expressing at least one gene of interest, and transcription of the

recombinant DNA construct of this invention is preferably effected with concurrent transcription of the gene expression element.

[0084] In some embodiments, the recombinant DNA constructs of this invention can be transcribed in any plant cell or tissue or in a whole plant of any developmental stage. Transgenic plants can be derived from any monocot or dicot plant, such as, but not limited to, plants of commercial or agricultural interest, such as crop plants (especially crop plants used for human food or animal feed), wood- or pulp-producing trees, vegetable plants, fruit plants, and ornamental plants. Examples of plants of interest include grain crop plants (such as wheat, oat, barley, maize, rye, triticale, rice, millet, sorghum, quinoa, amaranth, and buckwheat); forage crop plants (such as forage grasses and forage dicots including alfalfa, vetch, clover, and the like); oilseed crop plants (such as cotton, safflower, sunflower, soybean, canola, rapeseed, flax, peanuts, and oil palm); tree nuts (such as walnut, cashew, hazelnut, pecan, almond, and the like); sugarcane, coconut, date palm, olive, sugarbeet, tea, and coffee; wood- or pulp-producing trees; vegetable crop plants such as legumes (for example, beans, peas, lentils, alfalfa, peanut), lettuce, asparagus, artichoke, celery, carrot, radish, the brassicas (for example, cabbages, kales, mustards, and other leafy brassicas, broccoli, cauliflower, Brussels sprouts, turnip, kohlrabi), edible cucurbits (for example, cucumbers, melons, summer squashes, winter squashes), edible alliums (for example, onions, garlic, leeks, shallots, chives), edible members of the Solanaceae (for example, tomatoes, eggplants, potatoes, peppers, groundcherries), and edible members of the Chenopodiaceae (for example, beet, chard, spinach, quinoa, amaranth); fruit crop plants such as apple, pear, citrus fruits (for example, orange, lime, lemon, grapefruit, and others), stone fruits (for example, apricot, peach, plum, nectarine), banana, pineapple, grape, kiwifruit, papaya, avocado, and berries; plants grown for biomass or biofuel (for example, *Miscanthus* grasses, switchgrass, jatropha, oil palm, eukaryotic microalgae such as *Botryococcus braunii*, *Chlorella* spp., and *Dunaliella* spp., and eukaryotic macroalgae such as *Gracilaria* spp., and *Sargassum* spp.); and ornamental plants including ornamental flowering plants, ornamental trees and shrubs, ornamental groundcovers, and ornamental grasses.

[0085] This invention also provides commodity products produced from a transgenic plant cell, plant, or seed of this invention, including, but not limited to, harvested leaves, roots, shoots, tubers, stems, fruits, seeds, or other parts of a plant, meals, oils, extracts, fermentation or digestion products, crushed or whole grains or seeds of a plant, or any food or non-food product including such commodity products produced from a transgenic plant cell, plant, or seed of this invention. The detection of one or more of nucleic acid sequences of the recombinant DNA constructs of this invention in one or more commodity or commodity products contemplated herein is *de facto* evidence that the commodity or commodity product contains or is derived from a transgenic plant cell, plant, or seed of this invention.

[0086] Generally a transgenic plant having in its genome a recombinant DNA construct of this invention exhibits increased resistance to an insect infestation. In various embodiments, for example, where the transgenic plant expresses a recombinant DNA construct of this invention that is stacked with other recombinant DNA for imparting additional traits, the transgenic plant has at least one additional

altered trait, relative to a plant lacking the recombinant DNA construct, selected from the group of traits consisting of:

- (a) improved abiotic stress tolerance;
- (b) improved biotic stress tolerance;
- (c) modified primary metabolite composition;
- (d) modified secondary metabolite composition;
- (e) modified trace element, carotenoid, or vitamin composition;
- (f) improved yield;
- (g) improved ability to use nitrogen, phosphate, or other nutrients;
- (h) modified agronomic characteristics;
- (i) modified growth or reproductive characteristics; and
- (j) improved harvest, storage, or processing quality.

[0087] In some embodiments, the transgenic plant is characterized by: improved tolerance of abiotic stress (*e. g.*, tolerance of water deficit or drought, heat, cold, non-optimal nutrient or salt levels, non-optimal light levels) or of biotic stress (*e. g.*, crowding, allelopathy, or wounding); by a modified primary metabolite (*e. g.*, fatty acid, oil, amino acid, protein, sugar, or carbohydrate) composition; a modified secondary metabolite (*e. g.*, alkaloids, terpenoids, polyketides, non-ribosomal peptides, and secondary metabolites of mixed biosynthetic origin) composition; a modified trace element (*e. g.*, iron, zinc), carotenoid (*e. g.*, beta-carotene, lycopene, lutein, zeaxanthin, or other carotenoids and xanthophylls), or vitamin (*e. g.*, tocopherols) composition; improved yield (*e. g.*, improved yield under non-stress conditions or improved yield under biotic or abiotic stress); improved ability to use nitrogen, phosphate, or other nutrients; modified agronomic characteristics (*e. g.*, delayed ripening; delayed senescence; earlier or later maturity; improved shade tolerance; improved resistance to root or stalk lodging; improved resistance to “green snap” of stems; modified photoperiod response); modified growth or reproductive characteristics (*e. g.*, intentional dwarfing; intentional male sterility, useful, *e. g.*, in improved hybridization procedures; improved vegetative growth rate; improved germination; improved male or female fertility); improved harvest, storage, or processing quality (*e. g.*, improved resistance to pests during storage, improved resistance to breakage, improved appeal to consumers); or any combination of these traits.

[0088] In another embodiment, transgenic seed, or seed produced by the transgenic plant, has modified primary metabolite (*e. g.*, fatty acid, oil, amino acid, protein, sugar, or carbohydrate) composition, a modified secondary metabolite composition, a modified trace element, carotenoid, or vitamin composition, an improved harvest, storage, or processing quality, or a combination of these. In another embodiment, it can be desirable to change levels of native components of the transgenic plant or seed of a transgenic plant, for example, to decrease levels of an allergenic protein or glycoprotein or of a toxic metabolite.

[0089] Generally, screening a population of transgenic plants each regenerated from a transgenic plant cell is performed to identify transgenic plant cells that develop into transgenic plants having the desired trait. The transgenic plants are assayed to detect an enhanced trait, *e. g.*, enhanced water use efficiency, enhanced cold tolerance, increased yield, enhanced nitrogen use efficiency, enhanced seed protein, and enhanced seed oil. Screening methods include direct screening for the trait in a greenhouse or field trial or screening for a surrogate trait. Such analyses are directed to detecting changes in the chemical composition, biomass, physiological properties, or morphology of the plant. Changes in chemical compositions such as nutritional composition of grain are detected by analysis of the seed composition and content of protein, free amino acids, oil, free fatty acids, starch, tocopherols, or other nutrients. Changes in growth or biomass characteristics are detected by measuring plant height, stem diameter, internode length, root and shoot dry weights, and (for grain-producing plants such as maize, rice, or wheat) ear or seed head length and diameter. Changes in physiological properties are identified by evaluating responses to stress conditions, *e. g.*, assays under imposed stress conditions such as water deficit, nitrogen or phosphate deficiency, cold or hot growing conditions, pathogen or insect attack, light deficiency, or increased plant density. Other selection properties include days to flowering, days to pollen shed, days to fruit maturation, fruit or tuber quality or amount produced, days to silking in maize, leaf extension rate, chlorophyll content, leaf temperature, stand, seedling vigor, internode length, plant height, leaf number, leaf area, tillering, brace roots, staying green, stalk lodging, root lodging, plant health, fertility, green snap, and pest resistance. In addition, phenotypic characteristics of harvested fruit, seeds, or tubers can be evaluated.

#### EXAMPLES

##### Example 1

[0090] This example illustrates non-limiting embodiments of coding DNA sequences useful as target genes for controlling insect species and for making compositions and plants of this invention, and identifies dsRNA trigger sequences useful for controlling insect species. Orthologues to genes previously demonstrated to be efficacious targets for RNAi-mediated mortality in western corn rootworm were identified from insect species that have not previously been reported to be susceptible to orally delivered RNA. These orthologous target genes and examples of dsRNA trigger sequences are provided in **Table 1**.

**Table 1**

Target Gene SEQ ID NO.	Target Gene ID	Target Gene Source Species (common name)	Target Gene Annotation	Trigger ID	Trigger SEQ ID NO.*	Trigger size (bp)
1	CG3762	<i>Spodoptera frugiperda</i> (fall armyworm)	V-ATPase subunit A	T34640	17	300
2	F38E11	<i>Spodoptera frugiperda</i> (fall armyworm)	COPI coatomer beta prime subunit	T34644	19	301
3	CG6223	<i>Spodoptera frugiperda</i> (fall armyworm)	COPI coatomer beta subunit	T34642	18	301

4	CG3762	<i>Lygus hesperus</i> (western tarnished plant bug)	V-ATPase subunit A	T34617	15	300
5	CG2746	<i>Lygus hesperus</i> (western tarnished plant bug)	ribosomal protein L19	T34616	14	298
6	F38E11	<i>Lygus hesperus</i> (western tarnished plant bug)	COPI coatomer beta prime subunit	T34622	16	300
7	AT20865p	<i>Lygus hesperus</i> (western tarnished plant bug)	ubiquitin C	T42772	22	257
7	AT20865p	<i>Lygus hesperus</i> (western tarnished plant bug)	ubiquitin C	T44045	26	302
8	CG10370	<i>Euschistus heros</i> (neotropical brown stink bug)	TAT binding protein	T43718	23	300
9	AT20865p	<i>Euschistus heros</i> (neotropical brown stink bug)	ubiquitin C	T43720	24	300
9	AT20865p	<i>Euschistus heros</i> (neotropical brown stink bug)	ubiquitin C	T44042	25	302
10	CG3762	<i>Plutella xylostella</i> (diamondback moth)	V-ATPase subunit A	T42014	20	302
10	CG3762	<i>Plutella xylostella</i> (diamondback moth)	V-ATPase subunit A	T42017	21	301
10	CG3762	<i>Plutella xylostella</i> (diamondback moth)	V-ATPase subunit A	T33310	29	300
11	F38E11.5	<i>Plutella xylostella</i> (diamondback moth)	COPI coatomer beta prime subunit	T32937	13	302
12	CG6223	<i>Plutella xylostella</i> (diamondback moth)	COPI coatomer beta subunit	T32938	28	302
43	CG6223	<i>Lygus hesperus</i> (western tarnished plant bug)	COPI coatomer beta subunit	T34619	45	301
44	AT20865p	<i>Lygus hesperus</i> (western tarnished plant bug)	ubiquitin C variant (fragment)	T42768	46	255

\*Trigger sequences are provided for the sense strand of the dsRNA trigger in 5' to 3' direction.

[0091] The dsRNA trigger sequences that are confirmed to be effective in suppressing a target gene in a sequence-specific manner are useful for identifying efficacious RNA delivery agents and formulations. The insecticidal activity of formulations containing the dsRNA triggers can be optimized by various techniques, such as modifying the chemical entities in the formulation or modifying the ratio of the chemical components in the formulation. Non-limiting examples of delivery agents and formulations are provided in **Examples 6 and 8**.

#### Example 2

[0092] This example illustrates non-limiting embodiments of dsRNA trigger sequences useful for suppressing or silencing a target gene in an insect cell or causing stunting or mortality in an insect, and methods for validating dsRNA trigger efficacy or for causing stunting or mortality in an insect. More specifically this example illustrates use of dsRNA triggers for sequence-specific reduction of target gene mRNA transcript level in insect cells.

[0093] Cultured *Spodoptera frugiperda* (fall armyworm, FAW) SF9 cells were incubated with the dsRNA triggers T34640 (**SEQ ID NO:17**, targeting V-ATPase A subunit), T34642 (**SEQ ID NO:18**, targeting COPI coatomer B (beta) subunit), or T34644 (**SEQ ID NO:19**, targeting COPI coatomer B' (beta prime) subunit), or with a control trigger T35763 (**SEQ ID NO:27**, a 300 bp dsRNA trigger targeting green fluorescent protein); see **Table 1**. The dsRNA triggers were formulated with the

commercial transfection agent Cellfectin® II (Life Technologies, Inc., Grand Island, NY 14072).

