

CONTROL OF PESTS IN PLANTS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to U.S. provisional patent application
5 Serial No. 61/246,597 filed 29 September 2009, which application is incorporated
herein by reference.

SEQUENCE SUBMISSION

[0002] The present application is being filed along with a Sequence Listing in
10 electronic format. The Sequence Listing is entitled
2577_197PCT_Sequence_Listing.txt, created on 25 August 2010. The information in
the electronic format of the Sequence Listing is part of the present application and is
incorporated herein by reference in its entirety.

15 BACKGROUND OF THE INVENTION

[0003] The present invention relates to the field of controlling pests, such as insects,
using a virus to express pest genes in hosts. More specifically, the present invention
relates to a method for rapidly screening for pest genes which can lead to mortality of
the pest when the pest has ingested host tissues expressing virus-linked pest gene
20 sequences. The present invention also relates to a method for controlling pests by viral
expression of target pest sequences to modify endogenous expression of pest genes in
cells or tissues of the pest.

[0004] The publications and other materials used herein to illuminate the background of the invention or provide additional details respecting the practice, are incorporated by reference, and for convenience are respectively grouped in the Bibliography.

[0005] The earth is full of diverse pest problems and a larger number of methods
5 have been utilized for attempting to control infestations by these pests. Compositions for controlling infestations by microscopic pests such as bacteria, fungi and viruses have been provide in the form of antibiotic compositions, antiviral compositions, and antifungal compositions. Compositions for controlling infestations by larger pests such as nematodes, flatworm, roundworms, pinworms, heartworms, tapeworms,
10 trypanosomes, schistosomes, and the like have typically been in the form of chemical compositions which can either be applied to the surfaces of substrates on which pests are known to infest, or to be ingested by an infested animal in the form of pellets, powders, tablets, pastes, or capsules and the like.

[0006] Commercial crops are often the targets of insect attack. Chemical pesticides
15 have been very effective in eradicating pest infestations. However, it is well known that there are several disadvantages to using chemical pesticidal agents. First of all, chemical pesticidal agents are not selective, therefore, on the same time of controlling target insect, because of the lack of selectivity, they also exert their effects on non-target fauna, often effectively sterilizing a field for a period of time over which the pesticidal
20 agents have been applied. Second, chemical pesticidal agents persist in the environment and generally are slow to be metabolized, if at all. They accumulate in the food chain, and finally in the high predator species, such as human being, where these pesticidal agents act as a mutagens and/ or carcinogens, to cause irreversible and deleterious genetic modifications. This kind of accumulation causes to higher predator pest

resistance. Thus there has been a long felt need for environmentally friendly methods for controlling or eradicating insect infestation on or in plants, i.e., methods which are selective, environmental inset, non-persistent, and biodegradable, and that fit well into pest resistance management schemes. These environmental safe compositions, including

5 *Bacillus thuringiensis* (Bt) bacteria and transgenic plants expressing one or more genes encoding insecticidal Bt protein, have been remarkably efficient in controlling insect pest infestation. However, with the increased use of *Bt* crops, such as corn and cotton, comes the threat that target pests may develop resistance to these toxins. Although Bt-resistant insect populations have not yet been observed in the field, resistant strains have

10 been developed in the laboratory by selection with toxin-impregnated diet (McGaughy, 1985). Thus, beside to work out ways to delay Bt resistance development, it is greatly valuable to find a different mode of action to control pest infestations by single use or combined use with Bt expression strategy.

[0007] Double stranded RNA (dsRNA) mediated inhibition of specific genes in

15 eukaryotic organisms, has been used to silence genes and study gene function in few insect such as coleopteran *Tribolium castaneum* (Bucher et al., 2002) previously.

Normal delivery of dsRNA to mediate dsRNA-involved genetic control includes generating transgenic insects that express double stranded RNA molecules or injecting dsRNA solutions into the insect body or within the egg sac prior to or during embryonic

20 development. It is widely believed this method of transgenic expression in insect for controlling insect on field crop would be impractical to provide dsRNA molecules in the diet of most invertebrate pest species or to inject compositions containing dsRNA into the bodies of invertebrate pest. Recently, methods using transgenic plants to generate dsRNA have shown that transgenically expressed dsRNA can enhanced resistance to

the economically important agricultural pests cotton bollworm (*Helicoverpa armigera*; Lepidoptera) and Western corn rootworm (WCR; *Diabrotica virgifera virgifera* LeConte; Coleoptera) (Baum et al., 2007; Mao et al., 2007; U.S. published patent application No. 2006/0021087). These references have shown the possibility of using
5 dsRNA in the protection of crops against insect infestation. This approach holds great promise for the future because it allows a wide range of potential targets for suppression of gene expression in the insect to be exploited. However, at this moment, these identified genes are still not as effective as transgenic maize engineered to produce a modified Cry3Bb *Bacillus thuringiensis* (Bt) toxin.

10 [0008] Therefore the key to compete or even to replace Bt transgenic plant technology is to identify one or more suitable insect genes by feeding expressed dsRNA *in vivo* in specific plant-insect pair in the content of huge gene number for each agriculturally important pest (for example, 16,404 gene for the model beetle and pest *Tribolium castaneum*). Previously, one essential technology to evaluate these candidate
15 genes is stable transformation of plants. However, the inefficient production of transgenic plants in some important crops such as cotton limits gene identification on a large scale. Moreover, such procedure is laborious, expensive, time consuming and not suitable for high throughput analysis on a genomic scale.

[0009] RNA silencing in plant first was found as a virus resistance as early as 1928
20 (Wingard, 1928). Wingard described tobacco plants infected with tobacco ringspot virus. The upper leaves had become immune to the virus and consequently were asymptomatic and resistant to secondary infection (Wingard, 1928). Cross protection is therefore widely-used to artificial intervention severe strain virus infection after pre-treated crops with a mild strain in all over the world (Prins et al., 2008). Good examples

of diseases control by cross protection were successfully in citrus tristeza and barley yellow dwarf, respectively (Prins et al., 2008).

[0010] Infection of plants with both RNA and DNA viruses produces virus-related small interfering RNAs (siRNAs). dsRNA, either derived from a replication intermediate or a secondary-structure characters of some single-stranded viral RNA region, can be accumulated to high levels in virus-infected plant cells. In the case of plant DNA viruses, the dsRNA may be formed by annealing of overlapping complementary transcripts (Baulcombe, 2004). Virus-induced gene silencing for plant gene (VIGS) (Ruiz et al., 1998; Burch-Smith et al., 2004) offers an attractive alternative as it allows the investigation of gene functions without plant transformation in plant gene functional analysis. Recombinant viruses can be constructed carrying an inserted partial sequence of a candidate gene. Such recombinant viruses can move systemically in plants, producing dsRNA (further siRNA) including the inserted fragment of candidate gene that can mediate degradation of the endogenous gene transcripts (Brigneti et al., 2004; Burch-Smith et al., 2004), resulting in silencing of the candidate gene expression in inoculated plants. Depending on the plant species, the effects on endogenous gene expression can usually be assayed 1-2 weeks after virus infection. VIGS can be used as an efficient reverse genetics tool for gene/gene family knock-down in a rapid and high-throughout fashion (Nasir et al., 2005). Because the knock-down phenotype is transient and reversible, this method can be used to access functions of genes whose deficiency may cause embryo lethality (Burch-Smith et al., 2004). Using different injection methods, VIGS has been shown to function in different organs, such as leaves (Liu et al., 2002; Burch-Smith et al., 2006), roots (Valentine et al., 2004;

Bhattarai et al., 2007), flowers (Liu et al., 2004; Chen et al., 2005) and even fruits (Fu et al., 2005).

[0011] VIGS systems have been successfully applied to assay for gene functions in plants such as Tobacco Rattle Virus in tobacco (Ratcliff et al., 2001), pepper (Chung et al., 2004), tomato (Liu et al., 2002), *Jatropha* (US Provisional Patent Application No. 61/143,484), cotton (US Provisional Patent Application No. 61/185,631) and poppy (Hileman et al., 2005); Tobacco mosaic virus in tobacco (Hiriart et al., 2003) and pepper (Kim et al., 2007); Potato virus X (PVX) in tobacco (Saitoh and Terauchi, 2002) and potato (Faivre-Rampant et al., 2004); Brome mosaic virus (BMV) in rice, barley and maize (Ding et al., 2006); Barley stripe mosaic virus (BSMV) in barley and wheat (Holzberg et al., 2002); Cucumber mosaic virus in soybean (Nagamatsu et al., 2007); Apple latent spherical virus in tobacco, tomato and soybean (Igarashi et al., 2009; Yamagishi and Yoshikawa, 2009); Bean pod mottle virus in soybean (Zhang and Ghabrial, 2006); Pea early browning virus in *Pisum sativum* (Constantin et al., 2008), *Medicago truncatula* and *Lathyrus odoratus* (Grønlund, et al., 2008); plant DNA virus such as Beet curly top virus (Golenberg et al., 2009) and Tomato yellow leaf curl China virus (Huang et al., 2009). For a general review, see Unver and Budak (2009).

[0012] Thus, it is desired to provide alternative and selective means for controlling pest infestation. It is also desired to develop a method for the transient and high-throughput functional analysis of pest genes on a genomic scale to identify pest genes to target for pest control. The present invention provides a method for identifying target pest genes and also provides alternative and selective means for controlling pest infestations.

SUMMARY OF THE INVENTION

[0013] The present invention relates to the field of controlling pests, such as insects, using a virus to express pest genes in hosts. More specifically, the present invention relates to a method for rapidly screening for pest genes which can lead to mortality of the pest when the pest has ingested host tissues expressing virus-linked pest gene sequences. The present invention also relates to a method for controlling pests by viral expression of target pest sequences to modify endogenous expression of pest genes in cells or tissues of the pest.

[0014] Thus in a first aspect, the present invention provides a method of screening pest genes to identify pest genes which can lead to mortality of the pest when expression of the pest gene is silenced in the pest. In accordance with this aspect, the method comprises:

[0015] (a) inserting a nucleic acid comprising a sequence of a pest gene to be screened into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired host to produce a modified VIGS vector;

[0016] (b) inoculating the host with the modified VIGS vector to produce infected host;

[0017] (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host;

[0018] (d) feeding the host tissue with RNA to pests; and

[0019] (e) determining whether the RNA is toxic to the pest,

[0020] wherein pest toxicity identifies the pest gene as a pest gene that leads to mortality of the pest when the pest gene expression is silenced in the pest.

[0021] In one embodiment, the pest is an insect. In another embodiment, the host is a plant. In an additional embodiment, the VIGS vector is derived from a virus that can infect a desired host, such as a plant. In some embodiments, the modified VIGS vector comprises a single vector that includes the nucleic acid. In other embodiments, the VIGS vector comprises two vectors, one of which is modified to include the nucleic acid. In some embodiments, the virus is a DNA virus. In other embodiments, the virus is an RNA virus. In one embodiment, the host, such as a plant, is inoculated with the modified VIGS vector by inoculation with virus particles. In another embodiment, the host is inoculated by *Agrobacterium* infiltration, such as by syringe infiltration or vacuum infiltration or agro-drench or other inoculation methods to generate virus particles through agrobacterium infection as an intermediate step. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission or by other natural methods of transmission.

[0022] In one embodiment, the RNA is double stranded RNA (dsRNA). In another embodiment, the RNA is small interfering RNA (siRNA), which may be in the form of a short hairpin RNA (shRNA). In a further embodiment, the RNA is single stranded RNA (ssRNA). The RNA may be produced in the host from the modified VIGS vector as described herein.

[0023] In another aspect, the present invention provides a method of controlling pests by viral expression of target pest sequences in a host to modify endogenous expression of pest genes in cells or tissues of the pest. In accordance with this aspect, the method comprises:

[0024] (a) inserting a nucleic acid comprising a sequence of a desired pest gene to be silenced, in the sense or antisense orientation or as an inverted repeat, into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired host to produce a modified VIGS vector;

5 [0025] (b) inoculating the host with the modified VIGS vector to produce infected host; and

[0026] (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host,

[0027] wherein the RNA causes gene silencing in the pest upon ingestion of the
10 RNA produced in the host, whereby pests are controlled.

[0028] In one embodiment, the pest is an insect. In another embodiment, the host is a plant. In an additional embodiment, the VIGS vector is derived from a virus that can infect a desired host, such as a plant. In some embodiments, the modified VIGS vector comprises a single vector that includes the nucleic acid. In other embodiments, the
15 VIGS vector comprises two vectors, one of which is modified to include the nucleic acid. In some embodiments, the virus is a DNA virus. In other embodiments, the virus is an RNA virus. In one embodiment, the host, such as a plant, is inoculated with the modified VIGS vector by inoculation with virus particles. In another embodiment, the host is inoculated by Agrobacterium infiltration, such as by syringe infiltration or
20 vacuum infiltration. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission or by other natural methods of transmission.

