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**United States Patent** [19][11] **Patent Number:** **5,776,889**

Wei et al.

[45] **Date of Patent:** **Jul. 7, 1998****[54] HYPERSENSITIVE RESPONSE INDUCED RESISTANCE IN PLANTS****[75] Inventors:** Zhong-Min Wei; Steven V. Beer, both of Ithaca, N.Y.**[73] Assignee:** Cornell Research Foundation, Inc., Ithaca, N.Y.**[21] Appl. No.:** 891,254**[22] Filed:** Jul. 10, 1997**Related U.S. Application Data****[63] Continuation of Ser. No. 475,775, Jun. 7, 1995, abandoned.****[51] Int. Cl.<sup>6</sup> .....** A01N 37/18; A01N 63/00; A01N 65/00; A61K 38/00**[52] U.S. Cl. ....** 514/2; 424/93; 435/500; 435/847**[58] Field of Search .....** 514/2; 424/93; 435/847, 800**[56] References Cited****U.S. PATENT DOCUMENTS**

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**[57] ABSTRACT**

The present invention relates to a method of imparting pathogen resistance to plants. This involves applying a hypersensitive response elicitor polypeptide or protein in a non-infectious form to a plant under conditions where the polypeptide or protein contacts cells of the plant. The present invention is also directed to a pathogen resistant plant and a composition for imparting pathogen resistance to plants.

**26 Claims, 2 Drawing Sheets**

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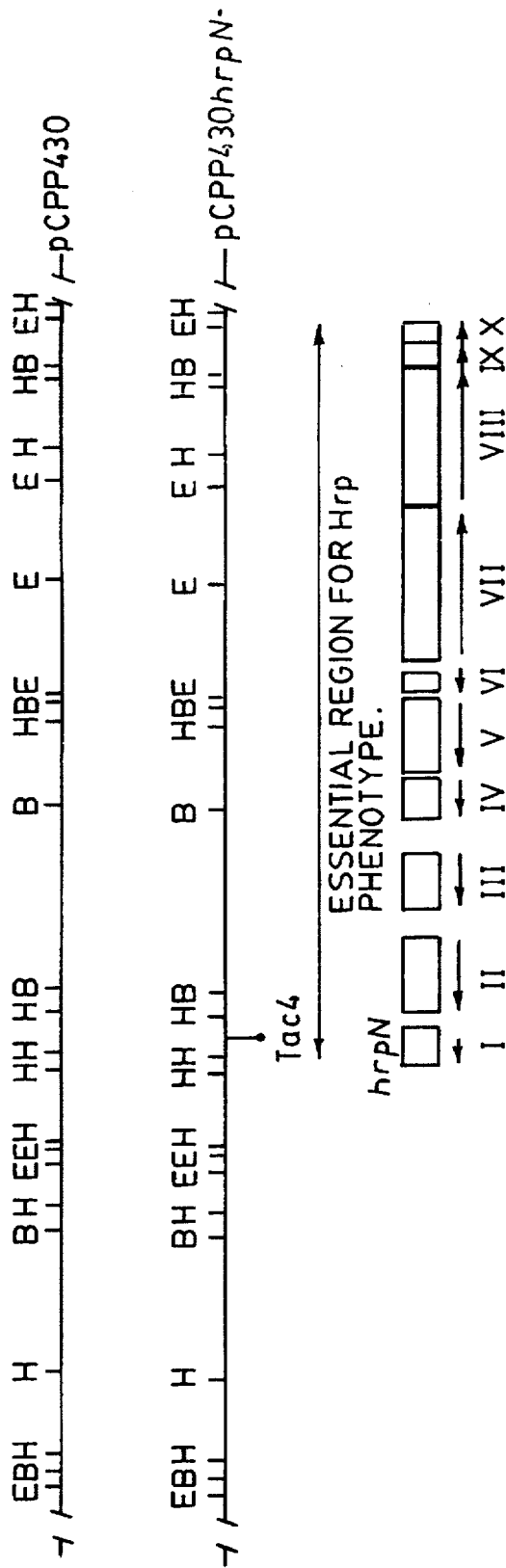