**Figure 1** depicts the results of the transfection experiments, demonstrating target-gene-specific suppression (reduction of target gene mRNA levels measured by Quantigene assays) by the dsRNA triggers in the insect cells. The control dsRNA trigger T35763 had no effect on the targeted insect gene mRNA levels.

[0094] Similar experiments were carried out with *Plutella xylostella* (diamondback moth, DBM) cells. The results demonstrate a similar target-gene-specific cytotoxic response to the DBM triggers but not to a non-specific trigger targeting green fluorescent protein. Cultured *Plutella xylostella* (diamondback moth) PxE-PO#5A3 cells were incubated with the dsRNA triggers T42017 (**SEQ ID NO:21**, targeting V-ATPase subunit A), T33310 (**SEQ ID NO:29**, targeting V-ATPase subunit A), T32938 (**SEQ ID NO:28**, targeting COPI coatomer beta subunit), and T32937 (**SEQ ID NO:13**, targeting COPI coatomer beta prime subunit), or with a control trigger T35763 (**SEQ ID NO:27**, a 300 bp dsRNA trigger targeting green fluorescent protein); see **Table 1**. The dsRNA triggers were formulated with the commercial transfection agent Cellfectin® II (Life Technologies, Inc., Grand Island, NY 14072). **Figure 2** depicts the results of the transfection experiments, demonstrating target-gene-specific suppression (reduction of target gene mRNA levels measured by Quantigene assays) by the dsRNA triggers in the insect cells. The control dsRNA trigger T35763 had no effect on the targeted insect gene mRNA levels. In this particular experiment, some reduction of mRNA levels was observed in all DBM-specific trigger treatments compared to cellfectin II or cellfectin II + T35763 (**SEQ ID NO:27**) treatments. Visual pathology was apparent for T32937 (**SEQ ID NO:13**, targeting COPI coatomer beta prime subunit) and T32938 (**SEQ ID NO:28**, targeting COPI coatomer beta subunit) treatments with some cell death, rounding, and dislodging occurring in transfected wells at 48 hours post-transfection. Treatments with T42017 (**SEQ ID NO:21**) and T33310 (**SEQ ID NO:29**) showed knockdown of the target gene, V-ATPase subunit A mRNA, but no visual pathology was apparent in cells transfected with those triggers.

### Example 3

[0095] This example illustrates non-limiting embodiments of dsRNA trigger sequences useful for suppressing or silencing a target gene in an insect cell or causing stunting or mortality in an insect, and methods for validating dsRNA trigger efficacy or for causing stunting or mortality in an insect. More specifically this example illustrates oral delivery of dsRNA triggers for causing stunting or mortality in insects.

[0096] An assay using *Euschistus heros* (neotropical brown stink bug, NBSB) nymphs fed on an artificial diet was used for testing the efficacy of dsRNA triggers designed specifically to target *Euschistus heros* genes. Using this assay, a ~500 base pair dsRNA trigger, T33199, which targets the *E. heros* ubiquitin C gene, was observed to effect a dose-dependent stunting and mortality response in *E.*

*heros* nymphs. A shorter (302 bp) dsRNA trigger, T44042 (SEQ ID NO:26) was designed, based on the sequence of T33199, for formulating for oral or topical delivery.

Example 4

[0097] This example illustrates non-limiting embodiments of dsRNA trigger sequences useful for suppressing or silencing a target gene in an insect cell or causing stunting or mortality in an insect, and methods for validating dsRNA trigger efficacy or for causing stunting or mortality in an insect. More specifically this example illustrates embodiments of dsRNA triggers for causing stunting or mortality in insects, and demonstrates systemic RNAi efficacy of these triggers.

[0098] **Table 2** provides dsRNA triggers tested by microinjection delivery in *Lygus hesperus* (Western tarnished plant bug) nymphs. The non-*Lygus*-specific trigger T35763 (SEQ ID NO:27, a 300 bp dsRNA trigger targetting green fluorescent protein) was used as a control.

**Table 2**

Trigger SEQ ID NO.*	Trigger ID	<i>Lygus hesperus</i> Target Gene	Amount injected per insect (micrograms)
14	T34616	ribosomal protein rpL19	1-2
15	T34617	V-ATPase subunit A	1-2
16	T34622	COPI coatomer B' (beta prime) subunit	1-2
22	T42772	ubiquitin C	1-2

[0099] **Table 3** presents mortality results for dsRNA triggers, T34617 (SEQ ID NO:15, targetting *Lygus hesperus* V-ATPase subunit A), and T34622 (SEQ ID NO:16, targetting *Lygus hesperus* COPI coatomer beta prime subunit) tested by microinjection delivery in *Lygus hesperus* (Western tarnished plant bug) nymphs. Control nymphs were microinjected with T35763 (targetting green fluorescent protein) or with deionized water. Increased percent mortality by day was observed for *Lygus*-target-gene-specific treatment groups (T34617 and T34622) compared to negative control treatment groups over the 5-day observation period.

**Table 3**

Trigger ID	Trigger SEQ ID NO:	<i>Lygus hesperus</i> Target gene	Percent mortality, shown by days after injection					Total <i>Lygus hesperus</i> nymphs injected	
			0	1	2	3	4		5
T34617	15	V-ATPase subunit A	12	25	58	75	88	100	24
T34622	16	COPI coatomer beta prime subunit	8	12	67	96	96	100	24
T35763	27	GFP	12	12	29	50	58	67	24
dH <sub>2</sub> O	(none)	(none)	0	5	20	45	55	75	20

[00100] **Table 4** presents mortality results for dsRNA triggers, T34616 (SEQ ID NO:14, targetting *Lygus hesperus* ribosomal protein rpL19), T34622 (SEQ ID NO:16, targetting *Lygus hesperus*

COPI coatomer beta prime subunit), and T42772 (SEQ ID NO:22, targetting *Lygus hesperus* ubiquitin C), tested by microinjection delivery in *Lygus hesperus* (Western tarnished plant bug) nymphs. Control nymphs were microinjected with T35763 (targetting green fluorescent protein). Increased percent mortality by day was observed for *Lygus*-target-gene-specific treatment groups (T34616, T34622, and T42772) compared to the negative control (T35763) treatment group over the 6-day observation period. Repeat activity of T34622 confirmed activity of this trigger observed in the earlier trial (Table 3).

**Table 4**

Trigger ID	Trigger SEQ ID NO:	<i>Lygus hesperus</i> Target gene	Percent mortality, shown by days after injection						Total <i>Lygus hesperus</i> nymphs injected	
			0	1	2	3	4	5		6
T34616	14	ribosomal protein rpL19	18	77	77	91	100	100	100	22
T34622	16	COPI coatomer beta prime subunit	12	50	83	88	100	100	100	24
T42772	22	ubiquitin C	17	61	100	100	100	100	100	23
T35763	27	GFP	8	22	44	48	56	56	61	23

Example 5

[00101] This example discloses embodiments related to polynucleotide molecules having a nucleotide sequence containing specific modifications such as nucleotide substitutions. Embodiments of such modifications include modified dsRNA triggers that provide improved sequence discrimination between the intended target gene of the insect pest of interest, and genetic sequences of other, non-target species.

[00102] Table 5 identifies examples of matches between the sequence of a target gene provided in Table 1 and a sequence identified in a non-target organism (NTO), where the match is a segment of at least 19 contiguous nucleotides. Table 5 further provides examples of sequence modifications (e. g., nucleotide changes at a specified location in the original target gene sequence) to eliminate the sequence match to a non-target organism.

**Table 5**

Target Gene SEQ ID NO:	Target Species	Non-Target Organism (NTO) species	Length (in nucleotides) of contiguous segment matching the NTO sequence	Nucleotide position of beginning of matching segment	Nucleotide position where change is made to eliminate match to NTO sequence	Nucleotide change made to eliminate match to NTO sequence
1	<i>Spodoptera frugiperda</i>	<i>Danaus plexippus</i>	19	398	408	G - A
		<i>Danaus plexippus</i>	23	562	575	C - T
		<i>Danaus plexippus</i>	26	604	617	A - T
		<i>Danaus plexippus</i>	20	631	642	C - T
		<i>Danaus plexippus</i>	20	661	671	A - T
		<i>Danaus plexippus</i>	28	695	710	T - A

		<i>Danaus plexippus</i>	20	727	737	T - A
		<i>Danaus plexippus</i>	20	793	802	A - G
		<i>Danaus plexippus</i>	20	847	858	C - T
		<i>Apis mellifera</i>	19	891	900	T - A
		<i>Homo sapiens</i>	21	905	900	T - A
		<i>Danaus plexippus</i>	19	968	977	T - C
		<i>Danaus plexippus</i>	23	1024	1035	G - A
		<i>Danaus plexippus</i>	48	1078	1092	C - T
				1110		G - A
2	<i>Spodoptera frugiperda</i>	<i>Danaus plexippus</i>	20	241	250	T - C
		<i>Danaus plexippus</i>	26	274	289	G - A
		<i>Homo sapiens</i>	19	516	526	A - G
		<i>Danaus plexippus</i>	26	1615	1628	A - G
		<i>Danaus plexippus</i>	20	1771	1780	C - T
		<i>Danaus plexippus</i>	20	1810	1820	T - C
		<i>Apis mellifera</i>	19	1870	1879	G - A
		<i>Homo sapiens</i>	20	1933	1945	G - A
		<i>Apis mellifera</i>	19	1934	1946	C - T
		<i>Homo sapiens</i>	21	1935	1946	C - T
		<i>Apis mellifera</i>	20	1936	1946	C - T
		<i>Homo sapiens</i>	20	1936	1946	C - T
		<i>Homo sapiens</i>	19	1936	1946	C - T
		<i>Homo sapiens</i>	19	1937	1946	C - T
		<i>Homo sapiens</i>	19	1939	1946	C - T
		<i>Homo sapiens</i>	19	1942	1946	C - T
<i>Apis mellifera</i>	19	2681	2690	T - C		
3	<i>Spodoptera frugiperda</i>	<i>Danaus plexippus</i>	19	62	72	C - T
		<i>Homo sapiens</i>	19	503	512	C - G
		<i>Homo sapiens</i>	19	544	553	A - G
		<i>Bombus impatiens</i>	22	659	669	G - A
		<i>Bombus terrestris</i>	22	659	669	G - A
		<i>Danaus plexippus</i>	26	859	873	C - T
		<i>Danaus plexippus</i>	19	925	934	G - A
		<i>Homo sapiens</i>	19	927	934	G - A
		<i>Homo sapiens</i>	19	934	945	G - A
		<i>Danaus plexippus</i>	19	935	945	G - A
		<i>Danaus plexippus</i>	20	936	945	G - A
		<i>Danaus plexippus</i>	26	952	964	G - A
		<i>Homo sapiens</i>	19	974	983	T - A
		<i>Homo sapiens</i>	19	1461	1470	G - T
		<i>Homo sapiens</i>	19	1712	1722	G - A
		<i>Homo sapiens</i>	20	1713	1722	G - A
		<i>Homo sapiens</i>	20	2223	2232	G - A
		<i>Homo sapiens</i>	19	2242	2256	G - A
		<i>Danaus plexippus</i>	20	2245	2256	G - A
		<i>Danaus plexippus</i>	24	2307	2319	G - C
		<i>Danaus plexippus</i>	20	2332	2340	C - T
		<i>Danaus plexippus</i>	29	2503	2517	C - T
		<i>Danaus plexippus</i>	41	2626	2633	T - C
4	<i>Lygus hesperus</i>	<i>Danaus plexippus</i>	20	323	333	G - A
		<i>Bombus impatiens</i>	20	1010	1020	T - A
		<i>Bombus terrestris</i>	20	1010	1020	T - A
		<i>Danaus plexippus</i>	20	1400	1410	G - A
		<i>Homo sapiens</i>	19	1603	1612	C - T
		<i>Bombus impatiens</i>	26	1607	1622	C - T
		<i>Bombus terrestris</i>	26	1607	1622	C - T
		<i>Homo sapiens</i>	19	1968	1977	C - T
		<i>Apis mellifera</i>	19	2001	2010	C - G
		<i>Apis mellifera</i>	20	2041	2050	A - T