[0029] In one embodiment, the RNA is double stranded RNA (dsRNA). In another embodiment, the RNA is small interfering RNA (siRNA), which may be in the form of a short hairpin RNA (shRNA). In a further embodiment, the RNA is single stranded RNA (ssRNA). The RNA may be produced in the host from the modified VIGS vector as described herein.

[0030] In one embodiment, the present invention uses a recombinant plant virus RNA sequence expressed in host plants to effect heterologous silencing in insect pests which ingest these RNA sequences. The invention is not restricted to the use of any single virus, such as TRV, but also includes the use of any plant DNA or RNA virus as described hereing, (e.g., Geminivirus, BSMV, BMV, PVX, CMV, etc) in those crops (such as monocot plants, including rice, wheat, barley, maize, etc. and dicot plants including cotton, Jatropha, tobacco, tomato, potato, soybean etc.) and other plants which may be infected by plant viruses.

[0031] In still another embodiment, non-pathogenic, attenuated strains of microorganisms may be used as a carrier for the insect control agents and, in this perspective, the microorganisms carrying such agents are also referred to as insect control agents. The microorganisms may be engineered to express a recombinant plant virus nucleotide sequence with an insect target gene to produce RNA molecules comprising RNA sequences homologous or complementary to RNA sequences typically found within the cells of an insect. Exposure of the insects to the microorganisms result in ingestion of the microorganisms and down-regulation of expression of target genes mediated directly or indirectly by the RNA molecules or fragments or derivatives thereof.

[0032] In a further embodiment, there are mild strains of viruses which do not elicit any symptoms on host plants but can protect the hosts from subsequent infection by a severe virus strain. Such mild virus strains which are said to be attenuated and can confer cross protection have been used in field experiments in several countries for virus resistance. In accordance with the present invention, it is possible to use such mild virus strains to produce pest sequences in host plants. Infected host plants would be resistant to subsequent infection by the severe strain of virus and also tolerant to pests (insect). These mild strains usually produce a weak suppressor of gene silencing so that viral RNAs are not completely degraded by the host machinery. In one embodiment, the present invention utilizes a synthetic TRV to demonstrate that a mild strain of TRV infection induces no obvious morphological phenotypes in cotton and weak phenotypes in tobacco. In a further embodiment, the present invention utilizes recombinant virus to produce pest sequences in host plants by inoculation with virus particles. In another embodiment, the host is inoculated by *Agrobacterium* infiltration, such as by sprayer inoculation, syringe infiltration or vacuum infiltration, or agro-drench or other inoculation methods to generate virus particles through agrobacterium infection as an intermediate step. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission or by other natural methods of transmission. In another embodiment, recombinant virus RNA embedded with target insect gene can be *in vitro* transcribed and were further used to infected plants to confer plants with insect resistance. In additional embodiment, a transgenic event that produces recombinant virus provides protection from invertebrate

pest infestation that is within the preferred effectiveness range against a target pest. In addition, it is well known to the skilled artisan that there are situations where it is advantageous to have such transgenic events within the preferred range of effectiveness.

[0033] It is envisioned that the compositions of the present invention can be incorporated within the seeds of a plant species either as a product of expression from a recombinant gene incorporated into a genome of the plant cells, or incorporated into a coating or seed treatment that is applied to the seed before planting. The plant cell containing a recombinant gene is considered herein to be a transgenic event.

[0034] The present invention also includes seeds and plants having more than one transgenic event. Such combinations are referred to as "stacked" transgenic events.

These stacked transgenic events can be events that are directed at the same target pest, or they can be directed at different target pests. In one preferred method, a seed having the ability to express a Cry3 protein or insecticidal variant thereof also has the ability to express at least one other insecticidal agent including but not limited to a protein that is different from a Cry3 protein and/or an RNA molecule the sequence of which is derived from the sequence of a recombinant virus RNA expressed in a target plant and that forms silencing upon expressing in the seed or cells of a plant grown from the seed, wherein the ingestion of one or more cells of the plant by the target pest results in the suppression of expression of the RNA in the cells of the target pest.

BRIEF DESCRIPTION OF THE FIGURES

[0035] Figure 1 illustrates a rapid recombinant virus method to screen for insect genes which can lead to mortality when expression is silenced.

[0036] Figure 2 illustrates a transient VIGS method for controlling insects in accordance with one embodiment of the present invention.

[0037] Figure 3 shows sTRV-mediated silencing of cotton bollworm (CBM) genes and control of insect infestation on cotton. Numbers represent mean relative values average mortality after 13 day-feeding with systemic leaves of plants treated with various sTRV vectors from at least 3 independent experiments with standard error. For each feeding experiment, synchronous larvae (2-3 instar) were selected, weighed individually and divided into groups; each group contained 6-18 individuals.

[0038] Figure 4 shows sTRV-mediated silencing of CBM genes and control of insect infestation on *N. benthamiana*. Numbers represent mean relative values average mortality after 13 day-feeding with systemic leaves of plants treated with various sTRV vectors from at least 3 independent experiments with standard error. For each feeding experiment, synchronous larvae (2-3 instar) were selected, weighed individually and divided into groups; each group contained 6-18 individuals.

[0039] Figure 5 shows sTRV-mediated silencing of CBM genes and control of insect infestation by sense, antisense and hairpin RNA structure on cotton. Numbers represent mean relative values average mortality after 13 day-feeding with systemic leaves of plants treated with various sTRV vectors.

[0040] Figure 6 shows sTRV-mediated silencing of CBM genes and control of insect infestation by sense, antisense and hairpin RNA structure on *N. benthamiana*. Numbers represent mean relative values average mortality after 13 day-feeding with systemic leaves of plants treated with various sTRV vectors.

DETAILED DESCRIPTION OF THE INVENTION

[0041] The present invention relates to the field of controlling pests, such as insects, using a virus to express pest genes in hosts. More specifically, the present invention relates to a method for rapidly screening for pest genes which can lead to mortality of the pest when the pest has ingested host tissues expressing virus-linked pest gene sequences. The present invention also relates to a method for controlling pests by viral expression of target pest sequences to modify endogenous expression of pest genes in cells or tissues of the pest.

[0042] The present invention utilizes recombinant DNA technologies to silence or inhibit expression of a target sequences in the cell of a pest, by feeding to the pest one or more viral RNA sequences carrying (a) a portion (part) of a target coding sequence, (b) a portion of a target 5' UTR sequence, (c) a portion of a target 3' UTR sequence, (d) a portion of a target 5' UTR and a portion of a target coding sequence or (e) a portion of a target coding sequence and a portion of a target 4' UTR sequence in (i) sense, (ii) antisense, or (iii) hairpin double stranded structure, thereby controlling the pest. In one embodiment, the length of the target sequences is in the range of about 50 nucleotides to about 2000 nucleotides and higher. In another embodiment, the length of the target sequences is in the range of about 150 to about 1500 nucleotides. In a further embodiment, the length of the target sequences is about 200 to about 1200 nucleotides. In another embodiment, the length of the target sequences is about 300 to about 1000 nucleotides. In a further embodiment, the length of the target sequences is about 300 to about 800 nucleotides. It is preferred to use a length of the target sequences of about 300 to about 1000 nucleotides. Further specifically, using a recombinant plant DNA or RNA virus sequence expressed in host plants to effect heterologous silencing in insect pests which ingest these corresponding RNA sequences. Compositions containing the

RNA nucleotide sequences of the present invention for use in topical applications onto plants or onto animals or into the environment of an animal to achieve the elimination or reduction of a pest is also described. The present invention also utilizes a virus as an expression vector to transiently transcribe RNA in order to quickly evaluate one or more nucleic acid molecules and recombinant DNA sequences for controlling pests. Using this method, several insect genes that can lead to mortality when silenced are also described.

[0043] The present invention relates to the use of heterologous virus-induced gene silencing (VIGS) to evaluate genes or target sequences in killing insects reliably and rapidly, and in a high-throughput manner. The present invention provides an efficient and reproducible system and procedure for VIGS in insect. In one embodiment, the present invention provides for the co-silencing of two genes to enhance the efficiency of controlling insects.

[0044] The present invention comprises a method of inhibiting expression of a target gene in an invertebrate pest. Inhibition of expression is also referred to herein as gene silencing. Specifically, the present invention comprises a method of modulating or inhibiting expression of one or more target genes in an invertebrate pest, such as an insect, that cause cessation of feeding, growth, development, reproduction and infectivity and eventually result in the death of the pest. Briefly, this method involves the expression in a host, such as a host plant, of a pest-related sequence contained within a viral RNA sequence (dsRNA or siRNA specific for a pest target sequence). In one embodiment, the pest RNA sequence (dsRNA or siRNA) is produced as a result of the replication of a virus containing a nucleic acid comprising a pest target sequence. When host plants are inoculated with a recombinant virus containing a target pest

sequence, the virus will replicate and the pest sequence linked to the viral RNA (dsRNA or siRNA) will accumulate in systemic leaves. The host plant can be inoculated by agrobacterium infiltration (such as syringe infiltration or vacuum infiltration), particle bombardment, virus particles directly, vector transmission (such as Bacteria, Fungi, Nematodes, Arthropods and Arachnids), mechanical transmission (such as rubbing virus-containing preparations into the plant parts such as leaves) or other natural methods of transmission. These leaves are then used as a diet to feed insects. If the viral RNA-linked pest sequence (insect dsRNA or siRNA) is toxic, it would cause mortality when ingested. Therefore, this is a rapid and high-throughput method to screen for insect genes that may lead to mortality when silenced.

[0045] The method comprises introduction of recombinant virus carrying pest sequences (expressed dsRNA or its modified forms such as small interfering RNAs (siRNA)) sequences, into the cells or into the extracellular environment of a pest, such as the midgut of an insect, within an invertebrate pest body wherein the viral RNA-pest sequences (dsRNA or siRNA) enters the cells and inhibits expression of at least one or more target genes and wherein inhibition of the one or more target genes causes cessation of feeding, growth, development, reproduction and infectivity and eventually results in the death of the invertebrate pest. It is specifically contemplated that the methods and compositions of the present will be useful in rapid screening genes useful for limiting or eliminating invertebrate pest infestation in or on any pest host plants, which is also a plant virus host.

[0046] The present invention also relates to a method that, instead of using dsRNA, uses single stranded RNA (ssRNA) (in sense or antisense orientation) in the virus. Although the exact mechanism is not known, it is possible, because of the plant virus,

that the ssRNA can have a replication intermediate or a secondary-structure characteristics of some single-stranded viral RNA region to form dsRNA. However, the key is that the sequence is not presented as a dsRNA construct but as an ssRNA construct in a sense orientation or an antisense orientation. RNA silencing in plants can be derived directly from the ssRNA of viral genome or via the action of host-encoded RNA-dependent RNA polymerases (RDRs) to mediate degradation of homologous RNA sequences including the virus genome. As shown herein, the incorporation of ssRNA in the viral RNA is a potent antipest defense mechanism. The exact mechanism of this potent antipest defense mechanism is not known.

10 [0047] Thus in a first aspect, the present invention provides a method of screening pest genes to identify pest genes which can lead to mortality of the pest when expression of the pest gene is silenced in the pest. A method in accordance with one embodiment of this aspect of the present invention is shown in Figure 1. In accordance with this aspect, the method comprises:

15 [0048] (a) inserting a nucleic acid comprising a sequence of a pest gene to be screened into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired host to produce a modified VIGS vector;

[0049] (b) inoculating the host with the modified VIGS vector to produce infected host;

20 [0050] (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host;

[0051] (d) feeding the host tissue with RNA to pests; and

[0052] (e) determining whether the RNA is toxic to the pest,

[0053] wherein pest toxicity identifies the pest gene as a pest gene that leads to mortality of the pest when the pest gene expression is silenced in the pest.

[0054] In one embodiment, the RNA is double stranded RNA (dsRNA). In another embodiment, the RNA is small interfering RNA (siRNA), which may be in the form of a short hairpin RNA (shRNA). In a further embodiment, the RNA is single stranded RNA (ssRNA). The RNA may be produced in the host from the modified VIGS vector as described herein. In this aspect of the invention, it is preferred that the RNA is dsRNA.

[0055] In one embodiment, the pest is an insect. In another embodiment, the host is a plant. In an additional embodiment, the VIGS vector is derived from a virus that can infect a desired host, such as a plant. In some embodiments, the modified VIGS vector comprises a single vector that includes the nucleic acid. In other embodiments, the VIGS vector comprises two vectors, one of which is modified to include the nucleic acid. In some embodiments, the virus is a DNA virus. In other embodiments, the virus is an RNA virus. In one embodiment, the host, such as a plant, is inoculated with the modified VIGS vector by inoculation with virus particles. In another embodiment, the host is inoculated by *Agrobacterium* infiltration, such as by syringe infiltration or vacuum infiltration. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission, such as by rubbing virus containing preparations into host tissue or by other natural methods of transmission.