FIG. 1

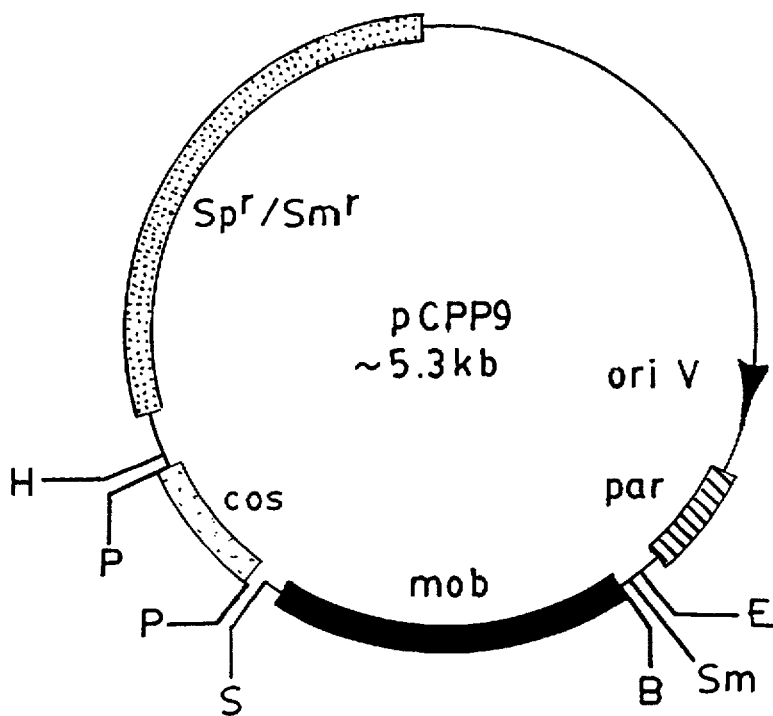


FIG.2

## HYPERSENSITIVE RESPONSE INDUCED RESISTANCE IN PLANTS

This application is a continuation of application Ser. No. 08/475,775, filed Jun. 7, 1995, now abandoned.

This invention was made with support from the U.S. Government under USDA NRI Competitive Research Grant No. 91-37303-6430.

### FIELD OF THE INVENTION

The present invention relates to imparting hypersensitive response induced resistance to plants.

### BACKGROUND OF THE INVENTION

Living organisms have evolved a complex array of biochemical pathways that enable them to recognize and respond to signals from the environment. These pathways include receptor organs, hormones, second messengers, and enzymatic modifications. At present, little is known about the signal transduction pathways that are activated during a plant's response to attack by a pathogen, although this knowledge is central to an understanding of disease susceptibility and resistance. A common form of plant resistance is the restriction of pathogen proliferation to a small zone surrounding the site of infection. In many cases, this restriction is accompanied by localized death (i.e., necrosis) of host tissues. Together, pathogen restriction and local tissue necrosis characterize the hypersensitive response. In addition to local defense responses, many plants respond to infection by activating defenses in uninfected parts of the plant. As a result, the entire plant is more resistant to a secondary infection. This systemic acquired resistance can persist for several weeks or more (R. E. F. Mathews, *Plant Virology* (Academic Press, New York, ed. 2, 1981)) and often confers cross-resistance to unrelated pathogens (J. Kuc, in *Innovative Approaches to Plant Disease Control*, I. Chet, Ed. (Wiley, New York, 1987), pp. 255-274, which is hereby incorporated by reference).

Expression of systemic acquired resistance is associated with the failure of normally virulent pathogens to ingress the immunized tissue (Kuc, J., "Induced Immunity to Plant Disease," *Bioscience*, 32:854-856 (1982), which is hereby incorporated by reference). Establishment of systemic acquired resistance is correlated with systemic increases in cell wall hydroxyproline levels and peroxidase activity (Smith, J. A., et al., "Comparative Study of Acidic Peroxidases Associated with Induced Resistance in Cucumber, Muskmelon and Watermelon," *Physiol. Mol. Plant Pathol.* 14:329-338 (1988), which is hereby incorporated by reference) and with the expression of a set of nine families of so-called systemic acquired resistance gene (Ward, E. R., et al., "Coordinate Gene Activity in Response to Agents that Induce Systemic Acquired Resistance," *Plant Cell* 3:49-59 (1991), which is hereby incorporated by reference). Five of these defense gene families encode pathogenesis-related proteins whose physiological functions have not been established. However, some of these proteins have antifungal activity in vitro (Bol, J. F., et al., "Plant Pathogenesis-Related Proteins Induced by Virus Infection," *Ann. Rev. Phytopathol.* 28:113-38 (1990), which is hereby incorporated by reference) and the constitutive expression of a bean chitinase gene in transgenic tobacco protects against infection by the fungus *Rhizoctonia solani* (Brogliè, K., et al., "Transgenic Plants with Enhanced Resistance to the Fungal Pathogen *Rhizoctonia Solani*," *Science* 254:1194-1197 (1991), which is hereby incorporated by reference), suggest-

ing that these systemic acquired resistance proteins may contribute to the immunized state (Uknes, S., et al., "Acquired Resistance in Arabidopsis," *Plant Cell* 4:645-656 (1992), which is hereby incorporated by reference).