5	<i>Lygus hesperus</i>	<i>Homo sapiens</i>	22	9	19	T - C
		<i>Homo sapiens</i>	20	11	20	T - A
		<i>Homo sapiens</i>	20	211	220	A - T
6	<i>Lygus hesperus</i>	<i>Bombus terrestris</i>	19	37	47	A - G
		<i>Danaus plexippus</i>	20	367	383	G - A
		<i>Homo sapiens</i>	19	374	383	G - A
		<i>Danaus plexippus</i>	20	637	647	A - T
		<i>Danaus plexippus</i>	26	802	815	A - T
		<i>Apis mellifera</i>	21	927	938	A - T
		<i>Danaus plexippus</i>	19	1529	1538	A - T
		<i>Homo sapiens</i>	19	2492	2501	T - C
		<i>Homo sapiens</i>	19	2493	2501	T - C
10	<i>Plutella xylostella</i>	<i>Danaus plexippus</i>	20	1390	1399	T - A
		<i>Danaus plexippus</i>	19	1427	1437	C - T
		<i>Danaus plexippus</i>	23	1471	1482	G - A
		<i>Danaus plexippus</i>	20	1543	1553	T - C
		<i>Homo sapiens</i>	20	1645	1654	G - A
		<i>Danaus plexippus</i>	35	1654	1671	G - A
		<i>Danaus plexippus</i>	23	1726	1736	C - T
		<i>Danaus plexippus</i>	35	1942	1959	G - A
		<i>Danaus plexippus</i>	20	2005	2016	C - T
		<i>Danaus plexippus</i>	20	2038	2048	C - T
		<i>Danaus plexippus</i>	20	2181	2190	G - A
11	<i>Plutella xylostella</i>	<i>Homo sapiens</i>	19	235	244	C - T
		<i>Danaus plexippus</i>	22	404	414	A - G
		<i>Homo sapiens</i>	19	517	526	T - A
		<i>Apis mellifera</i>	19	690	699	T - C
		<i>Danaus plexippus</i>	20	1771	1780	C - T
		<i>Danaus plexippus</i>	20	1891	1899	C - T
		<i>Homo sapiens</i>	20	1900	1910	A - T
		<i>Danaus plexippus</i>	23	1942	1953	C - T
12	<i>Plutella xylostella</i>	<i>Danaus plexippus</i>	21	184	194	T - C
		<i>Danaus plexippus</i>	19	384	393	G - A
		<i>Danaus plexippus</i>	20	613	622	C - T
		<i>Danaus plexippus</i>	32	916	931	A - T
		<i>Homo sapiens</i>	19	916	931	A - T
		<i>Homo sapiens</i>	21	935	931	A - T
		<i>Homo sapiens</i>	19	1066	1078	C - T
		<i>Danaus plexippus</i>	19	1067	1078	C - T
		<i>Danaus plexippus</i>	20	1068	1078	C - T
		<i>Homo sapiens</i>	19	1207	1219	T - C
		<i>Danaus plexippus</i>	19	1208	1219	T - C
		<i>Danaus plexippus</i>	20	1209	1219	T - C
		<i>Danaus plexippus</i>	19	1355	1365	G - A
		<i>Homo sapiens</i>	19	1474	1483	C - T
		<i>Homo sapiens</i>	20	1884	1894	G - A
					1895	C - T
		<i>Homo sapiens</i>	19	2142	2151	C - T
		<i>Bombus terrestris</i>	19	2203	2213	G - A
		<i>Homo sapiens</i>	19	2391	2401	G - A
		<i>Homo sapiens</i>	19	2808	2817	A - G
		<i>Danaus plexippus</i>	21	3172	3182	C - T
		<i>Danaus plexippus</i>	20	3236	3245	C - T
		<i>Homo sapiens</i>	19	3249	3258	A - G
		<i>Danaus plexippus</i>	21	3270	3280	G - A
<i>Homo sapiens</i>	19	3402	3411	C - T		
<i>Danaus plexippus</i>	27	3550	3564	C - T		

[00103] **Table 6** identifies examples of matches between the sequence of a dsRNA trigger provided in **Table 1** and a sequence identified in a non-target organism (NTO), where the match is a segment of at least 19 contiguous nucleotides. **Table 6** provides examples of sequence modifications (e.g., nucleotide changes at a specified location in the original dsRNA trigger sequence) which eliminate a specific sequence match of at least 19 contiguous nucleotides to a non-target organism. **Table 6** further provides non-limiting embodiments of a modified trigger sequence in which all of the nucleotide changes recited in **Table 6** for a given original trigger sequence have been made to eliminate the all of the recited match(es) of at least 19 contiguous nucleotides to a non-target organism sequence. For example, the modified dsRNA trigger having **SEQ ID NO:31** has one nucleotide change (A→U) at position 213, when compared to the original dsRNA trigger having **SEQ ID NO:15**; this single change eliminates matches of at least 19 contiguous nucleotides to two non-target organisms, *Bombus impatiens* and *Bombus terrestris*. In another example, the modified dsRNA trigger having **SEQ ID NO:35** has four nucleotide changes (at positions 42, 79, 124, and 194), when compared to the original dsRNA trigger having **SEQ ID NO:20**; these changes eliminate four matches of at least 19 contiguous nucleotides to the NTO *Danaus plexippus*. In another example, the modified dsRNA trigger having **SEQ ID NO:37** has four nucleotide changes (at positions 64, 72, 131, and 280), when compared to the original dsRNA trigger having **SEQ ID NO:20**; these changes eliminate four matches of at least 19 contiguous nucleotides to the NTOs *Bombus impatiens*, *Bombus terrestris*, *Homo sapiens*, and *Danaus plexippus*.

**Table 6**

Original Trigger SEQ ID NO:	Non-Target Organism (NTO) species	Length (in contiguous nucleotides) of segment matching the NTO sequence	Nucleotide position of beginning of matching segment	Nucleotide position where change is made to eliminate match to NTO sequence	Nucleotide change made to eliminate match to NTO sequence	Modified trigger sequence SEQ ID NO:
13	<i>Homo sapiens</i>	19	229	238	C - U	30
15	<i>Bombus impatiens</i>	20	202	213	A - U	31
	<i>Bombus terrestris</i>	20	202	213	A - U	
16	<i>Bombus terrestris</i>	19	22	32	A - G	32
17	<i>Danaus plexippus</i>	19	131	140	A - U	33
18	<i>Homo sapiens</i>	19	162	171	G - A	34
20	<i>Danaus plexippus</i>	20	33	42	U - A	35
	<i>Danaus plexippus</i>	19	70	79	A - U	
	<i>Danaus plexippus</i>	23	114	124	G - A	
	<i>Danaus plexippus</i>	20	186	196	U - A	
22	<i>Homo sapiens</i>	23	12	24	U - C	36
	<i>Homo sapiens</i>	26	12	24	U - C	
	<i>Homo sapiens</i>	20	15	26	G - A	
	<i>Homo sapiens</i>	23	15	26	G - A	
	<i>Danaus plexippus</i>	20	27	36	G - A	
	<i>Homo sapiens</i>	23	54	71	C - U	
	<i>Homo sapiens</i>	19	64	71	C - U	
	<i>Homo sapiens</i>	23	126	138	G - A	
	<i>Homo sapiens</i>	20	126	138	G - A	
<i>Apis mellifera</i>	20	210	220	A - G		

	<i>Bombus terrestris</i>	20	210	220	A - G			
	<i>Danaus plexippus</i>	20	216	220	A - G			
	<i>Apis mellifera</i>	20	225	220	A - G			
	<i>Apis mellifera</i>	29	228	220	A - G			
	<i>Apis mellifera</i>	23	234	243	C - U			
<b>23</b>	<i>Bombus impatiens</i>	29	53	64	A - G	<b>37</b>		
	<i>Bombus terrestris</i>	20	62	72	U - A			
	<i>Homo sapiens</i>	19	122	131	G - A			
	<i>Danaus plexippus</i>	20	271	280	A - G			
<b>24</b>	<i>Bombus impatiens</i>	27	98	99	G - C	<b>38</b>		
	<i>Danaus plexippus</i>	19	102	112	U - A			
	<i>Bombus impatiens</i>	20	164	176	A - U			
	<i>Apis mellifera</i>	20	167	176	A - U			
	<i>Apis mellifera</i>	29	167	176	A - U			
	<i>Danaus plexippus</i>	20	167	176	A - U			
	<i>Apis mellifera</i>	19	186	192	U - C			
	<i>Bombus impatiens</i>	26	188	196	A - G			
	<i>Apis mellifera</i>	26	200	204	A - U			
	<i>Apis mellifera</i>	20	203	213	U - C			
	<i>Bombus impatiens</i>	20	203	213	U - C			
	<i>Bombus terrestris</i>	20	203	213	U - C			
	<i>Danaus plexippus</i>	26	209	224	G - U			
	<i>Apis mellifera</i>	24	227	224	G - U			
	<i>Apis mellifera</i>	22	228	224	G - U			
	<i>Bombus impatiens</i>	19	228	224	G - U			
	<i>Homo sapiens</i>	20	231	242	G - A			
	<i>Apis mellifera</i>	23	251	264	G - A			
	<i>Bombus impatiens</i>	20	281	291	A - U			
	<i>Bombus impatiens</i>	23	47	63	A - U			
	<i>Bombus impatiens</i>	20	47	63	A - U			
	<i>Bombus terrestris</i>	20	50	63	A - U			
	<i>Danaus plexippus</i>	20	53	63	A - U			
	<i>Bombus impatiens</i>	39	86	99	G - C			
	<i>Bombus impatiens</i>	29	86	99	G - C			
	<i>Bombus terrestris</i>	39	86	99	G - C			
	<i>Bombus impatiens</i>	30	95	99	G - C			
	<i>Apis mellifera</i>	19	96	99	G - C			
	<i>Apis mellifera</i>	22	96	99	G - C			
	<b>25</b>	<i>Apis mellifera</i>	23	53	66		C - U	<b>39</b>
		<i>Apis mellifera</i>	26	68	66		C - U	
		<i>Bombus impatiens</i>	26	68	66		C - U	
<i>Apis mellifera</i>		26	71	84	A - U			
<i>Apis mellifera</i>		23	71	84	A - U			
<i>Bombus impatiens</i>		20	80	84	A - U			
<i>Apis mellifera</i>		20	89	99	A - U			
<i>Bombus impatiens</i>		23	155	168	A - U			
<i>Bombus impatiens</i>		20	155	168	A - U			
<i>Bombus terrestris</i>		20	158	168	A - U			
<i>Danaus plexippus</i>		20	161	168	A - U			
<i>Bombus impatiens</i>		39	194	206	G - A			
<i>Bombus impatiens</i>		29	194	206	G - A			
<i>Bombus terrestris</i>		39	194	206	G - A			
<i>Bombus impatiens</i>		30	203	206	G - A			
<i>Apis mellifera</i>		19	204	206	G - A			
<i>Apis mellifera</i>		22	204	206	G - A			
<i>Bombus impatiens</i>		27	206	221	U - G			
<i>Danaus plexippus</i>		19	210	221	U - G			
<i>Bombus impatiens</i>		20	272	285	A - U			
<i>Apis mellifera</i>		20	275	285	A - U			

	<i>Apis mellifera</i>	28	275	285	A - U	
	<i>Danaus plexippus</i>	20	275	285	A - U	
26	<i>Homo sapiens</i>	19	62	77	G - A	40
	<i>Danaus plexippus</i>	20	68	77	G - A	
	<i>Homo sapiens</i>	20	68	77	G - A	
	<i>Homo sapiens</i>	20	98	113	A - G	
	<i>Bombus terrestris</i>	20	104	113	A - G	
	<i>Danaus plexippus</i>	20	155	167	C - U	
	<i>Danaus plexippus</i>	23	155	167	C - U	
	<i>Homo sapiens</i>	23	155	167	C - U	
	<i>Danaus plexippus</i>	23	197	211	U - C	
	<i>Danaus plexippus</i>	19	201	211	U - C	
	<i>Danaus plexippus</i>	23	221	231	U - C	
	<i>Homo sapiens</i>	30	271	285	A - G	
	<i>Homo sapiens</i>	21	271	285	A - G	
	27	<i>Homo sapiens</i>	19	75	84	
28	<i>Homo sapiens</i>	19	222	231	C - A	42
	<i>Bombus terrestris</i>	19	283	291	U - C	

### Example 6

**[00104]** This example discloses embodiments related to polynucleotide molecules, such as dsRNA triggers designed to silence or suppress a target gene of an insect pest of interest, and techniques for determining efficacy of such molecules in suppressing a target gene or in controlling an insect pest. This example discloses a method of providing to an insect a polynucleotide, such as a recombinant RNA molecule or dsRNA trigger, in the form of an ingestible composition.