[0056] Potential pest genes for screening include those that encode an essential protein, such as one involved in development regulation, physiological or metabolic aspects of the pest. The predicted function of potential pest genes can be selected from the group consisting metabolic pathways such as energy metabolism and detoxification protein, organ or tissue differentiation and development regulation including small RNA biosynthesis, molting processing, and cytoskeleton protein.

[0057] In a second aspect, the present invention provides a method of controlling pests by viral expression of target pest sequences in a host to modify endogenous expression of pest genes in cells or tissues of the pest. A method in accordance with one embodiment of this aspect of the present invention is shown in Figure 2. In accordance with this aspect, the method comprises:

[0058] (a) inserting a nucleic acid comprising a sequence of a desired pest gene to be silenced into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired host to produce a modified VIGS vector;

[0059] (b) inoculating the host with the modified VIGS vector to produce infected host; and

[0060] (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host,

[0061] wherein the RNA causes gene silencing in the pest upon ingestion of the dsRNA produced in the host, whereby pests are controlled.

[0062] In one embodiment, the pest is an insect. In another embodiment, the host is a plant. In an additional embodiment, the VIGS vector is derived from a virus that can infect a desired host, such as a plant. In some embodiments, the modified VIGS vector comprises a single vector that includes the nucleic acid. In other embodiments, the

VIGS vector comprises two vectors, one of which is modified to include the nucleic acid. In some embodiments, the virus is a DNA virus. In other embodiments, the virus is an RNA virus. In one embodiment, the host, such as a plant, is inoculated with the modified VIGS vector by inoculation with virus particles. In another embodiment, the host is inoculated by *Agrobacterium* infiltration, such as by syringe infiltration or vacuum infiltration. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission, such as by rubbing virus containing preparations into host tissue or by other natural methods of transmission. In one embodiment, the pest target gene is as described above.

[0063] In one embodiment, the RNA is double stranded RNA (dsRNA). In another embodiment, the RNA is small interfering RNA (siRNA), which may be in the form of a short hairpin RNA (shRNA). In a further embodiment, the RNA is single stranded RNA (ssRNA). The RNA may be produced in the host from the modified VIGS vector as described herein.

[0064] In one embodiment, the present invention uses a recombinant plant virus RNA sequence expressed in host plants to effect heterologous silencing in insect pests which ingest these RNA sequences. The invention is not restricted to the use of any single virus, such as TRV, but also includes the use of any plant DNA or RNA virus as described hereing, (e.g., Geminivirus, BSMV, BMV, PVX, CMV, etc) in those crops (such as monocot plants, including rice, wheat, barley, maize, etc. and dicot plants including cotton, Jatropha, tobacco, tomato, potato, soybean etc.) and other plants which may be infected by plant viruses.

[0065] In still another embodiment, non-pathogenic, attenuated strains of microorganisms may be used as a carrier for the insect control agents and, in this perspective, the microorganisms carrying such agents are also referred to as insect control agents. The microorganisms may be engineered to express a recombinant plant virus nucleotide sequence with an insect target gene to produce RNA molecules comprising RNA sequences homologous or complementary to RNA sequences typically found within the cells of an insect. Exposure of the insects to the microorganisms result in ingestion of the microorganisms and down-regulation of expression of target genes mediated directly or indirectly by the RNA molecules or fragments or derivatives thereof.

[0066] In a further embodiment, there are mild strains of viruses which do not elicit any symptoms on host plants but can protect the hosts from subsequent infection by a severe virus strain. Such mild virus strains which are said to be attenuated and can confer cross protection have been used in field experiments in several countries for virus resistance. In accordance with the present invention, it is possible to use such mild virus strains to produce pest sequences in host plants. Infected host plants would be resistant to subsequent infection by the severe strain of virus and also tolerant to pests (insect). These mild strains usually produce a weak suppressor of gene silencing so that viral RNAs are not completely degraded by the host machinery. In one embodiment, the present invention utilizes a synthetic TRV to demonstrate that a mild strain of TRV infection induces no obvious morphological phenotypes in cotton and weak phenotypes in tobacco. In a further embodiment, the present invention utilizes recombinant virus to produce pest sequences in host plants by inoculation with virus particles. In another embodiment, the host is inoculated by *Agrobacterium* infiltration,

such as by sprayer inoculation, syringe infiltration or vacuum infiltration, or agro-drench or other inoculation methods to generate virus particles through agrobacterium infection as an intermediate step. In a further embodiment, the host is inoculated by particle bombardment. In an additional embodiment, the host is inoculated by vector transmission, such as by Bacteria, Fungi, Nematodes, Arthropods and Arachnids. In another embodiment, the host is inoculated by mechanical transmission or by other natural methods of transmission. In another embodiment, recombinant virus RNA embedded with target insect gene can be *in vitro* transcribed and were further used to infected plants to confer plants with insect resistance. In additional embodiment, a transgenic event that produces recombinant virus provides protection from invertebrate pest infestation that is within the preferred effectiveness range against a target pest. In addition, it is well known to the skilled artisan that there are situations where it is advantageous to have such transgenic events within the preferred range of effectiveness.

[0067] In one embodiment of the present invention, the VIGS vector is a tobacco rattle virus (TRV). In this embodiment, the nucleic acid is inserted to a TRV RNA2 sequence to produce a modified TRV RNA2 vector. A mixed *Agrobacterium* culture of *Agrobacterium* containing a TRV RNA1 vector and *Agrobacterium* containing the modified TRV RNA2 vector is prepared and used to inoculate the host plant. In one embodiment, the vector comprising TRV RNA2 and the vector comprising TRV RNA1 are synthetic plant vectors. In another embodiment, the sequence of the first desired gene is the sequence of a sense strand of the gene. In an additional embodiment, the sequence of the first desired gene is the sequence of an antisense strand of the gene. In an additional embodiment, the sequence of the first desired gene is the sequence of hairpin structure of the gene. In a further embodiment, the nucleic acid further

comprises a sequence of a second desired gene to be silenced. In one embodiment, the second desired gene is host plant virus resistance gene. In another embodiment, the plant virus resistance gene is selected from the group consisting of *RNase III Dicer-like 4 (DCL4)* gene, *RNase III Dicer-like 2 (DCL2)* gene, *RNase III Dicer-like 3 (DCL3)* gene, *ARGONAUTE1 (AGO1)*, *ARGONAUTE71 (AGO7)*, *RNA-dependent RNA polymerase 1 (RDR1)*, *RNA-dependent RNA polymerase 6 (RDR6)*, *Suppressor of gene silencing 1 (SGS1)*, *Suppressor of gene silencing 3 (SGS3)*, and *Silencing defective 3 (SDE3)*. In a further embodiment, the second desired gene is insect small RNA biosynthesis gene. In another embodiment, the small RNA biosynthesis gene is selected from the group consisting of *Dicer-1 (DCR1)* gene, *Pasha* gene, *Loquacious* gene (*Loqs*), *ARGONAUTE1* gene (*AGO1*), *ARGONAUTE2* gene (*AGO2*), *ARGONAUTE3* gene (*AGO3*), *Piwi* gene, *Stellate* gene, *Aubergine* gene (*Aub*). In a further embodiment, the nucleic acid comprises sequences of more than two desired genes to be silenced.

15 [0068] As described herein, the present invention relates to a method of inhibiting expression of a target gene in an invertebrate pest. Specifically, the present invention comprises a method of modulating or inhibiting expression of one or more target genes in an invertebrate pest that cause cessation of feeding, growth, development, reproduction and infectivity and eventually result in the death of the insect. The method
20 comprises introduction of virus expressed partial single-stranded RNA (ssRNA) or its modified forms such as small interfering RNAs (siRNA) sequences, into the cells or into the extracellular environment, such as the midgut, within an invertebrate pest body wherein the dsRNA or siRNA enters the cells and inhibits expression of at least one or more target genes and wherein inhibition of the one or more target genes exerts a

deleterious effect upon the invertebrates pest. In addition to controlling pests, the present invention is useful in rapidly screening genes to identify those useful for limiting or eliminating invertebrate pest infestation in or on any host, such as a plant. The present invention is illustrated herein with reference to cotton bollworm

5 (*Helicoverpa armigera*; Lepidoptera) as the pest. However, it is understood that the invention is applicable to any pest, such as those disclosed herein. The present invention is also illustrated using cotton or tobacco as the host plant. However, it is understood that the invention is applicable to any host plant, such as those disclosed herein. The present invention is further illustrated using TRV as the VIGS system.
10 However, it is understood that the invention can use any VIGS system, such as those disclosed herein.

[0069] Infection of plants with both RNA and DNA viruses produces virus-related small interfering RNAs (siRNAs). dsRNA, either derived from a replication intermediate or a secondary-structure characters of some single-stranded viral RNA
15 region, can be accumulated to high level in virus-infected plant cells. In the case of plant DNA viruses, the dsRNA may be formed by annealing of overlapping complementary transcripts (Baulcombe, 2004). Virus-induced gene silencing (VIGS) (Ruiz *et al.*, 1998; Burch-Smith *et al.*, 2004) offers an attractive alternative as it allows the investigation of gene functions without plant transformation. Recombinant viruses
20 can be constructed carrying an inserted partial sequence of a candidate gene. Such recombinant viruses can move systemically in plants, producing dsRNA (which can be modified to siRNA) including the inserted fragment of candidate gene that can mediate degradation of the endogenous gene transcripts (Brigneti *et al.*, 2004; Burch-Smith *et al.*, 2004), resulting in silencing of the candidate gene expression in inoculated plants.

Depending on the plant species, the effects on endogenous gene expression can usually be assayed 1-2 weeks after virus infection. VIGS can be used as an efficient reverse genetics tool for gene/gene family knock-down in a rapid and high-throughout fashion (Nasir *et al.*, 2005). Because the knock-down phenotype is transient and reversible, this method can be used to access functions of genes whose deficiency may cause embryo lethality (Burch-Smith *et al.*, 2004). Using different injection methods, VIGS has been shown to function in different organs, such as leaves (Liu *et al.*, 2002; Burch-Smith *et al.*, 2006), roots (Valentine *et al.*, 2004; Bhattarai *et al.*, 2007), flowers (Liu *et al.*, 2004; Chen *et al.*, 2005) and even fruits (Fu *et al.*, 2005).

[0070] The TRV VIGS system has been successfully applied to assay for gene functions in herbaceous plants. such as Tobacco Rattle Virus in tobacco (Ratcliff *et al.*, 2001), pepper (Chung *et al.*, 2004), tomato (Liu *et al.*, 2002), barley (Holzberg *et al.*, 2002), soybean (Fu *et al.*, 2006; Nagamatsu *et al.*, 2007), *Medicago truncatula* (Constantin *et al.*, 2008) and poppy (Hileman *et al.*, 2005), as well as others.

[0071] The TRV VIGS system has been successfully applied in some plants such as *Arabidopsis* (Burch-Smith *et al.*, 2006), *Capsicum annuum* (Chung *et al.*, 2004), *Lycopersicon esculentum* (Liu *et al.*, 2002; Dinesh Kumar *et al.*, 2007), *Petunia hybrida* (Chen *et al.*, 2005), *Nicotiana benthamian* (Liu *et al.*, 2002), *Solanum tuberosum* (Brigneti *et al.*, 2004), *Jatropha curcas* (U.S. Provisional Patent Application No.

61/143,484), cotton species (U.S. Provisional Patent Application No. 61/185,631), as well as other putative plants listed in Plant Virus Online ([http colon backslash backslash image dot fs dot uidaho dot edu backslash vide backslash descr808 dot htm](http://colon.backslash.backslash.image.dot.fs.dot.uidaho.dot.edu.backslash.vide.backslash.descr808.dot.htm)).

[0072] Thus, VIGS systems that can be used in accordance with the present invention include, but are not limited to, Tobacco Rattle Virus in tobacco (Ratcliff *et al.*,

2001), pepper (Chung et al., 2004), tomato (Liu et al., 2002), Jatropha (US Provisional Patent Application No. 61/143,484), cotton (US Provisional Patent Application No. 61/185,631) and poppy (Hileman et al., 2005); Tobacco mosaic virus in tobacco (Hiriart et al., 2003) and pepper (Kim et al., 2007); PVX in tobacco (Saitoh and Terauchi, 2002) and potato (Faivre-Rampant et al., 2004); BMV in rice, barley and maize (Ding et al., 2006); BSMV in barley and wheat (Holzberg et al., 2002); Cucumber mosaic virus in soybean (Nagamatsu et al., 2007); Apple latent spherical virus in tobacco, tomato and soybean (Igarashi et al., 2009; Yamagishi and Yoshikawa, 2009); Bean pod mottle virus in soybean (Zhang and Ghabrial, 2006); Pea early browning virus in *Pisum sativum* (Constantin et al., 2008), *Medicago truncatula* and *Lathyrus odoratus* (Grønlund, et al., 2008); plant DNA virus such as Beet curly top virus (Golenberg et al., 2009) and Tomato yellow leaf curl China virus (Huang et al., 2009). For a general review, see Unver and Budak (2009).