**[00105]** One method for determining efficacy of polynucleotide molecules in suppressing a target gene or in controlling a pest *Lygus* species is a sucrose feeding assay. In brief, this assay involves contacting western tarnished plant bug (*Lygus hesperus*) nymphs with dsRNA triggers in an ingestible composition (a sucrose solution), followed by maintenance on an artificial diet and monitoring of the nymphs' condition.

**[00106]** Parafilm sachets containing 2 milliliters of a 15% sucrose solution were prepared for the feeding experiments, with the treatment sachets containing dsRNA triggers (see **Table 1**) at either 500 micrograms/milliliter (or parts per million, ppm) or 1000 micrograms/milliliter (or parts per million, ppm). In some experiments the sucrose solution further included 5 milligrams/milliliter yeast tRNA to inhibit potential nuclease activity. Artificial diet sachets were also prepared using parafilm sachets containing 2 milliliters of a western tarnished plant bug (*Lygus hesperus*) artificial diet prepared by combining autoclaved, boiling water (518 milliliters) with 156.3 grams of Bio-Serv<sup>®</sup> diet F9644B (Bio-Serv, Frenchtown, NJ) in a surface-sterilized blender.

**[00107]** Third-instar *Lygus hesperus* nymphs were anesthetized under carbon dioxide vapor and distributed among 4-ounce glass jars (40 – 75 individuals per treatment). A piece of tissue paper was added to each jar to absorb honeydew. Each experiment was carried out over 7 days. The nymphs were allowed to feed for a 72-hour period (3 days) on the sucrose sachets, after which the sucrose sachets were removed and replaced with artificial diet sachets for the remaining 4 days of the 7-day observation period. All insects for a single treatment group were observed in a single arena, incubated at 27 degrees

Celsius, 60% relative humidity. Initial mortality at day 0 (start of the 72-hour sucrose-feeding stage) was 0 in all cases. Mortality was recorded from 3 days (*i. e.*, the end of the 72-hour sucrose-feeding stage) up to 7 days from the start of the experiment. For gene expression studies, immediately following the end of the 72-hour sucrose-feeding stage, 12 living nymphs were removed from each jar and immediately frozen on dry ice in individual matrix tubes to serve as samples for RNA measurement assays.

[00108] A series of feeding experiments using the above protocol was performed to assess activity of the dsRNA triggers T34616 (SEQ ID NO:14), T34617 (SEQ ID NO:15), T34619 (SEQ ID NO:45), T34622 (SEQ ID NO:16), T42772 (SEQ ID NO:22), T42768 (SEQ ID NO:46), and T44045 (SEQ ID NO:26) against *Lygus hesperus*. The dsRNA triggers T42772 (SEQ ID NO:22) and T44045 (SEQ ID NO:26) were also tested on *Lygus lineolaris*. A control trigger T35763 (SEQ ID NO:27, a 300 bp dsRNA trigger targetting green fluorescent protein) was used in the assays. At 500 micrograms/milliliter (500 ppm), enhanced mortality was observed with all *Lygus*-specific dsRNA triggers compared to control treatments in the presence (Table 7) or absence of yeast tRNA supplement (Table 8). T34622 (SEQ ID NO:16) (targetting the putative COPI coatomer beta prime subunit gene with SEQ ID NO:6) and T42772 (SEQ ID NO:22) (targetting the putative ubiquitin C gene with SEQ ID NO:7) were consistently the best performing triggers. Triggers T42772 (SEQ ID NO:22) and T44045 (SEQ ID NO:26), both targetting a putative ubiquitin C gene (SEQ ID NO:7), exhibited similar activity in the Western tarnished plant bug *Lygus hesperus* (Table 9A); both triggers also appeared active (although slower to act) in a related pest species, the tarnished plant bug, *Lygus lineolaris* (Table 9B).

[00109] A three-replicate experiment tested the ubiquitin C triggers T44045 (SEQ ID NO:26) and T42768 (SEQ ID NO:46) on *Lygus hesperus* at 1000 micrograms/milliliter (1000 ppm); the results demonstrated statistically significant differences in the means for insect mortality at days 3, 4, 5, 6, and 7 due to ubiquitin C trigger treatments when compared to control treatments with 15% sucrose alone or 15% sucrose plus the control trigger T35763 (SEQ ID NO:27) at 1000 micrograms/milliliter (1000 ppm) (Table 10).

**Table 7: Insect mortality (as percent of total insects in treatment), dsRNA triggers tested at 500 ppm in presence of 5 mg/mL yeast tRNA**

Treatment	Trigger SEQ ID NO:	Total insects in treatment	Days since start of assay					
			0	3	4	5	6	7
15% sucrose	–	58	0	10	33	55	64	72
15% sucrose + 5 mg/mL tRNA	–	57	0	16	37	54	63	70
T35763 GFP (control)	27	45	0	16	31	38	60	69
T34616 rpL19	14	58	0	31	50	72	86	97
T34617 V-ATPase subunit A	15	62	0	34	52	73	87	92
T34619 COPI coatomer beta subunit	45	56	0	36	43	68	71	89
T34622 COPI coatomer beta prime subunit	16	69	0	43	58	78	90	93
T42772 ubiquitin C	22	75	0	61	81	93	97	99

**Table 8: Insect mortality (as percent of total insects in treatment), dsRNA triggers tested at 500 ppm (without yeast tRNA)**

Treatment	Trigger SEQ ID NO:	Total insects in treatment	Days since start of assay					
			0	3	4	5	6	7
15% sucrose	–	65	0	26	42	63	71	78
T35763 GFP (control)	27	38	0	29	55	68	76	76
T34616 rpL19	14	62	0	24	47	71	87	94
T34617 V-ATPase subunit A	15	71	0	35	68	83	89	92
T34619 COPI coatomer beta subunit	45	56	0	38	86	91	95	95
T34622 COPI coatomer beta prime subunit	16	64	0	62	95	100	100	100
T42772 ubiquitin C	22	30	0	63	80	90	93	100

**Table 9A: *Lygus hesperus* mortality (as percent of total insects in treatment), dsRNA triggers tested at 500 ppm in presence of 5 mg/mL yeast tRNA**

Treatment	Trigger SEQ ID NO:	Total insects in treatment	Days since start of assay					
			0	3	4	5	6	7
15% sucrose	–	28	0	36	50	57	64	64
15% sucrose + 5 mg/mL tRNA	–	43	0	44	56	70	77	79
T35763 GFP (control)	27	32	0	50	66	78	88	91
T34622 COPI coatomer beta prime subunit	16	54	0	52	72	82	94	98
T42772 ubiquitin C	22	58	0	69	95	97	100	100
T44045 ubiquitin C	26	80	0	66	85	94	99	100

**Table 9B: *Lygus lineolaris* mortality (as percent of total insects in treatment), dsRNA triggers tested at 500 ppm in presence of 5 mg/mL yeast tRNA**

Treatment	Trigger SEQ ID NO:	Total insects in treatment	Days since start of assay					
			0	3	4	5	6	7
15% sucrose + 5 mg/mL tRNA	–	10	0	20	40	40	40	40
T35763 GFP (control)	27	16	0	19	44	50	56	69
T42772 ubiquitin C	22	20	0	30	45	60	75	95
T44045 ubiquitin C	26	21	0	29	43	67	86	90

**Table 10: *Lygus hesperus* mortality (as percent of total insects in treatment), dsRNA triggers tested at 1000 ppm**

Treatment	Trigger SEQ ID NO:	Replicate	Total insects in treatment	Days since start of assay					
				0	3	4	5	6	7
15% sucrose	–	1	29	0	45	45	48	48	52
		2	30	0	23	33	57	67	70
		3	30	0	21	28	34	41	41
<i>15% sucrose – mortality, mean (sd*)</i>				<i>0 (0)</i>	<i>30 (13)</i>	<i>35 (9)</i>	<i>46 (11)</i>	<i>52 (13)</i>	<i>54 (14)</i>
T35763 GFP (control)	27	1	30	0	20	30	53	53	53
		2	30	0	13	17	53	63	67
		3	30	0	30	40	50	57	60
<i>T35763 – mortality, mean (sd*)</i>				<i>0 (0)</i>	<i>21 (8)</i>	<i>29 (12)</i>	<i>52 (2)</i>	<i>58 (5)</i>	<i>60 (7)</i>
T44045 ubiquitin C	26	1	30	0	37	53	63	77	87
		2	29	0	24	38	59	76	86
		3	30	0	43	47	57	70	73
<i>T44045 – mortality, mean (sd*)</i>				<i>0 (0)</i>	<i>35 (10)</i>	<i>46 (8)</i>	<i>60 (3)</i>	<i>74 (4)</i>	<i>82 (8)</i>
T42768 ubiquitin C	46	1	29	0	17	55	90	97	97
		2	30	0	50	60	80	83	87
		3	30	0	40	60	70	77	80
<i>T42769 – mortality, mean (sd*)</i>				<i>0 (0)</i>	<i>36 (17)</i>	<i>58 (3)</i>	<i>80 (10)</i>	<i>86 (10)</i>	<i>88 (8)</i>

\*sd = standard deviation of the mean, given in percentage

[00110] Target gene suppression was assessed in *Lygus hesperus* by Quantigene analysis of three target genes (COPI coatomer beta prime subunit, V-ATPase subunit A, and COPI coatomer beta subunit). Sucrose feeding assays were carried out using the dsRNA triggers T34616 (SEQ ID NO:14), T34617 (SEQ ID NO:15), T34619 (SEQ ID NO:45), T34622 (SEQ ID NO:16), T42772 (SEQ ID NO:22), and T44045 (SEQ ID NO:26) tested at 500 or 100 ppm in 15% sucrose as described above. Immediately following the end of the 72-hour sucrose-feeding stage, the nymphs were individually frozen and subjected to Quantigene analysis. All values were normalized against the expression levels of two reference genes (EF1alpha and actin). The results (Tables 11A-C) demonstrated that each of the three tested target genes was specifically suppressed by the corresponding dsRNA trigger, coincident with observed increased mortality when compared to treatment with sucrose only or with the control GFP trigger T35763 (SEQ ID NO:27). The observed target gene suppression (reduction in target gene expression) was significant ( $p = 0.05$ ) compared to sucrose controls for five of six trigger experiments; in the sixth trigger experiment (T34622 at 1000 ppm, see Table 11A) visual suppression was observed just below the significance level. These results support the conclusion that the mortality observed in 15% sucrose feeding assays is mediated by RNAi.

**Table 11A: Target gene: *L. hesperus* COPI coatomer beta prime subunit (F38E11), SEQ ID NO:6**

Trigger concentration	Treatment	Target gene	% change from control	Significant @ $p=0.05$ from control?
n/a	sucrose only	n/a	n/a	n/a
1000 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	-4%	no
1000 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	33%	no
1000 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	-34%	no
1000 ppm	T35763 (SEQ ID NO:27)	GFP	4%	no
1000 ppm	T44045 (SEQ ID NO:26)	ubiquitin C	19%	no
n/a	sucrose only	n/a	n/a	n/a
500 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	-15%	no
500 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	-31%	no
500 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	-71%	yes
500 ppm	T35763 (SEQ ID NO:27)	GFP	-24%	no
n/a	untreated (artificial diet fed)	n/a	3%	no

**Table 11B: Target gene: *L. hesperus* V-ATPase A subunit (CG3762), SEQ ID NO:4**

Trigger concentration	Treatment	Target gene	% change from control	Significant @ $p=0.05$ from control?
n/a	sucrose only	n/a	n/a	n/a
1000 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	-77%	yes
1000 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	-21%	no
1000 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	-23%	no

1000 ppm	T35763 (SEQ ID NO:27)	GFP	-23%	no
1000 ppm	T44045 (SEQ ID NO:26)	ubiquitin C	-25%	no
n/a	sucrose only	n/a	n/a	n/a
500 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	-63%	yes
500 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	-25%	no
500 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	7%	no
500 ppm	T35763 (SEQ ID NO:27)	GFP	-35%	no
n/a	untreated (artificial diet fed)	n/a	20%	no

**Table 11C: Target gene: *L. hesperus* COPI coatomer beta subunit (CG6223), SEQ ID NO:43**

Trigger concentration	Treatment	Target gene	% change from control	Significant @ p=0.05 from control?
n/a	sucrose only	n/a	n/a	n/a
1000 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	6%	no
1000 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	-49%	yes
1000 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	28%	no
1000 ppm	T35763 (SEQ ID NO:27)	GFP	18%	no
1000 ppm	T44045 (SEQ ID NO:26)	ubiquitin C	21%	no
n/a	sucrose only	n/a	n/a	n/a
500 ppm	T34617 (SEQ ID NO:15)	V-ATPase subunit A	-22%	no
500 ppm	T34619 (SEQ ID NO:45)	COPI coatomer beta subunit	-54%	yes
500 ppm	T34622 (SEQ ID NO:16)	COPI coatomer beta prime subunit	-21%	no
500 ppm	T35763 (SEQ ID NO:27)	GFP	-34%	no
n/a	untreated (artificial diet fed)	n/a	18%	no

n/a = not applicable

Example 7

[00111] The polynucleotides of this invention are generally designed to modulate expression by inducing regulation or suppression of an insect target gene and are designed to have a nucleotide sequence essentially identical or essentially complementary to the nucleotide sequence an insect target gene or cDNA (*e. g.*, SEQ ID NOs:1 – 12 and 43 – 44) or to the sequence of RNA transcribed from an insect target gene, which can be coding sequence or non-coding sequence. These effective polynucleotide molecules that modulate expression are referred to herein as a “trigger”, or “triggers”. This example describes non-limiting techniques useful in the design and selection of polynucleotides as “triggers” to modulate expression of an insect target gene.

Selection of Polynucleotide Triggers by “Tiling”

[00112] Polynucleotides of use in the invention need not be of the full length of a target gene, and in many embodiments are of much shorter length in comparison to the target gene. An example of a technique that is useful for selecting effective triggers is “tiling”, or evaluation of polynucleotides corresponding to adjacent or partially overlapping segments of a target gene.

[00113] Effective polynucleotide “triggers” can be identified by “tiling” gene targets in selected length fragments, *e. g.*, fragments of 200 – 300 nucleotides in length, with partially overlapping regions, *e. g.*, of about 25 nucleotides, along the length of the target gene. To suppress a single gene,

trigger sequences are designed to correspond to (have a nucleotide identity or complementarity with) regions that are unique to the target gene; the selected region of the target gene can include coding sequence or non-coding sequence (*e. g.*, promoter regions, 3' untranslated regions, introns and the like) or a combination of both.

[00114] Where it is of interest to design a target effective in suppressing multiple target genes, the multiple target gene sequences are aligned and polynucleotide triggers designed to correspond to regions with high sequence homology in common among the multiple targets. Conversely, where it is of interest to design a target effective in selectively suppressing one among multiple target sequences, the multiple target gene sequences are aligned and polynucleotide triggers designed to correspond to regions with no or low sequence homology in common among the multiple targets.

[00115] In a non-limiting example, anti-sense single-stranded RNA triggers are designed for each of the target genes listed in **Table 1** as follows. Multiple anti-sense single-stranded RNA triggers, each of 200 – 300 nucleotides in length and with a sequence corresponding to (*i. e.*, for anti-sense triggers, complementary to) a fragment of a target gene having a sequence selected from **SEQ ID NOs:1 – 12** and **43 – 44** are designed so that each trigger's sequence overlaps about 25 nucleotides of the next adjacent trigger's sequence, in such a way that the multiple triggers in combination cover the full length of the target gene. (Sense triggers are designed in an analogous fashion, where the trigger sequence is identical to a fragment of the target gene. Similarly, double-stranded triggers can be designed by providing pairs of sense and anti-sense triggers, each pair of triggers overlapping the next adjacent pair of triggers.)

[00116] The polynucleotide triggers are tested by any convenient means for efficacy in silencing the insect target gene. Examples of a suitable test include the bioassays described herein in the working Examples. Another test involves the topical application of the polynucleotide triggers either directly to individual insects or to the surface of a plant to be protected from an insect infestation. One desired result of treatment with a polynucleotide of this invention is prevention or control of an insect infestation, *e. g.*, by inducing in an insect a physiological or behavioural change such as, but not limited to, growth stunting, increased mortality, decrease in reproductive capacity, decrease in or cessation of feeding behavior or movement, or decrease in or cessation of metamorphosis stage development. Another desired result of treatment with a polynucleotide of this invention is provision of a plant that exhibits improved resistance to an insect infestation.

[00117] The tiling procedure can be repeated, if desired. A polynucleotide trigger found to provide desired activity can itself be subjected to a tiling procedure. For example, multiple overlapping anti-sense single-stranded RNA triggers are designed, each of 50 – 60 nucleotides in length and with a sequence corresponding to (*i. e.*, for anti-sense triggers, complementary to) the fragment of a target gene having a sequence selected from **SEQ ID NOs:1 – 12** and **43 – 44** for which a single polynucleotide trigger of 300 nucleotides was found to be effective. Additional rounds of tiling analysis can be carried out, where triggers as short as 18 or 19 nucleotides are tested.

[00118] Effective polynucleotide triggers of any size can be used, alone or in combination, in the various methods of this invention. In some embodiments, a single polynucleotide trigger is used to make a composition of this invention (*e. g.*, a composition for topical application, or a recombinant DNA construct useful for making a transgenic plant). In other embodiments, a mixture or pool of different polynucleotide triggers is used; in such cases the polynucleotide triggers can be for a single target gene or for multiple target genes. In some embodiments, a polynucleotide trigger is designed to target different regions of the target gene, *e. g.*, a trigger can include multiple segments that correspond to different exon regions of the target gene, and “spacer” nucleotides which do not correspond to a target gene can optionally be used in between or adjacent to the segments.

#### Thermodynamic Considerations in Selecting Polynucleotide Triggers

[00119] Polynucleotide triggers can be designed or their sequence optimised using thermodynamic considerations. For example, polynucleotide triggers can be selected based on the thermodynamics controlling hybridization between one nucleic acid strand (*e. g.*, a polynucleotide trigger or an individual siRNA) and another (*e. g.*, a target gene transcript)

[00120] Methods and algorithms to predict nucleotide sequences that are likely to be effective at RNAi-mediated silencing of a target gene are known in the art. Non-limiting examples of such methods and algorithms include “i-score”, described by Ichihara *et al.* (2007) *Nucleic Acids Res.*, 35(18): 123e; “Oligowalk”, publicly available at [rna.urmc.rochester.edu/servers/oligowalk](http://rna.urmc.rochester.edu/servers/oligowalk) and described by Lu *et al.* (2008) *Nucleic Acids Res.*, 36:W104-108; and “Reynolds score”, described by Khovorova *et al.* (2004) *Nature Biotechnol.*, 22:326-330.

#### Permitted mismatches

[00121] By “essentially identical” or “essentially complementary” is meant that the trigger polynucleotide (or at least one strand of a double-stranded polynucleotide) has sufficient identity or complementarity to the target gene or to the RNA transcribed from a target gene (*e. g.*, the transcript) to suppress expression of a target gene (*e. g.*, to effect a reduction in levels or activity of the target gene transcript and/or encoded protein). Polynucleotides of this invention need not have 100 percent identity or complementarity to a target gene or to the RNA transcribed from a target gene to suppress expression of the target gene (*e. g.*, to effect a reduction in levels or activity of the target gene transcript or encoded protein, or to provide control of an insect species). In some embodiments, the polynucleotide or a portion thereof is designed to be essentially identical to, or essentially complementary to, a sequence of at least 18 or 19 contiguous nucleotides in either the target gene or the RNA transcribed from the target gene. In certain embodiments, an “essentially identical” polynucleotide has 100 percent sequence identity or at least about 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, or 99 percent sequence identity when compared to the sequence of 18 or more contiguous nucleotides in either the endogenous target gene or to an RNA transcribed from the target gene. In certain embodiments, an “essentially complementary” polynucleotide has 100 percent sequence complementarity or at least about 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, or 99 percent sequence complementarity when compared

to the sequence of 18 or more contiguous nucleotides in either the target gene or RNA transcribed from the target gene.

[00122] Polynucleotides containing mismatches to the target gene or transcript can be used in certain embodiments of the compositions and methods of this invention. In some embodiments, the polynucleotide includes at least 18 or at least 19 contiguous nucleotides that are essentially identical or essentially complementary to a segment of equivalent length in the target gene or target gene's transcript. In certain embodiments, a polynucleotide of 19 contiguous nucleotides that is essentially identical or essentially complementary to a segment of equivalent length in the target gene or target gene's transcript can have 1 or 2 mismatches to the target gene or transcript (*i. e.*, 1 or 2 mismatches between the polynucleotide's 19 contiguous nucleotides and the segment of equivalent length in the target gene or target gene's transcript). In certain embodiments, a polynucleotide of 20 or more nucleotides that contains a contiguous 19 nucleotide span of identity or complementarity to a segment of equivalent length in the target gene or target gene's transcript can have 1 or 2 mismatches to the target gene or transcript. In certain embodiments, a polynucleotide of 21 continuous nucleotides that is essentially identical or essentially complementary to a segment of equivalent length in the target gene or target gene's transcript can have 1, 2, or 3 mismatches to the target gene or transcript. In certain embodiments, a polynucleotide of 22 or more nucleotides that contains a contiguous 21 nucleotide span of identity or complementarity to a segment of equivalent length in the target gene or target gene's transcript can have 1, 2, or 3 mismatches to the target gene or transcript.

[00123] In designing polynucleotides with mismatches to an endogenous target gene or to an RNA transcribed from the target gene, mismatches of certain types and at certain positions that are more likely to be tolerated can be used. In certain exemplary embodiments, mismatches formed between adenine and cytosine or guanosine and uracil residues are used as described by Du *et al.* (2005) *Nucleic Acids Res.*, 33:1671–1677. In some embodiments, mismatches in 19 base-pair overlap regions are located at the low tolerance positions 5, 7, 8 or 11 (from the 5' end of a 19-nucleotide target), at medium tolerance positions 3, 4, and 12-17 (from the 5' end of a 19-nucleotide target), and/or at the high tolerance positions at either end of the region of complementarity, *i. e.*, positions 1, 2, 18, and 19 (from the 5' end of a 19-nucleotide target) as described by Du *et al.* (2005) *Nucleic Acids Res.*, 33:1671–1677. Tolerated mismatches can be empirically determined in routine assays such as those described herein in the working Examples.