[0073] Insects that may cause damage in plants generally belong to three categories based upon their methods of feeding and these three categories are, respectively, chewing, sucking and boring insects that belong to the Orders Coleoptera, Lepidoptera, Diptera, Orthoptera, Heteroptera, Ctenophalides, Arachnidiae, and Hymenoptera. It has been found that the present method is useful to protect seeds and plants against a wide array of agricultural insect pests.

[0074] When an insect is the target pest for the present invention, such pests include but are not limited to: from the order **Lepidoptera**, for example, *Acleris* spp., *Adoxophyes* spp., *Aegeria* spp., *Agrotis* spp., *Alabama argillaceae*, *Amylois* spp., *Anticarsia gemmatalis*, *Archips* spp., *Argyrotaenia* spp., *Autographa* spp., *Busseola fusca*, *Cadra cautella*, *Carposina nipponensis*, *Chilo* spp., *Choristoneura* spp., *Clysia*

- ambiguella, *Cnaphalocrocis* spp., *Cnephasia* spp., *Cochylis* spp., *Coleophora* spp.,
Crocidolomia binotalis, *Cryptophlebia* leucotreta, *Cydia* spp., *Diatraea* spp., *Diparopsis*
castanea, *Earias* spp., *Ephestia* spp., *Eucosma* spp., *Eupoecilia* ambiguella, *Euproctis*
spp., *Euxoa* spp., *Grapholita* spp., *Hedya* nubiferana, *Heliothis* spp., *Hellula* undalis,
5 *Hyphantria* cunea, *Keiferia* lycopersicella, *Leucoptera* scitella, *Lithocollethis* spp.,
Lobesia botrana, *Lymantria* spp., *Lyonetia* spp., *Malacosoma* spp., *Mamestra* brassicae,
Manduca sexta, *Operophtera* spp., *Ostrinia* Nubilalis, *Pammene* spp., *Pandemis* spp.,
Panolis flammea, *Pectinophora* gossypiella, *Phthorimaea* operculella, *Pieris* rapae, *Pieris*
spp., *Plutella* xylostella, *Prays* spp., *Scirpophaga* spp., *Sesamia* spp., *Sparganothis* spp.,
10 *Spodoptera* spp., *Synanthedon* spp., *Thaumetopoea* spp., *Tortrix* spp., *Trichoplusia* ni
and *Yponomeuta* spp.;
- [0075] from the order **Coleoptera**, for example, *Agriotes* spp., *Anthonomus* spp.,
Atomaria linearis, *Chaetocnema* tibialis, *Cosmopolites* spp., *Curculio* spp., *Dermestes*
spp., *Diabrotica* spp., *Epilachna* spp., *Eremnus* spp., *Leptinotarsa* decemlineata,
15 *Lissorhoptrus* spp., *Melolontha* spp., *Oryzaephilus* spp., *Otiorhynchus* spp., *Phlyctinus*
spp., *Popillia* spp., *Psylliodes* spp., *Rhizopertha* spp., *Scarabeidae*, *Sitophilus* spp.,
Sitotroga spp., *Tenebrio* spp., *Tribolium* spp. and *Trogoderma* spp.;
- [0076] from the order **Orthoptera**, for example, *Blattella* spp., *Gryllotalpa*
spp., *Leucophaea* maderae, *Locusta* spp., *Periplaneta* spp., and *Schistocerca* spp.;
- 20 [0077] from the order **Isoptera**, for example, *Reticulitermes* spp; from the order
Psocoptera, for example, *Liposcelis* spp.;
- [0078] from the order **Anoplura**, for example, *Haematopinus* spp., *Linognathus* spp.,
Pediculus spp., *Pemphigus* spp. and *Phylloxera* spp.;

- [0079] from the order **Mallophaga**, for example, *Damalinea* spp. and *Trichodectes* spp.;
- [0080] from the order **Thysanoptera**, for example, *Franklinella* spp., *Hercinothrips* spp., *Taeniothrips* spp., *Thrips palmi*, *Thrips tabaci* and *Scirtothrips aurantii*;
- 5 [0081] from the order **Heteroptera**, for example, *Cimex* spp., *Distantiella theobroma*, *Dysdercus* spp., *Euchistus* spp., *Eurygaster* spp., *Leptocorisa* spp., *Nezara* spp., *Piesma* spp., *Rhodnius* spp., *Sahlbergella singularis*, *Scotinophara* spp., *Triatoma* spp., *Miridae* family spp. such as *Lygus hesperus* and *Lygus lineoloris*, *Lygaeidae* family spp. such as *Blissus leucopterus*, and *Pentatomidae* family spp.;
- 10 [0082] from the order **Homoptera**, for example, *Aleurothrixus floccosus*, *Aleyrodes brassicae*, *Aonidiella* spp., *Aphididae*, *Aphis* spp., *Aspidiotus* spp., *Bemisia tabaci*, *Ceroplaster* spp., *Chrysomphalus aonidium*, *Chrysomphalus dictyospermi*, *Coccus hesperidum*, *Empoasca* spp., *Eriosoma larigerum*, *Erythroneura* spp., *Gascardia* spp., *Laodelphax* spp., *Lacanium corni*, *Lepidosaphes* spp., *Macrosiphus* spp., *Myzus* spp.,
- 15 *Nehotettix* spp., *Nilaparvata* spp., *Paratoria* spp., *Pemphigus* spp., *Planococcus* spp., *Pseudaulacaspis* spp., *Pseudococcus* spp., *Psylla* spp., *Pulvinaria aethiopica*, *Quadraspidotus* spp., *Rhopalosiphum* spp., *Saissetia* spp., *Scaphoideus* spp., *Schizaphis* spp., *Sitobion* spp., *Trialeurodes vaporariorum*, *Triozae treae* and *Unaspis citri*;
- [0083] from the order **Hymenoptera**, for example, *Acromyrmex*, *Atta* spp., *Cephus* spp., *Diprion* spp., *Diprionidae*, *Gilpinia polytoma*, *Hoplocampa* spp., *Lasius* spp.,
- 20 *Monomorium pharaonis*, *Neodiprion* spp., *Solenopsis* spp. and *Vespa* spp.;
- [0084] from the order **Diptera**, for example, *Aedes* spp., *Antherigona soccata*, *Bibio hortulanus*, *Calliphora ethrocephala*, *Ceratitis* spp., *Chrysomyia* spp., *Culex* spp., *Cuterebra* spp., *Dacus* spp., *Drosophila melanogaster*, *Fannia* spp., *Gastrophilus* spp.,

Glossina spp., Hypoderma spp., Hyppobosca spp., Liriomyza spp., Lucilia spp., Melanagromyza spp., Musca spp., Oestrus spp., Orseolia spp., Oscinella frit, Pegomyia hyoscyami, Phorbia spp., Rhagoletis pomonella, Sciara spp., Stomoxys spp., Tabanus spp., Tannia spp. and Tipula spp.;

5 **[0085]** from the order **Siphonaptera**, for example, Ceratophyllus spp. and Xenopsylla cheopis; and

[0086] from the order **Thysanura**, for example, Lepisma saccharina.

[0087] It is envisioned that the compositions of the present invention can be incorporated within the seeds of a plant species either as a product of expression from a
10 recombinant gene incorporated into a genome of the plant cells, or incorporated into a coating or seed treatment that is applied to the seed before planting. The plant cell containing a recombinant gene is considered herein to be a transgenic event.

[0088] The present invention also includes seeds and plants having more than one transgenic event. Such combinations are referred to as "stacked" transgenic events.

15 These stacked transgenic events can be events that are directed at the same target pest, or they can be directed at different target pests. In one preferred method, a seed having the ability to express a Cry3 protein or insecticidal variant thereof also has the ability to express at least one other insecticidal agent including but not limited to a protein that is different from a Cry3 protein and/or an RNA molecule the sequence of which is derived
20 from the sequence of a recombinant virus RNA expressed in a target plant and that forms silencing upon expressing in the seed or cells of a plant grown from the seed, wherein the ingestion of one or more cells of the plant by the target pest results in the suppression of expression of the RNA in the cells of the target pest.

[0089] The practice of the present invention employs, unless otherwise indicated, conventional techniques of chemistry, molecular biology, microbiology, recombinant DNA, genetics, immunology, cell biology, cell culture and transgenic biology, which are within the skill of the art. See, e.g., Maniatis *et al.*, 1982, *Molecular Cloning* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Sambrook *et al.*, 1989, *Molecular Cloning*, 2nd Ed. (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Sambrook and Russell, 2001, *Molecular Cloning*, 3rd Ed. (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Ausubel *et al.*, 1992), *Current Protocols in Molecular Biology* (John Wiley & Sons, including periodic updates); Glover, 1985, *DNA Cloning* (IRL Press, Oxford); Russell, 1984, *Molecular biology of plants: a laboratory course manual* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.); Anand, *Techniques for the Analysis of Complex Genomes*, (Academic Press, New York, 1992); Guthrie and Fink, *Guide to Yeast Genetics and Molecular Biology* (Academic Press, New York, 1991); Harlow and Lane, 1988, *Antibodies*, (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); *Nucleic Acid Hybridization* (B. D. Hames & S. J. Higgins eds. 1984); *Transcription And Translation* (B. D. Hames & S. J. Higgins eds. 1984); *Culture Of Animal Cells* (R. I. Freshney, Alan R. Liss, Inc., 1987); *Immobilized Cells And Enzymes* (IRL Press, 1986); B. Perbal, *A Practical Guide To Molecular Cloning* (1984); the treatise, *Methods In Enzymology* (Academic Press, Inc., N.Y.); *Methods In Enzymology*, Vols. 154 and 155 (Wu et al. eds.), *Immunochemical Methods In Cell And Molecular Biology* (Mayer and Walker, eds., Academic Press, London, 1987); *Handbook Of Experimental Immunology*, Volumes I-IV (D. M. Weir and C. C. Blackwell, eds., 1986); Riott, *Essential Immunology*, 6th Edition, Blackwell Scientific Publications, Oxford, 1988;

- Fire et al., *RNA Interference Technology: From Basic Science to Drug Development*, Cambridge University Press, Cambridge, 2005; Schepers, *RNA Interference in Practice*, Wiley-VCH, 2005; Engelke, *RNA Interference (RNAi): The Nuts & Bolts of siRNA Technology*, DNA Press, 2003; Gott, *RNA Interference, Editing, and Modification: Methods and Protocols (Methods in Molecular Biology)*, Human Press, Totowa, NJ, 2004; Sohail, *Gene Silencing by RNA Interference: Technology and Application*, CRC, 2004.

EXAMPLES

- 10 [0090] The present invention is described by reference to the following Examples, which is offered by way of illustration and is not intended to limit the invention in any manner. Standard techniques well known in the art or the techniques specifically described below were utilized.

15 EXAMPLE 1

Experimental Procedures

- [0091] *Plant seedlings*: Tobacco (*Nicotiana benthamiana*) and cotton (*Gossypium hirsutum* L. cv. *Coker 312*) seeds were propagated in Singapore and were germinated in a greenhouse. Plants of tobacco and cotton were grown in presterilized soil at 25°C on a 20 16-h-day/8-h-night cycle. Tobacco seedlings with 3-5 true leaves were used for agroinjection and cotton seedlings with 2-3 true leaves were used for vacuum infiltration.

- [0092] *Cotton bollworm*: Cotton bollworm (*Helicoverpa armigera*) eggs were obtained from Chinese Academy of Agricultural Sciences and reared in the laboratory at

25 °C and 70% relative humidity on a 14-h-day/10-h-night cycle. The larvae were fed on a modified artificial diet as described. Leaves of tobacco plants (1-2 weeks post-agroinjection) or cotton plants (2-3 weeks post vacuum-infiltration) were used for feeding experiments. For each feeding experiment, synchronous larvae were selected, weighed individually and divided into groups; each group contained 6-12 individuals. After feeding on different diets for indicated days, larvae were weighed and death of each individual was recorded. Statistics of data was performed with student *t*-test in the Excel program.

[0093] *Synthetic TRV RNA1 expression vector*: Synthetic TRV1 vector full length (7756bp) sequence including: SphI site, T-DNA right border sequence (152bp), the duplicated cauliflower mosaic virus (CaMV) 35S enhancer region (752bp) (Shi et al., 1997) the TRV Ppk20 strain RNA1 (6791bp), Subterranean Clover Mottle Virus satellite RNA ribozyme sequence (46bp) and SmaI site sequence. This full length sequence was divided into two parts by an endogenous SalI site. The two parts were separately synthesized and cloned into pGH vector to give two vectors pGH-YeJ-V1-1 and pGH-YeJ-V1-2. The synthetic TRV RNA1 fragments, V1-1, released from pGH-YeJ-V1-1 by treatment with SphI and SalI enzymes, and V1-2, released from pGH-YeJ-V1-2 by treatment with SalI and SmaI enzymes, were linked with the pBIN121 vector treated with SphI and EcoICRI enzymes. The new synthetic TRV RNA1 vector was named psTRV1001. The sequence of the synthetic psTRV1001 is set forth in SEQ ID NO:1. The synthetic TRV RNA1 sequence is the same as the published TRV RNA1 sequence.

[0094] *Synthetic TRV RNA2 expression vector*: Synthetic TRV2 vector full length (2915bp) sequence including: HindIII site, the duplicated cauliflower mosaic virus

(CaMV) 35S enhancer region (752bp) (Shi et al., 1997) the TRV strain ppk20 RNA2 5'-sequence (1639bp), multiple cloning site (61bp), the TRV strain ppk20 RNA2 3'-sequence (396bp), HpaI site. The full length sequence was synthesized and cloned into pGH vector give pGH-YeJ-V2. The synthetic TRV RNA2 fragment V2 was linked into the pCAMBIA0390 by HindIII and HpaI sites. The new synthetic TRV RNA2 vector was named psTRV2001. The sequence of the synthetic psTRV2002 is set forth in SEQ ID NO:2.

[0095] *Gene cloning and vector construction:* Gene sequences of three genes *HaGST1*, *HaCHT*, *HaCYP6AE14*, were obtained from the GenBank. Another four genes were cloned by PCR using designed primers of conserved regions shared by homologous gene sequences of *Drosophila melanogaster* (*HaDCR1*, *HaCG4572*, *HaTub* and *HaVATP*) or plant (*NbDCL4*). For single gene VIGS, all candidate genes were amplified by PCR from cDNA products of *H. armigera* (CBM) whole body samples, and cloned into the XbaI and BamHI sites of the synthetic vector psTRV2001. For co-silencing vectors, cDNA fragment of the second gene was inserted into KpnI and XhoI sites of the vector. The primers used in cloning the genes are set forth in Table 1, which also includes reference to the sequence of the cloned gene. *Jatropha curcin* gene, encoded for *Jatropha*-specific toxin, was used as a non-insect sequence control in CBM larval feeding experiments (U.S. Provisional Patent Application No. 61/143,484, filed on 9 January 2009; International Patent Application No. PCT/SG2009/000481 filed on 16 December 2009 and published as WO 2010/080071). Meanwhile, the δ -*cadinene synthase* gene (*DCS*), encoded an enzyme important for biosynthesis of insect inhibitory toxic phytochemicals gossypol, was used as a positive control in feeding experiments

(U.S. Provisional Patent Application No. 61/185,631 filed on 10 June 2009;
International Patent Application No. PCT/SG2010/000220 filed on 10 June 2010).

[0096] *Antisense and hairpin structure construction:* Antisense sequence of *HaTub*, which is set forth as SEQ ID NO:29, was PCR-amplified using designed primers as set forth in SEQ ID NO:27 and SEQ ID NO:28 (see Table 1) when the psTRV2:*HaTub* plasmid as template. The amplified PCR product was further cloned into the XbaI and BamHI sites of the synthetic vector psTRV2001. For *hpHaTub* hairpin structure construction, sense fragment was amplified by PCR with PCR primers set forth as SEQ ID NO:30 and SEQ ID NO:31 (see Table 1) and further cloned into the BamHI and EcoRI sites of pSK-intron (Guo et al., 2003), followed insertion of the antisense fragment amplified with PCR primers set forth as SEQ ID NO:32 and SEQ ID NO:33 (see Table 1). The *hpHaTub* hairpin structure was subcloned into the BamHI and XhoI sites of psTRV2001 to give psTRV:*hpHaTub*.

TABLE 1

Gene Primers and Gene Sequences

Gene	Primers: Sequence (5' → 3') (SEQ ID NO:)	Cloned Gene (SEQ ID NO:)
<i>HaCYP6A</i> <i>E14</i>	F: aatatctagacctccggaagatgaagaacatgttcc (3) R: ctccggatccgggaagaactccggg (4)	859 bp (5) GenBank: DQ986461
<i>HaVATP</i>	F: ggaatctagacgacgtgggtatcgtgcaa (6) R: gagaagttgtggggatccgccaac (7)	763 bp (8)

<i>HaTub</i>	F: ataattctagacaagcctcttaccgggtcgcgc (9) R: aatgcggatccagtgctccaccgaaggagtg (10)	506 bp (11)
<i>HaCG457</i> 2	F: ctatggtaccagttcttctggtactttccygc (12) R: ccattctcgagccatgtgtcccgcgttctgaccatgayctccac (13)	1075 bp (14)
<i>HaCHT1</i>	F: aaaatctagacctgctccgtacaccaatgtactg (15) R: gtaaggatccgtaatcctcttcagaattgcagacg (16)	693 bp (17) GenBank: AY325496
<i>HaDCR1</i>	F: caatggtaccgtgccgaaggctctcagcgacatattcga (18) R: gtctctcgagcgccagtttggcggcggcgcgttt (19)	330 bp (20) Co-silencing with <i>HaTub</i>
<i>NbDCL4</i>	F: acatggtaccaagaaaacaattgctgatatagttga (21) R: atccctcgagactgatctcagatcagtcactg (22)	395 bp (23) Co-silencing with <i>HaTub</i>
<i>HaGST1</i>	F: aatatctagaggcacgaagggcgaatcaca (24) R: gtgtggatcctttgcttctggtatcccgggg (25)	641 bp (26) GenBank: EF033109
<i>HaAnti-tub</i>	F: ctagtctagaagtgcctccaccgaaggagtggaag (27) R: tcgcggatccaagcctcttaccgggtcgcgctga (28)	506 bp (29)
<i>HaHp-tub</i>	Sense fragment: F: acgcggatccaagcctcttaccgggtcgcgctga (30)	506 bp (11)

	R: tccggaattcagtgccctccaccgaaggagtgaaga (31)	
	Antisense fragment:	506 bp (29)
	F: acccaagcttagtgccctccaccgaaggagtgaag (32)	
	R: tccgctcgagcaagcctcttaccggtcgcgctgaa (33)	

[0097] *RNA extraction and cDNA synthesis:* 100 mg leaf or CBM tissues was ground in liquid N₂ and extracted with Trizol (Invitrogen). Reverse transcription (RT) reactions were performed to get cDNA as described (Qu et al., 2007).

- 5 [0098] *Agrobacterium infiltration:* Synthetic psTRV1, psTRV2 vectors and its derivatives were introduced into *Agrobacterium* strain AGL1 by electroporation. A 3 ml culture was grown for 24 hr at 28° C in 50 mg/L kanamycin and 25 mg/L rifampicin. On the following day, the culture was inoculated into LB medium containing 50 mg/L kanamycin, 10 mM 2-(N-morpholino)ethanesulfonic acid (MES) and 20 μM
- 10 acetosyringone and grown overnight in a 28° C shaker. *Agrobacterial* cells were collected by centrifugation and resuspended in MMA solution (10 mM MES, 10 mM MgCl₂, 200 μM acetosyringone) to a final OD₆₀₀ of 1.5. The agrobacterial suspension was left at room temperature for 3-4hr without shaking. Before infiltration, *Agrobacterium* culture containing the psTRV1 or psTRV2 vectors was mixed in a 1:1
- 15 ratio. Tobacco plants were infiltrated with cultures by syringe infiltration. For syringe infiltration, agrobacterial-inocula were delivered into the underside of three or four youngest fully-expanded leaf using a 1 ml needleless syringe. For cotton vacuum infiltration, whole plants were submerged into agrobacterial-inocula and subjected to 80-90 kPa vacuum for 2 min, and then quickly releasing the vacuum, letting the

inoculum rapidly enter plant tissues. After vacuum infiltration, excess agrobacterial cell suspension was used to drench the root system of infiltrated plants. Infiltrated plants were grown in a growth chamber at 25° C with 16 hr light/8 hr dark photoperiod cycle.

5 EXAMPLE 2

Identification of Insect Target Sequence

[0099] This example illustrates the identification of nucleotide sequences that, when inserted into the VIGS vector to produce recombinant virus replicating in the host plants, which can be a diet of a cotton bollworm (CBM), are useful for controlling a
10 CBM species insect pest. This example shows that the VIGS system can be used to rapidly screen for genes useful for controlling insects with RNAi technology.

[0100] Insect P450 monooxygenases play a central role in adaptation to plant defense compounds and in developing insecticide resistance. Cotton bollworm requires an elevated level of a gossypol-induced cytochrome P450 (*HaCYP6AE14*) to detoxify
15 gossypol when they grow on cotton, downregulation of *HaCYP6AE14* might reduce larval tolerance of gossypol if larvae are fed plant material that expresses VIGS vector against a target of interest.

[0101] A *CYP6AE14* gene coding sequence derived from GenBank was used to construct a nucleotide sequence encoding in a single strand inserted VIGS vector. A 859
20 bp coding sequence as set forth in SEQ ID NO:5 encoding a part of a *CYP6AE14* sequence was used to construct a primer pair for use in a thermal amplification reaction using CBM cDNA product generated as Example 1. The primer pair as set forth at SEQ ID NO:3 and SEQ ID NO:4 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in

SEQ ID NO:5. To amplify the bollworm sense *CYP6AE14* gene for functional analysis using VIGS in cotton, SEQ ID NO:3 and SEQ ID NO:4 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:5

5 was inserted into psTRV2 in the sense orientation to give psTRV2:*HaCYP6AE14*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaCYP6AE14* vector was vacuum infiltrated into 2-3 true leaf cotton plants.

[0102] After 14 days post inoculation, new systemic leaves of agrobacterium treated
10 cotton plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p < 0.05$) was observed for larvae group feeding on leaves of cotton plants infected with sTRV:*HaCYP6AE14* whose include a sense *HaCYP6AE14* gene sequences as set forth in SEQ ID NO:5 compared to the non-insect sequence control (*JcCurcin*) (Fig. 3). In contrast with *HaCYP6AE14* inhibitory role on larval
15 mortality, a significant reduction ($p < 0.05$) of larval mortality at same period was observed for larvae group feeding on leaves of cotton plants infected with sTRV:*GhDCS* whose include a cotton δ -cadinene synthase gene (*DCS*), an enzyme important for biosynthesis of insect inhibitory toxic phytochemicals gossypol. Much lower gossypol content were detected with High-performance liquid chromatography in
20 cotton leaves infected with sTRV:*GhDCS* (cotton VIGS patent). Lower gossypol content leads to higher survival rate compared with *JcCurcin* control.

[0103] These results indicated that the synthetic sTRV-VIGS systems could be used to induce silencing of desirable endogenous insect genes to inhibit insect infestation. Because *HaCYP6AE14* only leads to weak inhibitory effect on CBM larvae growth,

additional screening is performed to find other useful genes which silencing can lead to a higher inhibitory effect and can be used to generate transgenic plants for biotechnological application in controlling insects.

5 EXAMPLE 3

Identification of Insect Target Sequence

[0104] This example illustrates the identification of nucleotide sequences that, when inserted into the VIGS vector produces recombinant virus replicating in the host plants, which can be a diet of a cotton bollworm, are useful for controlling a cotton bollworm species insect pest.

[0105] Bio-energy metabolism pathway of eukaryotic systems is a basal and essential function for living organism. The vacuolar H^+ -ATPase (V-ATPase) is one of the most fundamental enzymes in nature. It functions in maintaining sufficient levels of ATP in almost every eukaryotic cell and energizes a wide variety of organelles and membranes. Null mutations in genes encoding V-ATPase subunits are likely to be lethal for most eukaryotic cells because primary energization of the vacuolar system by this enzyme drives vital secondary transport processes across membranes of vacuolar-derived organelles. Disruption of genes encoding V-ATPase subunits in *Drosophila* is also lethal. Therefore, V-ATPase may be a useful target for VIGS mediated inhibition of insect.

[0106] V-ATPase is consisting of several subunits. Subunit A, the 68-kDa subunit A binds ATP and catalyzes its hydrolysis. In order to study the inhibition role of VATPase gene in insect growth, we first cloned putative V-ATPase subunit A cotton bollworm gene homologue. We used the amino acid sequence of known tobacco

hornworm (*Manduca sexta*, GenBank accession Number: P31400) subunit A to search the GenBank cotton bollworm (*Helicoverpa armigera*) EST database using TBLASTN. Cotton bollworm EST sequences BU038734 and EE399876 showed significant homology to hornworm V-ATPase catalytic subunit A. Based on this information, we got a contig with 896 bp encoded C terminal domain cotton bollworm V-ATPase subunit A protein. The nucleotide sequence of putative cotton bollworm *VATP-A* gene was listed as SEQ ID NO:34. The nucleotide sequence analysis of *HaVATP-A* gene show 89.4% identity in coding region. Amino acid sequence analysis of cotton bollworm V-ATPase subunit A shows 86.3% identity and 93.9% similarity to hornworm *VATPase subunit A gene*.