[00124] In some embodiments, the polynucleotides include additional nucleotides for reasons of stability or for convenience in cloning or synthesis. In one embodiment, the polynucleotide is a dsRNA including an RNA strand with a segment of at least 21 contiguous nucleotides of a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46** and further including an additional 5' G or an additional 3' C or both, adjacent to the segment. In another embodiment, the polynucleotide is a double-stranded RNA including additional nucleotides to form an overhang, for example, a dsRNA including 2 deoxyribonucleotides to form a 3' overhang.

### Embedding Active Triggers in Neutral Sequence

[00125] In an embodiment, a bioactive trigger (*i. e.*, a polynucleotide with a sequence corresponding to the target gene and which is responsible for an observed suppression of the target gene) is embedded in “neutral” sequence, *i. e.*, inserted into additional nucleotides that have no sequence identity or complementarity to the target gene. Neutral sequence can be desirable, *e. g.*, to increase the overall length of a polynucleotide. For example, it can be desirable for a polynucleotide to be of a particular size for reasons of stability, cost-effectiveness in manufacturing, or biological activity.

[00126] It has been reported that in another coleopteran species, *Diabrotica virgifera*, dsRNAs greater than or equal to approximately 60 base-pairs (bp) are required for biological activity in artificial diet bioassays; see Bolognesi *et al.* (2012) PLoS ONE 7(10): e47534. doi:10.1371/journal.pone.0047534. Thus, in one embodiment, a 21-base-pair dsRNA trigger corresponding to a target gene in **Table 1** and found to provide control of an insect infestation is embedded in neutral sequence of an additional 39 base pairs, thus forming a polynucleotide of about 60 base pairs. In another embodiment, a single 21-base-pair trigger is found to be efficacious when embedded in larger sections of neutral sequence, *e. g.*, where the total polynucleotide length is from about 60 to about 300 base pairs. In another embodiment, at least one segment of at least 21 contiguous nucleotides of a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46** is embedded in larger sections of neutral sequence to provide an efficacious trigger. In another embodiment, segments from multiple sequences selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46** are embedded in larger sections of neutral sequence to provide an efficacious trigger.

[00127] It is anticipated that the combination of certain recombinant RNAs of this invention (*e. g.*, the dsRNA triggers having a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**, or active fragments of these triggers) with one or more non-polynucleotide pesticidal agents will result in a synergetic improvement in prevention or control of insect infestations, when compared to the effect obtained with the recombinant RNA alone or the non-polynucleotide pesticidal agent alone. Routine insect bioassays such as the bioassays described herein in the working Examples are useful for defining dose-responses for larval mortality or growth inhibition using combinations of the polynucleotides of this invention and one or more non-polynucleotide pesticidal agents (*e. g.*, a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein). One of skill in the art can test combinations of polynucleotides and non-polynucleotide pesticidal agents in routine bioassays to identify combinations of bioactives that are synergistic and desirable for use in protecting plants from insect infestations.

Example 8

[00128] This example illustrates non-limiting embodiments of the use of polynucleotides of this invention in topically applied compositions for preventing or controlling insect infestations.

[00129] Compositions containing one or more polynucleotides of this invention are useful as topical treatments of plants, animals, or environments wherein prevention or control of a *Leptinotarsa* species infestation is desired. In embodiments, a polynucleotide trigger for a target gene with a sequence selected from SEQ ID NOs:1 – 12 and 43 – 44, *i. e.*, the target genes identified in Table 1, as described in the preceding examples, is included in an effective amount in a composition designed to be provided directly (*e. g.*, by contact or ingestion) to an insect species, or a plant or environment wherein prevention or control of infestation by that insect is desired. In embodiments, a polynucleotide trigger for a target gene with a sequence selected from SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46 is included in an effective amount in such compositions. In embodiments, a dsRNA trigger with a strand having a sequence selected from the group consisting of SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46, or active fragments of these triggers, is included in an effective amount in such compositions. Such compositions are formulated and manufactured according to the art and can be in any convenient form, *e. g.*, a solution or mixture of solutions, an emulsion, a suspension, a dispersible powder, a solid or liquid bait, a seed coating, or a soil drench. Embodiments of such compositions include those where the polynucleotide of this invention is provided in a living or dead microorganism such as a bacterium or fungal or yeast cell, or provided as a microbial fermentation product, or provided in a living or dead plant cell, or provided as a synthetic recombinant polynucleotide. In an embodiment the composition includes a non-pathogenic strain of a microorganism that contains a polynucleotide of this invention; ingestion or intake of the microorganism results in stunting or mortality of the insect pest; non-limiting examples of suitable microorganisms include *E. coli*, *B. thuringiensis*, *Pseudomonas* sp., *Photorhabdus* sp., *Xenorhabdus* sp., *Serratia entomophila* and related *Serratia* sp., *B. sphaericus*, *B. cereus*, *B. laterosporus*, *B. popilliae*, *Clostridium bif fermentans* and other *Clostridium* species, or other spore-forming gram-positive bacteria. In an embodiment, the composition includes a plant virus vector including a polynucleotide of this invention; feeding by an insect on a plant treated with the plant virus vector results in stunting or mortality of the insect. In an embodiment, the composition includes a baculovirus vector including a polynucleotide of this invention; ingestion or intake of the vector results in stunting or mortality of the insect. In an embodiment, a polynucleotide of this invention is encapsulated in a synthetic matrix such as a polymer or attached to particulates and topically applied to the surface of a plant; feeding by an insect on the topically treated plant results in stunting or mortality of the insect. In an embodiment, a polynucleotide of this invention is provided in the form of a plant cell (*e. g.*, a transgenic plant cell of this invention) expressing the polynucleotide; ingestion of the plant cell or contents of the plant cell by an insect results in stunting or mortality of the insect.

[00130] Embodiments of the compositions optionally include the appropriate stickers and wetters required for efficient foliar coverage as well as UV protectants to protect polynucleotides such as

dsRNAs from UV damage. Such additives are commonly used in the bioinsecticide industry and are known to those skilled in the art. Compositions for soil application can include granular formulations that serve as bait for insect larvae. Embodiments include a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator. In embodiments, the composition further includes at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporus* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.

[00131] Such compositions are applied in any convenient manner, *e. g.*, by spraying or dusting the insect directly, or spraying or dusting a plant or environment wherein prevention or control of infestation by that insect is desired, or by applying a coating to a surface of a plant, or by applying a coating to a seed (or seed potato) in preparation for the seed's planting, or by applying a soil drench around roots of a plant for which prevention or control of infestation by that insect is desired.

[00132] An effective amount of a polynucleotide of this invention is an amount sufficient to provide control of the insect, or to prevent infestation by the insect; determination of effective amounts of a polynucleotide of this invention are made using routine assays such as those described in the working Examples herein. While there is no upper limit on the concentrations and dosages of a polynucleotide of this invention that can be useful in the methods and compositions provided herein, lower effective concentrations and dosages will generally be sought for efficiency and economy. Non-limiting embodiments of effective amounts of a polynucleotide include a range from about 10 nanograms per milliliter to about 100 micrograms per milliliter of a polynucleotide in a liquid form sprayed on a plant, or from about 10 milligrams per acre to about 100 grams per acre of polynucleotide applied to a field of plants, or from about 0.001 to about 0.1 microgram per milliliter of polynucleotide in an artificial diet for feeding the insect. Where compositions of this invention are topically applied to a plant, the concentrations can be adjusted in consideration of the volume of spray or treatment applied to plant leaves or other plant part surfaces, such as flower petals, stems, tubers, fruit, anthers, pollen, leaves, roots, or seeds. In one embodiment, a useful treatment for herbaceous plants using 25-mer polynucleotides of this invention is about 1 nanomole (nmol) of polynucleotides per plant, for example, from about 0.05 to 1 nmol polynucleotides per plant. Other embodiments for herbaceous plants include useful ranges of about 0.05 to about 100 nmol, or about 0.1 to about 20 nmol, or about 1 nmol to about 10 nmol of polynucleotides per plant. In certain embodiments, about 40 to about 50 nmol of a ssDNA polynucleotide of this invention are applied. In certain embodiments, about 0.5 nmol to about 2 nmol of a dsRNA of this invention is applied. In certain embodiments, a composition containing about 0.5 to about 2.0 milligrams per milliliter, or about 0.14 milligrams per milliliter of a dsRNA or an ssDNA (21-mer) of this invention is applied. In certain embodiments, a composition of about 0.5 to about 1.5 milligrams per milliliter of a dsRNA polynucleotide of this invention of about 50 to about 200 or more

nucleotides is applied. In certain embodiments, about 1 nmol to about 5 nmol of a dsRNA of this invention is applied to a plant. In certain embodiments, the polynucleotide composition as typically applied to the plant contains at least one polynucleotide of this invention at a concentration of about 0.01 to about 10 milligrams per milliliter, or about 0.05 to about 2 milligrams per milliliter, or about 0.1 to about 2 milligrams per milliliter. Very large plants, trees, or vines can require correspondingly larger amounts of polynucleotides. When using long dsRNA molecules of this invention that can be processed into multiple oligonucleotides (*e. g.*, multiple triggers encoded by a single recombinant DNA molecule of this invention), lower concentrations can be used. Non-limiting examples of effective polynucleotide treatment regimes include a treatment of between about 0.1 to about 1 nmol of polynucleotide molecule per plant, or between about 1 nmol to about 10 nmol of polynucleotide molecule per plant, or between about 10 nmol to about 100 nmol of polynucleotide molecule per plant.

**[00133]** Embodiments of compositions of this invention include a “transfer agent”, *i. e.*, an agent that, when combined with a composition including a polynucleotide of this invention that is typically applied to the surface of an organism, enables the polynucleotide to enter the cells of that organism. Such transfer agents can be incorporated as part of the composition including a polynucleotide of this invention, or can be applied prior to, contemporaneously with, or following application of the composition including a polynucleotide of this invention. In embodiments, a transfer agent is an agent that improves the uptake of a polynucleotide of this invention by an insect. In embodiments, a transfer agent is an agent that conditions the surface of plant tissue, *e. g.*, seeds, leaves, stems, roots, flowers, or fruits, to permeation by a polynucleotide of this invention into plant cells. In embodiments, the transfer agent enables a pathway for a polynucleotide of this invention through cuticle wax barriers, stomata, and/or cell wall or membrane barriers into plant cells.

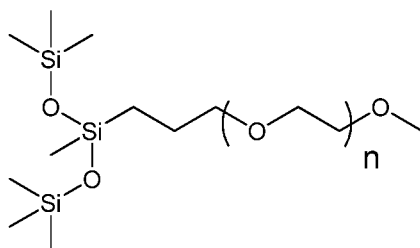
**[00134]** Suitable transfer agents include agents that increase permeability of the exterior of the organism or that increase permeability of cells of the organism to polynucleotides of this invention. Suitable transfer agents include a chemical agent, or a physical agent, or combinations thereof. Chemical agents for conditioning or transfer include (a) surfactants, (b) an organic solvent or an aqueous solution or aqueous mixtures of organic solvents, (c) oxidizing agents, (d) acids, (e) bases, (f) oils, (g) enzymes, or combinations thereof. In embodiments, application of a composition of this invention and a transfer agent optionally includes an incubation step, a neutralization step (*e. g.*, to neutralize an acid, base, or oxidizing agent, or to inactivate an enzyme), a rinsing step, or combinations thereof. Suitable transfer agents can be in the form of an emulsion, a reverse emulsion, a liposome, or other micellar-like composition, or can cause the polynucleotide composition to take the form of an emulsion, a reverse emulsion, a liposome, or other micellar-like composition. Embodiments of transfer agents include counter-ions or other molecules that are known to associate with nucleic acid molecules, *e. g.*, inorganic ammonium ions, alkyl ammonium ions, lithium ions, polyamines such as spermine, spermidine, or putrescine, and other cations. Embodiments of transfer agents include organic solvents such as DMSO, DMF, pyridine, *N*-pyrrolidine, hexamethylphosphoramide, acetonitrile, dioxane, polypropylene glycol, or

other solvents miscible with water or that dissolve phosphonucleotides in non-aqueous systems (such as is used in synthetic reactions). Embodiments of transfer agents include naturally derived or synthetic oils with or without surfactants or emulsifiers, *e. g.*, plant-sourced oils, crop oils (such as those listed in the 9<sup>th</sup> Compendium of Herbicide Adjuvants, publicly available on-line at [herbicide.adjuvants.com](http://herbicide.adjuvants.com)), paraffinic oils, polyol fatty acid esters, or oils with short-chain molecules modified with amides or polyamines such as polyethyleneimine or *N*-pyrrolidine.

**[00135]** Embodiments of transfer agents include organosilicone preparations. For example, a suitable transfer agent is an organosilicone preparation that is commercially available as SILWET L-77® brand surfactant having CAS Number 27306-78-1 and EPA Number: CAL.REG.NO. 5905-50073-AA, and currently available from Momentive Performance Materials, Albany, New York. In embodiments where a SILWET L-77® brand surfactant organosilicone preparation is used as transfer agent in the form of a spray treatment (applied prior to, contemporaneously with, or following application of the composition including a polynucleotide of this invention) of plant leaves or other plant surfaces, freshly made concentrations in the range of about 0.015 to about 2 percent by weight (wt percent) (*e. g.*, about 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, 0.05, 0.055, 0.06, 0.065, 0.07, 0.075, 0.08, 0.085, 0.09, 0.095, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.5 wt percent) are efficacious in preparing a leaf or other plant surface for transfer of a polynucleotide of this invention into plant cells from a topical application on the surface. One embodiment includes a composition that comprises a polynucleotide of this invention and a transfer agent including an organosilicone preparation such as Silwet L-77 in the range of about 0.015 to about 2 percent by weight (wt percent) (*e. g.*, about 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, 0.05, 0.055, 0.06, 0.065, 0.07, 0.075, 0.08, 0.085, 0.09, 0.095, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.5 wt percent). One embodiment includes a composition that comprises a polynucleotide of this invention and a transfer agent including SILWET L-77® brand surfactant in the range of about 0.3 to about 1 percent by weight (wt percent) or about 0.5 to about 1%<sub>w</sub> by weight (wt percent).

**[00136]** Organosilicone compounds useful as transfer agents for use in this invention include, but are not limited to, compounds that include: (a) a trisiloxane head group that is covalently linked to, (b) an alkyl linker including, but not limited to, an *n*-propyl linker, that is covalently linked to, (c) a polyglycol chain, that is covalently linked to, (d) a terminal group. Trisiloxane head groups of such organosilicone compounds include, but are not limited to, heptamethyltrisiloxane. Alkyl linkers can include, but are not limited to, an *n*-propyl linker. Polyglycol chains include, but are not limited to, polyethylene glycol or polypropylene glycol. Polyglycol chains can comprise a mixture that provides an average chain length “*n*” of about “7.5”. In certain embodiments, the average chain length “*n*” can vary from about 5 to about 14. Terminal groups can include, but are not limited to, alkyl groups such as a methyl group. Organosilicone compounds useful as transfer agents for use in this invention include, but

are not limited to, trisiloxane ethoxylate surfactants or polyalkylene oxide modified heptamethyl trisiloxane. An example of a transfer agent for use in this invention is Compound I:



(Compound I: polyalkyleneoxide heptamethyltrisiloxane, average  $n=7.5$ ).

**[00137]** Organosilicone compounds useful as transfer agents for use in this invention are used, *e. g.*, as freshly made concentrations in the range of about 0.015 to about 2 percent by weight (wt percent) (*e. g.*, about 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, 0.05, 0.055, 0.06, 0.065, 0.07, 0.075, 0.08, 0.085, 0.09, 0.095, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.5 wt percent).

**[00138]** Embodiments of transfer agents include one or more salts such as ammonium chloride, tetrabutylphosphonium bromide, and ammonium sulfate, provided in or used with a composition including a polynucleotide of this invention. In embodiments, ammonium chloride, tetrabutylphosphonium bromide, and/or ammonium sulfate are used at a concentration of about 0.5% to about 5% (w/v), or about 1% to about 3% (w/v), or about 2% (w/v). In certain embodiments, the composition including a polynucleotide of this invention includes an ammonium salt at a concentration greater or equal to 300 millimolar. In certain embodiments, the composition including a polynucleotide of this invention includes an organosilicone transfer agent in a concentration of about 0.015 to about 2 percent by weight (wt percent) as well as ammonium sulfate at concentrations from about 80 to about 1200 mM or about 150 mM to about 600 mM.

**[00139]** Embodiments of transfer agents include a phosphate salt. Phosphate salts useful in a composition including a polynucleotide of this invention include, but are not limited to, calcium, magnesium, potassium, or sodium phosphate salts. In certain embodiments, the composition including a polynucleotide of this invention includes a phosphate salt at a concentration of at least about 5 millimolar, at least about 10 millimolar, or at least about 20 millimolar. In certain embodiments, the composition including a polynucleotide of this invention includes a phosphate salt in a range of about 1mM to about 25mM or in a range of about 5mM to about 25mM. In certain embodiments, the composition including a polynucleotide of this invention includes sodium phosphate at a concentration of at least about 5 millimolar, at least about 10 millimolar, or at least about 20 millimolar. In certain embodiments, the composition including a polynucleotide of this invention includes sodium phosphate at a concentration of about 5 millimolar, about 10 millimolar, or about 20 millimolar. In certain embodiments, the composition including a polynucleotide of this invention includes a sodium phosphate salt in a range of about 1mM to about 25mM or in a range of about 5mM to about 25mM. In certain embodiments, the composition including a polynucleotide of this invention includes a sodium phosphate

salt in a range of about 10mM to about 160mM or in a range of about 20mM to about 40mM. In certain embodiments, the composition including a polynucleotide of this invention includes a sodium phosphate buffer at a pH of about 6.8.

[00140] Embodiments of transfer agents include surfactants and/or effective molecules contained therein. Surfactants and/or effective molecules contained therein include, but are not limited to, sodium or lithium salts of fatty acids (such as tallow or tallowamines or phospholipids) and organosilicone surfactants. In certain embodiments, the composition including a polynucleotide of this invention is formulated with counter-ions or other molecules that are known to associate with nucleic acid molecules. Non-limiting examples include, tetraalkyl ammonium ions, trialkyl ammonium ions, sulfonium ions, lithium ions, and polyamines such as spermine, spermidine, or putrescine. In certain embodiments, the composition including a polynucleotide of this invention is formulated with a non-polynucleotide herbicide *e. g.*, glyphosate, auxin-like benzoic acid herbicides including dicamba, chloramben, and TBA, glufosinate, auxin-like herbicides including phenoxy carboxylic acid herbicide, pyridine carboxylic acid herbicide, quinoline carboxylic acid herbicide, pyrimidine carboxylic acid herbicide, and benazolin-ethyl herbicide, sulfonylureas, imidazolinones, bromoxynil, delapon, cyclohezanedione, protoporphyrinogen oxidase inhibitors, and 4-hydroxyphenyl-pyruvate-dioxygenase inhibiting herbicides. In certain embodiments, the composition including a polynucleotide of this invention is formulated with a non-polynucleotide pesticide, *e. g.*, a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.

[00141] All of the materials and methods disclosed and claimed herein can be made and used without undue experimentation as instructed by the above disclosure. Although the materials and methods of this invention have been described in terms of preferred embodiments and illustrative examples, it will be apparent to those of skill in the art that variations can be applied to the materials and methods described herein without departing from the concept, spirit and scope of this invention. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of this invention as defined by the appended claims.

What is claimed is:

1. A method for controlling an insect infestation of a plant comprising contacting with a dsRNA an insect that infests a plant, wherein said dsRNA comprises at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% complementarity with a fragment of a target gene of said insect, and wherein said target gene has a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 12** and **43 – 44**.
2. The method of claim 1, wherein said insect is selected from the group consisting of *Spodoptera* spp., *Lygus* spp., *Euschistus* spp., and *Plutella* spp.
3. The method of claim 1, wherein:
  - (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 3**;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:4 – 7, 43, and 44**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:8 – 9**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**.
4. The method of claim 1, wherein:
  - (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said dsRNA comprises a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said dsRNA comprises a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said dsRNA comprises a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and said dsRNA comprises a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**.
5. The method of claim 1, wherein said at least one segment is multiple segments.
6. The method of claim 1, wherein said dsRNA is (a) blunt-ended, or (b) has an overhang at at least one terminus.
7. The method of claim 1, wherein said dsRNA is (a) chemically synthesized, or (b) produced by expression in a microorganism, expression in a plant cell, or by microbial fermentation.
8. The method of claim 1, wherein said dsRNA is chemically modified.
9. The method of claim 1, wherein said contacting comprises application of a composition comprising said dsRNA to a surface of said insect or to a surface of said plant infested by said insect.
10. The method of claim 9, wherein said composition comprises a solid, liquid, powder, suspension, emulsion, spray, encapsulation, microbeads, carrier particulates, film, matrix, or seed treatment.

11. The method of claim 1, wherein said contacting comprises providing said dsRNA in a composition that further comprises one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator.
12. The method of claim 1, wherein said contacting comprises providing said dsRNA in a composition that further comprises at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.
13. The method of claim 1, wherein said contacting comprises providing said dsRNA in a composition that is ingested by said insect.
14. The method of claim 13, wherein said composition that is ingested further comprises one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator.
15. The method of claim 13, wherein said composition that is ingested further comprises at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.
16. A method of causing mortality or stunting in an insect, comprising providing in the diet of an insect at least one recombinant RNA comprising at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of said insect, wherein said target gene sequence is selected from the group consisting of SEQ ID NOs:1 – 12 and 43 – 44, and wherein ingestion of said recombinant RNA by said insect results in mortality or stunting in said insect.
17. The method of claim 16, wherein said recombinant RNA comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46.
18. The method of claim 16, wherein:
  - (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said target gene comprises a DNA sequence selected from the group consisting of SEQ ID NOs:1 – 3;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said target gene comprises a DNA sequence selected from the group consisting of SEQ ID NOs:4 – 7, 43, and 44;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said target gene comprises a DNA sequence selected from the group consisting of SEQ ID NOs:8 – 9; or

- (d) said insect is *Plutella xylostella* (diamondback moth) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**.
19. The method of claim 16, wherein:
- (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said silencing element comprises a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said silencing element comprises a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said silencing element comprises a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and said silencing element comprises a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**.
20. The method of claim 16, wherein said recombinant RNA is dsRNA.
21. The method of claim 16, wherein said recombinant RNA is (a) blunt-ended dsRNA, or (b) dsRNA with an overhang at at least one terminus.
22. The method of claim 16, wherein said recombinant RNA is provided in a microbial or plant cell or in a microbial fermentation product.
23. The method of claim 16, wherein said recombinant RNA is chemically synthesized.
24. The method of claim 16, wherein said insect is in a larval or nymph stage.
25. The method of claim 16, wherein said insect is an adult.
26. The method of claim 20, wherein said dsRNA comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.
27. An insecticidal composition comprising an insecticidally effective amount of a recombinant RNA molecule, wherein said recombinant RNA molecule comprises at least one segment of 18 or more contiguous nucleotides with a sequence of about 95% to about 100% complementarity with a fragment of a target gene of an insect that infests a plant, and wherein said target gene has a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**.
28. The insecticidal composition of claim 27, wherein said recombinant RNA molecule comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.
29. The insecticidal composition of claim 27, wherein said recombinant RNA molecule is a dsRNA comprising an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.
30. The insecticidal composition of claim 29, wherein said dsRNA is at least 50 base pairs in length.
31. The insecticidal composition of claim 27, wherein:
- (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:1 – 3**;