[0107] A *VATP-A* gene coding sequence was used to construct a nucleotide sequence encoding *HaVATP-A* in a single strand inserted VIGS vector. A 763 bp coding sequence as set forth in SEQ ID NO:8 encoding a part of a *VATP-A* sequence was used to construct a primer pair for use in a thermal amplification reaction using CBM cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:6 and SEQ ID NO:7 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:8. To amplify the bollworm sense *VATP-A* gene for functional analysis using VIGS in cotton and tobacco, SEQ ID NO:6 and SEQ ID NO:7 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:8 was inserted into psTRV2 in the sense orientation to give psTRV2:*HaVATP*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or

psTRV2:*HaVATP* vector was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0108] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton plants were used to feed to CBM larvae. For tobacco plants, after 7-10 days post inoculation, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p < 0.01$) was observed for larvae group feeding on leaves of cotton plants or tobacco infected with sTRV:*HaVATP* whose include a sense *HaVATP* gene sequences as set forth in SEQ ID NO:8 compared to the non-insect sequence control (*JcCurcin*) (Fig. 3 and Fig. 4). Better insect inhibitory effect has been observed in *HaVATP* cotton treated group than that of *HaCYP6AE14*.

[0109] These results indicated that the synthetic sTRV-VIGS systems could be used to rapidly screen for desirable endogenous insect genes whose silencing can inhibit insect infestation both in cotton and tobacco. These results showed that the VIGS systems may also use in other important crops like Brome mosaic virus in rice and Barley Stripe Mosaic Virus in wheat for screening genes for RNAi controlling insect infestation.

EXAMPLE 4

20 Identification of Insect Target Sequence

[0110] This example illustrates the identification of nucleotide sequences that, when inserted into the VIGS vector produces recombinant virus replicating in the host plants, which can be a diet of a cotton bollworm, are useful for controlling a cotton bollworm species insect pest.

[0111] Chitin is a β (1 $\rightarrow$ 4) homopolymer of N-acetylglucosamine and composes the insect exoskeletons. In insect, chitin supports the cuticles of the epidermis and trachea as well as the peritrophic matrices lining the gut epithelium. Insect growth and morphogenesis are strictly dependent on the capability to remodel chitin-containing structures. Chitin must also be degraded to some extent to mediate the steps involved in the insect molting process. Chitinases are digestive enzymes that break down glycosidic bonds in chitin. Therefore, suppression of chitinase protein formation may be a useful target for VIGS mediated inhibition of insect.

[0112] On the other hand, genes and cDNAs encoding insect chitinases have been identified and characterized from several lepidopteran, dipteran, and coleopteran insects. Even though only one (or occasionally two) chitinase gene had been previously identified in studies involving many insect species, database searches of fully sequenced genomes from *Drosophila*, *Anopheles*, and, more recently, *Tribolium*, have revealed that each of these insects has a rather large family of genes encoding chitinase and chitinase-like proteins with 16–23 members, depending on the species. With our rapid VIGS system in insect, we can quickly evaluate them and identify the gene's function individually. In order to study the inhibitory role of chitinase gene silencing in insect growth, we cloned one chitinase gene homologue. We searched in GenBank and found at least 5 chitinase genes in the bollworm genome. We chose one chitinase gene (GenBank accession number: AY325496) as an example. This *chitin* gene full length cDNA sequence set forth in SEQ ID NO:35.

[0113] A *chitin* gene coding sequence was used to construct a nucleotide sequence encoding in a single strand inserted VIGS vector. A 693 bp coding sequence as set forth in SEQ ID NO:17 encoding a part of a *chitin* sequence was used to construct a primer

pair for use in a thermal amplification reaction using CBM cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:15 and SEQ ID NO:16 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:17. To amplify the bollworm sense *CHT* gene for functional analysis using VIGS in cotton, SEQ ID NO:15 and SEQ ID NO:16 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:17 was inserted into psTRV2 in the sense orientation to give psTRV2:*HaCHT*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaCHT1* vector was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0114] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton plants were used to feed to CBM larvae. For tobacco plants, after 7-10 days post inoculation, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p < 0.01$) was observed for larvae group feeding on leaves of cotton plants or tobacco infected with sTRV:*HaCHT* whose include a sense *HaCHT* gene sequences as set forth in SEQ ID NO:17 compared to the non-insect sequence control (*JcCurcin*) (Fig. 3 and Fig. 4).

Better insect inhibitory effect has been observed in *HaCHT* tobacco treated group than these of *HaCYP6AE14* and *HaVATP*, while a slightly weaker inhibitory effect than that of *HaVATP* was also found in cotton.

EXAMPLE 5

Identification of Insect Target Sequence

[0115] This example illustrates the identification of nucleotide sequences that, when inserted into the VIGS vector produces recombinant virus replicating in the host plants, which can be a diet of a cotton bollworm, are useful for controlling a cotton bollworm species insect pest.

[0116] A glutathione-S-transferase GSTs catalyse the conjugation of reduced glutathione via a sulfhydryl group to electrophilic centers on a wide variety of substrates. This de-toxin activity may function as a transport protein to detoxify endogenous toxin to help insect survival in the living environment filled with phytoalexin. Therefore, suppression of this protein formation may be a useful target for VIGS mediated inhibition. We chose one *GST1* gene (GenBank accession number: EF033109) as an example. This *GST1* gene full length cDNA sequence set forth in SEQ ID NO:36.

[0117] A *GST1* gene coding sequence was used to construct a nucleotide sequence encoding in a single strand inserted VIGS vector. A 641 bp coding sequence as set forth in SEQ ID NO:26 encoding a part of a *GST1* sequence was used to construct a primer pair for use in a thermal amplification reaction using CBM cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:24 and SEQ ID NO:25 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:26. To amplify the bollworm sense *GST1* gene for functional analysis using VIGS in cotton, SEQ ID NO:24 and SEQ ID NO:25 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:26 was inserted into

psTRV2 in the sense orientation to give psTRV2:*HaGST1*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaGST1* vector was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0118] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton plants were used to feed to CBM larvae. For tobacco plants, after 7-10 days post inoculation, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p < 0.01$) was observed for larvae group feeding on leaves of cotton plants or tobacco infected with sTRV:*HaGST1* whose include a sense *HaGST1* gene sequences as set forth in SEQ ID NO:26 compared to the non-insect sequence control (*JcCurcin*) (Fig. 3 and Fig. 4).

Better insect inhibitory effect has been observed in *HaGST1* cotton and tobacco treated group than these of *HaCYP6AE14*, *HaVATP* and *HaCHT*.

EXAMPLE 6

Identification of Insect Target Sequence

[0119] This example illustrates the identification of nucleotide sequences that, when inserted into the VIGS vector produces recombinant virus replicating in the host plants, which can be a diet of a cotton bollworm, are useful for controlling a cotton bollworm species insect pest.

[0120] The cytoskeleton is a cellular "scaffolding" or "skeleton" contained within the cytoplasm. Tubulin proteins are important structural components of many cellular structures in all eukaryote cells and principally in the formation of microtubules.

Inhibition of microtubule formation in cells results in severe phenotypes, such as blocking cell division and the like, leads to stopping growth. Therefore, suppression of tubulin protein formation may be a useful target for VIGS mediated inhibition.

[0121] In order to study the inhibition role of *tubulin* gene in insect growth, we first
5 cloned its alpha-tubulin putative cotton bollworm gene homologue. We used the amino acid sequence of known domestic silkworm (*Bombyx mori*) alpha-tubulin (NP_001036884) to search the GenBank cotton bollworm (*Helicoverpa armigera*) EST database using TBLASTN. Cotton bollworm EST clone BU038726 showed significant homology to *Bmtub*. The nucleotide sequence of putative cotton bollworm *Hatub* gene
10 was 689 bp and listed as SEQ ID NO:37. The nucleotide sequence analysis of *Hatub* gene shows 89.4% identity in the coding region of silkworm *Bmtub*. Amino acid sequence analysis of cotton bollworm *Hatub* shows 86.3% identity and 93.9% similarity with *Bmtub*. The amino acid of putative *Hatub* gene is set forth in SEQ ID NO:38.

[0122] An alpha-*tubulin* coding sequence was used to construct a nucleotide
15 sequence encoding in a single strand inserted VIGS vector. A 506 bp coding sequence as set forth in SEQ ID NO:11 including a 5' UTR and coding region encoding a partial alpha-tubulin protein was used to construct a primer pair for use in a thermal amplification reaction using CBM cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:9 and SEQ ID NO:10 enabled the amplification
20 of a double stranded sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:11. To amplify the bollworm sense *tub* gene for functional analysis using VIGS in cotton and tobacco, SEQ ID NO:9 and SEQ ID NO:10 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment

sequence as set forth in SEQ ID NO:11 was inserted into psTRV2 in the sense orientation to give psTRV2:*Hatub*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*Hatub* vector was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0123] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton plants were used to feed to CBM larvae. For tobacco plants, after 7-10 days post inoculation, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p<0.01$) was observed for larvae group feeding on leaves of cotton plants or tobacco infected with sTRV:*Hatub* whose include a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 compared to the non-insect sequence control (*JcCurcin*) (Fig. 3 and Fig. 4). Better insect inhibitory effect has been observed in *Hatub* cotton and tobacco treated group than these of *HaCYP6AE14*, *HaVATP*, *HaCHT* and *HaGST1*.

EXAMPLE 7

Co-Silencing of Insect Small RNA Pathway Increases the Inhibitory Efficiency

[0124] This example illustrates the synergistic effects of providing in the diet of an invertebrate pest one or more pesticidally effective genes together with single ss-RNA sequences derived from the invertebrate pest.

[0125] As indicated in Example 6, providing feeding with plant materials infected with recombinant VIGS virus results in the inhibition of one or more biological functions in the pest and therefore functions to achieve a pesticidal effect, resulting in the mortality of the pest or some other measurable feature that reduces the ability of the

pest to infest a particular environment or host. The addition of one or more other gene, each different from each other and each functioning to achieve its pesticidal effect by a means different from the different pathway in which the RNA functions to achieve its pesticidal effect, may result in achieving an improvement in the level of pest control and would further decrease the likelihood that the pest would develop resistance to any one or more of the pesticidal agents or RNA's when used alone to achieve inhibition of the pest.

[0126] Small RNAs (smRNAs) regulate processes as diverse as invertebrate development and differentiation. We tested the ability of the co-silencing of smRNA biosynthesis pathway for increase the inhibitory efficiency.

[0127] All RNA-silencing pathways require the genesis of 18- to 26-nt smRNAs from the cleavage of double-stranded RNA (dsRNA) or highly structured regions within single-stranded viral RNAs. MicroRNA is one important kind of smRNAs. miRNAs are naturally occurring triggers of the RNAi pathway and play an important role in gene regulation in many organisms. During the biogenesis pathway of miRNA, Dicer-1 (DCR1) or its homologues in diverse organism is responsible for pre-microRNA to process into mature miRNA. When DCR1 or its homolog is mutated or downregulated or misregulated, severe development defects, such as embryo-lethal and defects in ovule development in plants, and tumor in human being would result. We tested the ability of the VIGS system to co-silence putative *DCR1* gene and also explored the possibility of increasing silencing efficiency of a candidate gene by co-silencing of *HaDCR1*. We used the marker gene *Hatub* to examine this possibility.

[0128] A *DCR1* gene coding sequence was used to construct a nucleotide sequence encoding in a single strand inserted into an *alpha-tubulin* gene VIGS vector for co-

silencing. A 330 bp coding sequence as set forth in SEQ ID NO:20 encoding a part of a *DCR1* sequence was used to construct a primer pair for use in a thermal amplification reaction using CBM cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:18 and SEQ ID NO:19 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:20. To amplify the bollworm sense *HaDCR1* gene for functional analysis using VIGS in cotton and tobacco, SEQ ID NO:18 and SEQ ID NO:19 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:20 was inserted into psTRV2:*Hatub* in the sense orientation to give psTRV2:*Hatub*+*HaDCR1*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaVATP* vector or psTRV2:*Hatub* or psTRV2:*Hatub*+*HaDCR1* was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0129] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton plants were used to feed to CBM larvae. For tobacco plants, after 7-10 days post inoculation, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p<0.01$) was observed for larvae group feeding on leaves of cotton plants or tobacco infected with sTRV:*Hatub*+*HaDCR1* whose includes a sense *HaDCR1* gene sequences as set forth in SEQ ID NO:20 plus a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 compared to the sTRV:*Hatub* includes a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 only (Fig. 3 and Fig. 4). The mortality rate with addition of the

HaDCR1 was up to 79.4% from 64.7% of *Hatub* only. Beside that, mortality speed of *Hatub+HaDCR1* is 2-3 days early than that of *Hatub* only.

[0130] These results indicate that co-silencing of two insect different pathway gene can increase the silencing efficiency at least in the case of co-silencing small RNA pathway gene *DCR1*. This new strategy may useful for more effective insect controlling.

EXAMPLE 8

Co-Silencing of Plant Viral Resistance System Increases the Inhibitory Efficiency

[0131] This example illustrates the synergistic effects of providing in the diet of an invertebrate pest one or more pesticidally effective genes RNA sequences derived from the invertebrate pest together with silencing of plant host gene.

[0132] As indicated in Example 2 to Example 7 feeding with plant materials infected with recombinant VIGS virus results in the inhibition of one or more biological functions in the pest and therefore functions to achieve a pesticidal effect, resulting in the mortality of the pest or some other measurable feature that reduces the ability of the pest to infest a particular environment or host. The addition of one or more other gene of host plant, involving in plant virus replication, insect infestation process, plant-resistance signal transduction pathway (jasmonic acid, salicylic acid), other physic resistance to insect, and so on, each different from each other and each functioning to achieve its pesticidal effect by a means different from the different pathway in which the RNA functions to achieve its pesticidal effect, may result in achieving an improvement in the level of pest control and would further decrease the likelihood that

the pest would develop resistance to any one or more of the pesticidal agents or RNA's when used alone to achieve inhibition of the pest.

[0133] RNA silencing is one of the natural plant defense mechanisms against virus infection. We hypothesized that the co-silencing of the host viral resistance system using VIGS should result in more efficient VIGS in insect.

[0134] A current model for antiviral silencing in higher plants, using *Arabidopsis thaliana* as an example, suggests that dsRNA replication intermediates of viral genomic RNAs or highly structured regions within single-stranded viral RNAs are first cleaved by RNase III-type Dicer-like 4 (DCL4) or alternatively by DCL2 to produce 21- or 22-nucleotide (nt) small interfering RNAs (siRNAs) (Baulcombe, 2004). This model implies that *DCL4* is an important *Arabidopsis* viral resistance gene (Deleris et al., 2006). We tested the ability of the TRV-VIGS system to silence *DCL4* and also explored the possibility of increasing silencing efficiency of a candidate gene by co-silencing of *DCL4*, an important gene dsRNA metabolism. We used the marker gene *Hatub* to examine this possibility.

[0135] First, we have shown that infection with TRV:*Hatub* alone can result in inhibitory controlling role on *H.armigera*. Next, we investigated whether the silencing efficiency can be increased by co-silencing of tobacco *DCL4*.

[0136] In order to study the effect of co-silencing of tobacco *DCL4* gene in insect growth, we first cloned the putative *N. benthamiana* *DCL4* homologue. We used the amino acid sequence of known *Arabidopsis thaliana* *DCL4* (*AtDCL4*) gene (At5g20320) to search the GenBank EST database limited in Solanaceae using TBLASTN. Two EST, one tomato EST (GenBank Accession number BF051638) and one common tobacco EST (GenBank Accession number AM846087), encode protein

sequences containing conserved ribonuclease III domain. PCR primers for *N. benthamiana DCL4* gene cloning were designed to target the conserved region between these two EST sequences. PCR products were cloned by pGEM-T-easy vector (Promega, U.S.A) and were further sequenced. A 395 bp coding sequence as set forth

5 in SEQ ID NO:23 encoding a part of a *NbDCL4* sequence was used to construct a primer pair for use in a thermal amplification reaction using *N. benthamiana* cDNA product generated as Example 1. The primer pair as set forth at SEQ ID NO:21 and SEQ ID NO:22 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:39.

10 We used SEQ ID NO:23 sequence to further find another EST sequence (GenBank Accession number: FM986783) from *N. benthamiana* cDNA sequence database. One contig of *NbDCL4* is as forth in SEQ ID NO:39. The *NbDCL4* gene coding sequence was used to construct a nucleotide sequence encoding in a single strand inserted into an *alpha-tubulin* gene VIGS vector for co-silencing. DNA fragment sequence as set forth

15 in SEQ ID NO:23 was inserted into psTRV2:*Hatub* in the sense orientation to give psTRV2:*Hatub+NbDCL4* by KpnI and XhoI sites. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaVATP* vector or psTRV2:*Hatub* or psTRV2:*Hatub+NbDCL4* was vacuum infiltrated into 2-3 true leaf

20 cotton plants or 5-6 true leaf tobacco plants.

[0137] After 7-10 days post inoculation, new systemic leaves of agrobacterium treated *N. benthamiana* plants, new systemic leaves of agrobacterium treated plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p<0.01$) was observed for larvae group feeding on leaves of cotton plants

or tobacco infected with sTRV:*Hatub*+*NbDCL4* whose includes a sense *NbDCL4* gene sequences as set forth in SEQ ID NO:23 plus a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 compared to the sTRV:*Hatub* includes a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 only (Fig. 4). The mortality rate with addition of the

5 *NbDCL4* was up to 84.2% from 64.7% of *Hatub* only. Beside that, mortality speed of *Hatub*+*NbDCL4* is 2-3 days earlier than that of *Hatub* only.

[0138] These results indicate that co-silencing of insect and host gene involved in dsRNA metabolism can increase the silencing. This new strategy may useful for more effective insect controlling. This can be explained that more dsRNA accumulated in

10 plants leads to higher mortality after insect feed with these plants.

[0139] Taken together the enhancement of VIGS effect on plant with co-silencing of *Jatropha DCL4* homolog (US Provisional Patent Application No. 61/143,484), co-silencing of plant DCL4 homolog can be a general strategy to enhance VIGS effect either in plant or in insect controlling.

15 EXAMPLE 9

The Role of Endocytosis-Mediated dsRNA Uptake in Controlling Insects by VIGS

[0140] dsRNA is taken up in *Drosophila* S2 cells by an active pathway, involving receptor-mediated endocytosis. This pathway is also involved in the antiviral RNAi

20 response against *Drosophila* C virus and Sindbis virus via a systemic spreading silencing signal that elicits protective RNAi-dependent immunity throughout the organism. To examine whether this pathway in CBM is involved in the RNA-mediated insect controlling also, we selected one gene implicated with dsRNA uptaking and

important for RNAi resistance to virus infection: *CG4572* by VIGS system used in previous examples.

[0141] A *CG4572* gene coding sequence was used to construct a nucleotide sequence encoding in a single strand inserted into an *alpha-tubulin* gene VIGS vector for co-silencing. To amplify the *CG4572* homolog from *H. armigera*, we used the amino acid sequence of *Drosophila melanogaster* *CG4572* protein sequence as seed sequence to search the GenBank insecta EST database using TBLASTN. Two ESTs from *Heliconius melpomene* (GE842295.1) and *Heliothis virescens* (EY122719.1) were found by this way and further used to design degenerated PCR primers to target conserved sequence motifs of *CG4572* from different species of insect. A 1075 bp coding sequence as set forth in SEQ ID NO:14 encoding a part of a *CG4572* gene sequence was used to construct a primer pair for use in a thermal amplification reaction using cotton bollworm cDNA product generated as in Example 1. The primer pair as set forth at SEQ ID NO:12 and SEQ ID NO:13 enabled the amplification of a double stranded coding sequence DNA amplicon, one strand of which exhibited the sequence as set forth in SEQ ID NO:14. To amplify the cotton bollworm gene for functional analysis using VIGS in cotton and tobacco, SEQ ID NO:12 and SEQ ID NO:13 correspond respectively to forward and reverse genome amplification primers for use in producing a fragment from cotton bollworm cDNA product. DNA fragment sequence as set forth in SEQ ID NO:14 was inserted into psTRV2:*Hatub* in the sense orientation to give psTRV2:*Hatub*+*HaCG4572*. A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*HaVATP* vector or psTRV2:*Hatub* or

psTRV2:*Hatub*+*HaCG4572* was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

[0142] After 7-10 days post inoculation, new systemic leaves of agrobacterium treated *N. benthamiana* plants were used to feed to CBM larvae. No significant higher larval mortality at 13 days-feeding with ($p<0.01$) was observed for larvae group feeding on leaves of cotton or tobacco infected with sTRV:*Hatub*+*HaCG4572* which includes a sense *HaCG4572* gene sequences as set forth in SEQ ID NO:14 plus a sense *Hatub* gene sequences as set forth in SEQ ID NO: 11 compared to the sTRV:*Hatub* that includes a sense *Hatub* gene sequences as set forth in SEQ ID NO:11 only (Fig. 3 and Fig. 4).

[0143] It is important to mention that although it is critical to determine the potential to kill larvae by simply monitoring the mortality rate of each treated groups, it may be preferred to check whether the expression of the *HaCG4572* in CBM was downregulated when feed with sTRV2:*HaCG4572* plants by Northern blot or quantitative PCR.

EXAMPLE 10

Viral-Expressed Antisense RNA Is Inhibitory to Insects

[0144] This example illustrates the inhibitory effect of viral-expressed antisense RNA in the diet of an invertebrate pest.

[0145] An antisense *alpha-tubulin* gene sequence was used to construct a nucleotide sequence encoding in a single strand inserted VIGS vector. A 506 bp sequence as set forth in SEQ ID NO:29 encoding a partial *alpha-tubulin* protein was used to construct a primer pair (SEQ ID NO:27 and SEQ ID NO:28) for use in a thermal amplification

reaction using psTRV2:*Hatub* plasmid generated as in Example 1. The antisense *Hatub* expression viral vector was constructed as introduced as in Example 1. An antisense *Hatub* gene was used to construct a nucleotide sequence encoding in an antisense orientation single strand inserted into the psTRV2001 to form the psTRV2:*anti-Hatub*.

5 A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*GhDCS* (see Example 1 as a positive control) or psTRV2:*Hatub* vector or psTRV2:*Hatub* or psTRV2:*anti-Hatub* was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco plants.

10 EXAMPLE 11

Viral-Expressed Hairpin RNA Is Inhibitory to Insects

[0146] This example illustrates that not only single strand sense insect RNA, but also antisense insect RNA and hairpin structure dsRNA can be made as a recombinant virus which can replicate in the host plants, can be diet of an insect pest and are useful for

15 controlling an insect pest.

[0147] Single sense strand DNA fragment sequence as set forth in SEQ ID NO:11 was inserted into psTRV2 to give psTRV2:*Hatub* as described in Example 6.

[0148] A similar strategy as used for the sense tubulin sequence was used to amplify the antisense tubulin sequence from CBM. The bollworm antisense *tub* gene for

20 functional analysis using VIGS in cotton and tobacco was amplified from cotton bollworm cDNA using the primer pair as set forth at SEQ ID NO:27 and SEQ ID NO:28 which correspond respectively to forward and reverse genome amplification primers. The amplified DNA fragment sequence as set forth in SEQ ID NO:29 was

used for producing an antisense *Hatub* silencing vector psTRV2:*Antisense-Hatub* (psTRV2:*anti:Hatub*) as described in Example 10.

[0149] A hairpin alpha-tubulin gene sequence was used to construct a nucleotide sequence encoding in a hairpin structure containing VIGS vector. Sense fragment was amplified by PCR with PCR primers set forth as SEQ ID NO:30 and SEQ ID NO:31 and further cloned into the BamHI and EcoRI sites of pSK-intron (Guo et al., 2003), followed insertion of the antisense fragment amplified with PCR primers set forth as SEQ ID NO:32 and SEQ ID NO:33. The *Hairpin-Hatub* (*hpHatub*) hairpin structure was subcloned into the BamHI and XhoI sites of psTRV2001 to give psTRV:*Hairpin-Hatub* (psTRV:*hpHatub*).

[0150] A mixture of *Agrobacterium* cultures containing psTRV1 with psTRV2:*JcCurcin* (as a non-insect sequence control) or psTRV2:*Hatub* or psTRV2:*Antisense-Hatub* or psTRV2:*Hairpin-Hatub* was vacuum infiltrated into 2-3 true leaf cotton plants or 5-6 true leaf tobacco (*N. benthamiana*) plants.

[0151] After 14 days post inoculation, new systemic leaves of agrobacterium treated cotton or *N. benthamiana* plants were used to feed to CBM larvae. A significant higher larval mortality at 13 days-feeding with ($p < 0.05$) was observed for larvae group feeding on leaves of cotton plants infected with sTRV:*Hatub* or sTRV:*Antisense-Hatub* or sTRV:*Hairpin-Hatub* compared to the non-insect sequence control (*JcCurcin*) (cotton shown in Fig. 5 and *N. benthamiana* shown in Fig. 6).

[0152] These results indicate that the synthetic sTRV-VIGS systems could be used to induce silencing of desirable endogenous insect genes to inhibit insect infestation by insertion of sense, antisense and hairpin structure of an insect gene.

EXAMPLE 12

Conserved Insect Target Genes

[0153] This example lists target genes, sharing conservation with cDNA sequences identified by this invention, in other Insecta order organisms.

5 [0154] Using the method we developed in this invention, we have identified 6 insect genes that can lead to mortality when silenced by recombinant viral vector expression in cotton and tobacco plants. These cDNA sequences can be used to find potential RNAi target genes in other Insecta order organisms, especially these pests for important crops and they were those that encoded V-ATPase A subunit, alpha-tubulin, chitin, GST and
10 DCR1 proteins, the nucleotide sequences of which are as set forth in SEQ ID NOs:8, 11, 17, 26 and 20, respectively. The homologs were defined as the most significant matches to the 6 CBM sequences, as indicated by the best expectation value of NCBI Blast searches. The CBM cDNA sequences were then matched to the sequence database containing all public cDNAs of various organisms in Insecta order from GenBank. The
15 top 100 matches and alignments were kept. The resulting cDNA clones were further chosed as at least one cDNA contain a 21-mer consecutively perfect match with the CBM cDNA sequences.