- (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:4 – 7, 43, and 44**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:8 – 9**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and said target gene comprises a DNA sequence selected from the group consisting of **SEQ ID NOs:10 – 12**.
32. The insecticidal composition of claim 27, wherein:
- (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said recombinant RNA molecule comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and said recombinant RNA molecule comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and said recombinant RNA molecule comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and said recombinant RNA molecule comprises at least one RNA strand having a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**.
33. The insecticidal composition of claim 27, wherein:
- (a) said insect is *Spodoptera frugiperda* (fall armyworm) and said recombinant RNA molecule is a dsRNA comprising an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:17 – 19**;
  - (b) said insect is *Lygus hesperus* (western tarnished plant bug) and recombinant RNA molecule is a dsRNA comprising an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:14 – 16, 22, 26, 45, and 46**;
  - (c) said insect is *Euschistus heros* (neotropical brown stink bug) and recombinant RNA molecule is a dsRNA comprising an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:23 – 25**; or
  - (d) said insect is *Plutella xylostella* (diamondback moth) and recombinant RNA molecule is a dsRNA comprising an RNA strand having a sequence selected from the group consisting of **SEQ ID NOs:13, 20 – 21, and 28 – 29**.
34. The insecticidal composition of claim 27, further comprising one or more components selected from the group consisting of a carrier agent, a surfactant, an organosilicone, a polynucleotide herbicidal

- molecule, a non-polynucleotide herbicidal molecule, a non-polynucleotide pesticide, a safener, an insect attractant, and an insect growth regulator.
35. The insecticidal composition of claim 27, further comprising at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.
  36. The insecticidal composition of claim 27, wherein said composition is in a form selected from the group consisting of a solid, liquid, powder, suspension, emulsion, spray, encapsulation, microbeads, carrier particulates, film, matrix, soil drench, insect diet or insect bait, and seed treatment.
  37. A plant treated with the insecticidal composition of claim 27, or seed of said plant, wherein said plant exhibits improved resistance to said insect.
  38. A method of providing a plant having improved resistance to an insect, comprising expressing in said plant a recombinant DNA construct comprising DNA encoding RNA that includes at least one silencing element essentially identical or essentially complementary to a fragment of a target gene sequence of said insect, wherein said target gene sequence is selected from the group consisting of **SEQ ID NOs:1 – 12 and 43 – 44**, and wherein ingestion of said RNA by said insect results in mortality or stunting in said insect.
  39. The method of claim 38, wherein said silencing element has a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.
  40. The method of claim 38, wherein said recombinant DNA construct further comprises a heterologous promoter operably linked to said DNA encoding RNA that includes at least one silencing element, wherein said heterologous promoter is functional in a plant cell.
  41. The method of claim 38, wherein said expressing is by means of transgenic expression or transient expression.
  42. The method of claim 38, further comprising expression in said plant of at least one pesticidal agent selected from the group consisting of a patatin, a plant lectin, a phytoecdysteroid, a *Bacillus thuringiensis* insecticidal protein, a *Xenorhabdus* insecticidal protein, a *Photorhabdus* insecticidal protein, a *Bacillus laterosporous* insecticidal protein, and a *Bacillus sphaericus* insecticidal protein.
  43. The plant having improved resistance to an insect, provided by the method of claim 38.
  44. Fruit, seed, or propagatable parts of the plant of claim 43.
  45. A recombinant DNA construct comprising a heterologous promoter operably linked to DNA encoding an RNA transcript comprising a sequence of about 95% to about 100% identity or complementarity with a sequence selected from the group consisting of **SEQ ID NOs:13 – 26, 28 – 29, 30 – 42, 45, and 46**.
  46. The recombinant DNA construct of claim 45, wherein said heterologous promoter is (a) functional for expression of said RNA transcript in a bacterium.

47. The recombinant DNA construct of claim 46, wherein said bacterium is selected from the group consisting of *Escherichia coli*, *Bacillus* species, *Pseudomonas* species, *Xenorhabdus* species, or *Photorhabdus* species.
48. The recombinant DNA construct of claim 45, wherein said heterologous promoter is functional in a plant cell.
49. A recombinant vector comprising the recombinant DNA construct of claim 45.
50. The recombinant vector of claim 49, wherein said recombinant vector is a recombinant plant virus vector or a recombinant baculovirus vector.
51. A plant chromosome or plastid comprising the recombinant DNA construct of claim 45.
52. A transgenic plant cell having in its genome the recombinant DNA construct of claim 45.
53. A transgenic plant comprising the transgenic plant cell of claim 52.
54. A commodity product produced from the transgenic plant of claim 53.
55. A transgenic progeny seed or propagatable plant part of the transgenic plant of claim 53.

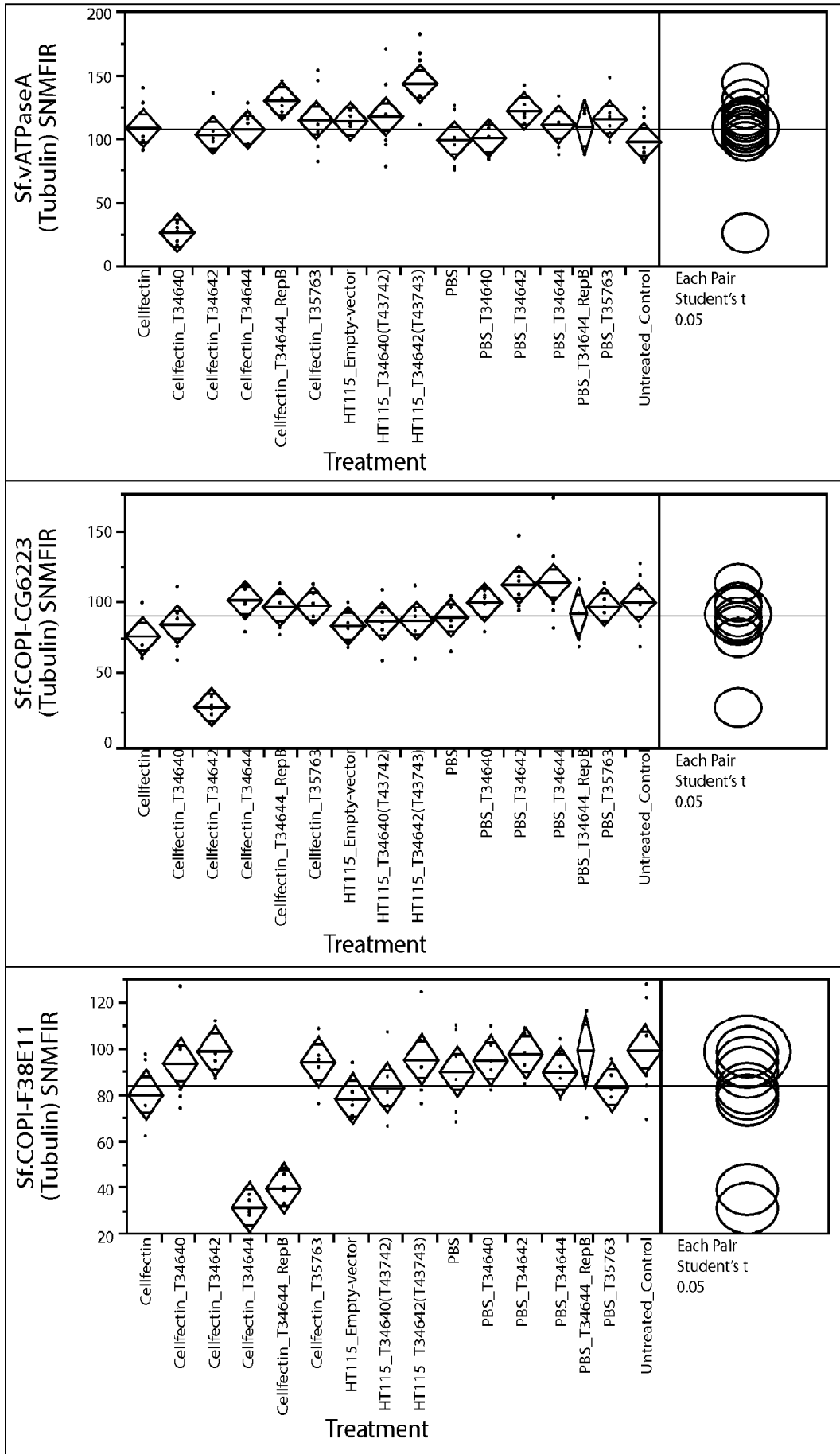


Figure 1  
SUBSTITUTE SHEET (RULE 26)

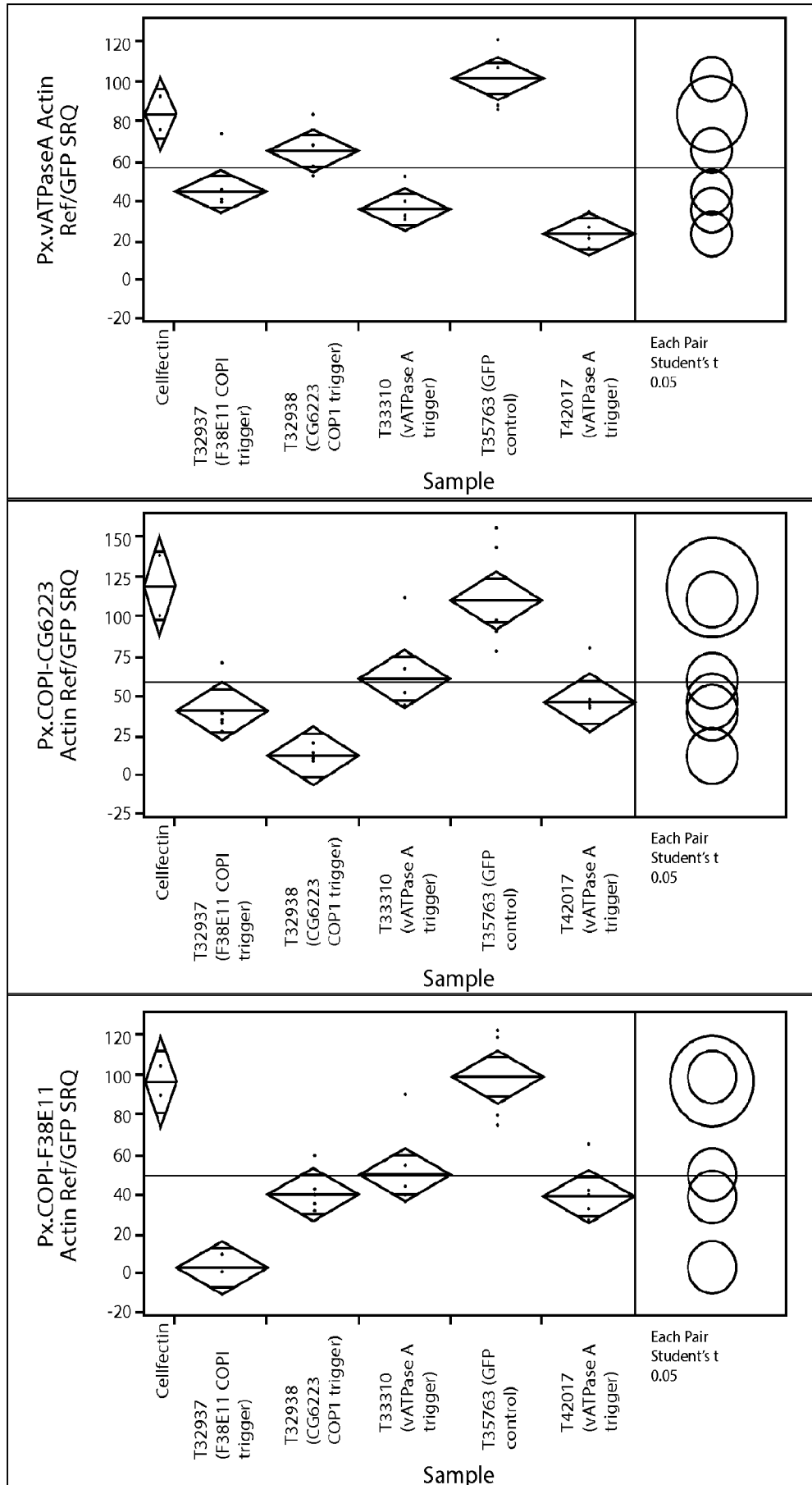


Figure 2

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