[0155] Using the 6 CBM cDNA sequences, 30 matches were identified with a minimum of 21-mer perfect match region, from 21 distinct organisms, including several
20 pest species, such as Asiatic Rice Borer (*Chilo suppressalis*). The results are listed in Table 2 below with coordinates of match on the query sequence and the hit, percent identity of the match, and the insect species from which the hit sequence was derived. For example, a segment from nucleotide sequence with SEQ ID NO:11 of gene named

Hatub was identified to be 97% identical to a segment from a GenBank sequence with the accession number EY118187 from tobacco budworm (*Heliothis virescens*).

TABLE 2

5 Homologs of Cotton Bollworm Genes

SEQ ID NO:	Genus species of	Gene Accession	% Identity
Gene name	hit genes	Number	
Seq ID NO:11	<i>Heliothis</i>	EY118187	97
<i>Hatub</i> ,	<i>virescens</i>		
	<i>Agrotis ipsilon</i>	EU100018	94.9
Seq ID NO:11			
<i>Hatub</i> ,	<i>Spodoptera</i>	DY896617	94.6
Seq ID NO:11	<i>frugiperda</i>		
<i>Hatub</i> ,			
Seq ID NO:11	<i>Xestia c-nigrum</i>	EU100014	94.4
<i>Hatub</i> ,			
Seq ID NO:11	<i>Mythimna</i>	EU100016	94.3
<i>Hatub</i> ,	<i>separata</i>		
Seq ID NO:11	<i>Spodoptera</i>	EU10017	93.3
<i>Hatub</i> ,	<i>exigua</i>		

Seq ID NO:11	<i>Trichoplusia ni</i>	FF369778	92.3
<i>Hatub,</i>			
Seq ID NO:11	<i>Danaus</i>	EY262486	88.8
<i>Hatub,</i>	<i>plexippus</i>		
Seq ID NO:11	<i>Ostrinia</i>	GH994602	88.2
<i>Hatub,</i>	<i>nubilalis</i>		
Seq ID NO:11	<i>Heliconius erato</i>	EL599100	88.0
<i>Hatub,</i>			
Seq ID NO:11	<i>Heliconius</i>	EF207983	86.6
<i>Hatub,</i>	<i>melpomene</i>		
Seq ID NO:11	<i>Culex</i>	XM_001867913	85.3
<i>Hatub,</i>	<i>quinquefasciatus</i>		
Seq ID NO:11	<i>Aedes aegypti</i>	XM_001652094	78.8
<i>Hatub,</i>			
Seq ID NO:11	<i>Tribolium</i>	XM_961399	78.6

<i>Hatub,</i>	<i>castaneum</i>		
Seq ID NO:11	<i>Acyrtosiphon</i>	XR_045883	78.5
<i>Hatub,</i>	<i>pisum</i>		
Seq ID NO:8	<i>Trichoplusia ni</i>	CF259336	90.1
HaVATP			
Seq ID NO:8	<i>Bombyx mori</i>	BY917060	90.2
HaVATP			
Seq ID NO:8	<i>Spodoptera</i>	DV076251	90.4
HaVATP	<i>frugiperda</i>		
Seq ID NO:8	<i>Danaus</i>	EY264737	88.8
HaVATP	<i>plexippus</i>		
Seq ID NO:8	<i>Epiphyas</i>	EV803951	89.4
HaVATP	<i>postvittana</i>		
Seq ID NO:8	<i>Drosophila</i>	DR155248	83.9
HaVATP	<i>pseudoobscura</i>		
Seq ID NO:8	<i>Ostrinia</i>	GH997265	92.4

HaVATP	<i>nubilalis</i>		
Seq ID NO:8	<i>Plodia</i>	EB826765	89.2
HaVATP	<i>interpunctella</i>		
Seq ID NO:8	<i>Heliconius erato</i>	EL599764	85.1
HaVATP			
Seq ID NO:5	<i>Heliothis</i>	EY121794	83.5
HaCYP6AE14	<i>virescens</i>		
Seq ID NO:17	<i>Mythimna</i>	AY508698	90.1
HaCHT1	<i>separata</i>		
Seq ID NO:17	<i>Mamestra</i>	FJ436415	89.1
HaCHT1	<i>brassicae</i>		
Seq ID NO:17	<i>Agrotis ipsilon</i>	EU035316	88.2
HaCHT1			
Seq ID NO:17	<i>Spodoptera</i>	AY527414	86.3
HaCHT1	<i>frugiperda</i>		

Seq ID NO:17	<i>Chilo</i>	AY705930	83.2
HaCHT1	<i>suppressalis</i>		

[0156] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each
10 separate value is incorporated into the specification as if it were individually recited herein. For example, if the range 10-15 is disclosed, then 11, 12, 13, and 14 are also disclosed. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended
15 merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0157] It will be appreciated that the methods and compositions of the instant
20 invention can be incorporated in the form of a variety of embodiments, only a few of which are disclosed herein. Embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention.

Variations of those embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

[0158] The present invention has several embodiments and relies on patents, patent applications and other references for details known to those of the art. Therefore, when a patent, patent application, or other reference is cited or repeated herein, it should be understood that it is incorporated by reference in its entirety for all purposes as well as for the proposition that is recited.

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CLAIMS

1. A method of screening insect pest genes to identify pest genes which can lead to mortality of the pest when expression of the pest gene is silenced in the pest, the method comprising:
 - (a) inserting a nucleic acid comprising a sequence of a first desired gene into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired plant host to produce a modified VIGS vector, wherein the first desired gene is an pest gene to be screened;
 - (b) inoculating the host with the modified VIGS vector to produce infected host;
 - (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host;
 - (d) feeding the host tissue with RNA to pests; and
 - (e) determining whether the RNA is toxic to the pest,wherein pest toxicity identifies the pest gene as an pest gene that leads to mortality of the pest when the pest gene expression is silenced in the pest, and wherein the pest genes are insect pest genes and the host is a plant host.
2. The method of claim 1, wherein the virus is a DNA virus or an RNA virus.
3. The method of claim 2, wherein the RNA virus is an RNA virus containing two RNA molecules and one of the RNA molecules is the VIGS vector.
4. The method of claim 3, wherein the RNA virus is tobacco rattle virus (TRV).
5. The method of claim 3, wherein the plant host is inoculated with the modified VIGS vector and a vector containing the other RNA molecule.
6. The method of any one of claims 1-5, wherein the host is a plant host and the host tissue is a plant leaf.

7. The method of any one of claims 1-6, wherein the nucleic acid further comprises a sequence of a second desired gene, wherein the second desired gene is a plant host resistance gene.
8. The method of claim 7, wherein the plant host resistance gene is selected from the group consisting of *RNase III Dicer-like 4 (DCL4)* gene, *RNase III Dicer-like 2 (DCL2)* gene, *RNase III Dicer-like 3 (DCL3)* gene, *ARGONAUTE1 (AGO1)*, *ARGONAUTE71 (AGO7)*, *RNA-dependent RNA polymerase 1 (RDR1)*, *RNA-dependent RNA polymerase 6 (RDR6)*, *Suppressor of gene silencing 1 (SGS1)*, *Suppressor of gene silencing 3 (SGS3)*, and *Silencing defective 3 (SDE3)*.
9. The method of any one of claims 1-6, wherein the nucleic acid further comprises a sequence of a second desired gene, wherein the second desired gene is a pest small RNA biosynthesis gene, and wherein the pest gene is an insect pest gene.
10. The method of claim 9, wherein the pest small RNA biosynthesis gene is selected from the group consisting of *Dicer-1 (DCR1)* gene, *Pasha* gene, *Loquacious* gene (*Loqs*), *ARGONAUTE1* gene (*AGO1*), *ARGONAUTE2* gene (*AGO2*), *ARGONAUTE3* gene (*AGO3*), *Piwi* gene, *Stellate* gene and *Aubergine* gene (*Aub*).
11. The method of any one of claims 1-10, wherein the RNA produced is dsRNA.
12. The method of claim 11, wherein the dsRNA is an siRNA or modified to form an siRNA.
13. The method of claim 12, wherein the nucleic acid is inserted into the vector as a hairpin structure.
14. The method of any one of claims 1-10, wherein the RNA produced is ssRNA.
15. The method of claim 14, wherein the nucleic acid is inserted into the vector in a sense orientation or an antisense orientation.

16. The method of any one of claims 1-15, wherein the sequence is selected from the group consisting of (a) a part of a 5' UTR of the first desired gene, (b) a part of a 3' UTR of the first desired gene, (c) a part of a coding sequence of the first desired gene, (d) a part of a 5' UTR of the first desired gene and a part of a coding sequence of the first desired gene and (e) a part of a coding sequence of the first desired gene and part of a 3' UTR of the first desired gene.
17. A method of controlling pests by viral expression of target pest sequences in a host to modify endogenous expression of pest genes in cells or tissues of the pest, the method comprising:
 - (a) inserting a nucleic acid comprising a sequence of a first desired gene to be silenced into a virus-induced gene silencing (VIGS) vector of a virus that can infect a desired host to produce a modified VIGS vector, wherein the first desired gene is an pest gene;
 - (b) inoculating the host with the modified VIGS vector to produce infected host; and
 - (c) growing the infected host under conditions in which the modified VIGS vector is replicated to produce RNA which accumulates in tissue of the host, wherein the RNA causes gene silencing in the pest upon ingestion of the RNA produced in the host, whereby pests are controlled, and wherein the pest genes are insect pest genes and the host is a plant host.
18. The method of claim 17, wherein the virus is a DNA virus or an RNA virus.
19. The method of claim 18, wherein the RNA virus is an RNA virus containing two RNA molecules and one of the RNA molecules is the VIGS vector.
20. The method of claim 19, wherein the RNA virus is tobacco rattle virus (TRV).
21. The method of claim 19 or 20, wherein the plant host is inoculated with the modified VIGS vector and a vector containing the other RNA molecule.

22. The method of any one of claims 17-21, wherein the host is a plant and the host tissue is a plant leaf.
23. The method of any one of claims 17-22, wherein the nucleic acid further comprises a sequence of a second desired gene, wherein the second desired gene is a plant host resistance gene.
24. The method of claim 23, wherein the host resistance gene is selected from the group consisting of *RNase III Dicer-like 4 (DCL4)* gene, *RNase III Dicer-like 2 (DCL2)* gene, *RNase III Dicer-like 3 (DCL3)* gene, *ARGONAUTE1 (AGO1)*, *ARGONAUTE71 (AGO7)*, *RNA-dependent RNA polymerase 1 (RDR1)*, *RNA-dependent RNA polymerase 6 (RDR6)*, *Suppressor of gene silencing 1 (SGS1)*, *Suppressor of gene silencing 3 (SGS3)*, and *Silencing defective 3 (SDE3)*.
25. The method of any one of claims 17-22, wherein the nucleic acid further comprises a sequence of a second desired gene, wherein the second desired gene is a pest small RNA biosynthesis gene, and wherein the pest gene is an insect pest gene.
26. The method of claim 25, wherein, the pest small RNA biosynthesis gene is selected from the group consisting of *Dicer-1 (DCR1)* gene, *Pasha* gene, *Loquacious* gene (*Loqs*), *ARGONAUTE1* gene (*AGO1*), *ARGONAUTE2* gene (*AGO2*), *ARGONAUTE3* gene (*AGO3*), *Piwi* gene, *Stellate* gene and *Aubergine* gene (*Aub*).
27. The method of any one of claims 17-26, wherein the RNA produced is dsRNA.
28. The method of claim 27, wherein the ds RNA is an siRNA or modified to form an siRNA.
29. The method of claim 28, wherein the nucleic acid is inserted into the vector as a hairpin structure.
30. The method of any one of claims 17-29, wherein the RNA produced is ssRNA.

31. The method of claim 30, wherein the nucleic acid is inserted into the vector in a sense orientation or an antisense orientation.
32. The method of any one of claims 17-31, wherein the pest gene is selected from the group consisting of *gossypol-induced cytochrome P450 (CYP6AE14)*, *H⁺-ATPase (V-ATPase)*, *glutathione-S-transferase (GST)*, *Dicer-1 (DCR1)*, *alpha-tubulin* and *chitin*.
33. The method of any one of claims 17-32, wherein the sequence is selected from the group consisting of (a) a part of a 5' UTR of the first desired gene, (b) a part of a 3' UTR of the first desired gene, (c) a part of a coding sequence of the first desired gene, (d) a part of a 5' UTR of the first desired gene and a part of a coding sequence of the first desired gene and (e) a part of a coding sequence of the first desired gene and part of a 3' UTR of the first desired gene.