5 Salicylic acid appears to play a signal function in the induction of systemic acquired resistance since endogenous levels increase after immunization (Malamy, J., et al., "Salicylic Acid: A Likely Endogenous Signal in the Resistance Response of Tobacco to Viral Infection," *Science* 250:1002-1004 (1990), which is hereby incorporated by reference) and exogenous salicylate induces systemic acquired resistance genes (Yalpani, N., et al., "Salicylic Acid is a Systemic Signal and an Inducer of Pathogenesis-Related Proteins in Virus-Infected Tobacco," *Plant Cell* 3:809-818 (1991), which is hereby incorporated by reference), and acquired resistance (Uknes, S., et al., "Acquired Resistance in Arabidopsis," *Plant Cell* 4:645-656 (1992), which is hereby incorporated by reference). Moreover, transgenic tobacco plants in which salicylate is destroyed by the action of a bacterial transgene encoding salicylate hydroxylase do not exhibit systemic acquired resistance (Gaffney, T., et al., "Requirement of Salicylic Acid for the Induction of Systemic Acquired Resistance," *Science* 261:754-296 (1993), which is hereby incorporated by reference). However, this effect may reflect inhibition of a local rather than a systemic signal function, and detailed kinetic analysis of signal transmission in cucumber suggests that salicylate may not be essential for long-distance signaling (Rasmussen, J. B., et al., "Systemic Induction of Salicylic Acid Accumulation in Cucumber after Inoculation with *Pseudomonas Syringae* pv. *Syringae*," *Plant Physiol.* 97:1342-1347 (1991), which is hereby incorporated by reference).

Immunization using biotic agents has been extensively studied. Green beans were systemically immunized against disease caused by cultivar-pathogenic races of *Colletotrichum lindemuthianum* by prior infection with either cultivar-nonpathogenic races (Rahe, J. E., "Induced Resistance in *Phaseolus Vulgaris* to Bean Anthracnose," *Phytopathology* 59:1641-5 (1969); Elliston, J., et al., "Induced Resistance to Anthracnose at a Distance from the Site of the Inducing Interaction," *Phytopathology* 61:1110-12 (1971); Skipp, R., et al., "Studies on Cross Protection in the Anthracnose Disease of Bean," *Physiological Plant Pathology* 3:299-313 (1973), which are hereby incorporated by reference), cultivar-pathogenic races attenuated by heat in host tissue prior to symptom appearance (Rahe, J. E., et al., "Metabolic Nature of the Infection-Limiting Effect of Heat on Bean Anthracnose," *Phytopathology* 60:1005-9 (1970), which is hereby incorporated by reference) or nonpathogens of bean. The anthracnose pathogen of cucumber, *Colletotrichum lagenarium*, was equally effective as non-pathogenic races as an inducer of systemic protection against all races of bean anthracnose. Protection was induced by *C. lagenarium* in cultivars resistant to one or more races of *C. lindemuthianum* as well as in cultivars susceptible to all reported races of the fungus and which accordingly had been referred to as 'lacking genetic resistance' to the pathogen (Elliston, J., et al., "Protection of Bean Against Anthracnose by *Colletotrichum* Species Nonpathogenic on Bean," *Phytopathologische Zeitschrift* 86:117-26 (1976); Elliston, J., et al., "A Comparative Study on the Development of Compatible, Incompatible and Induced Incompatible Interactions Between *Colletotrichum* Species and *Phaseolus Vulgaris*," *Phytopathologische Zeitschrift* 87:289-303 (1976), which are hereby incorporated by reference). These results suggest that the same mechanisms may be induced in cultivars reported as 'possessing' or 'lacking' resistance genes

(Elliston, J., et al., "Relation of Phytoalexin Accumulation to Local and Systemic Protection of Bean Against Anthracnose." *Phytopathologische Zeitschrift* 88:114-30 (1977), which is hereby incorporated by reference). It also is apparent that cultivars susceptible to all races of *C. lindemuthianum* do not lack genes for resistance mechanisms against the pathogen.

Kuc, J., et al., "Protection of Cucumber Against *Colletotrichum lagenarium* by *Colletotrichum lagenarium*," *Physiological Plant Pathology* 7:195-9 (1975), which is hereby incorporated by reference), showed that cucumber plants could be systemically protected against disease caused by *Colletotrichum lagenarium* by prior inoculation of the cotyledons or the first true leaf with the same fungus. Subsequently, cucumbers have been systemically protected against fungal, bacterial, and viral diseases by prior localized infection with either fungi, bacteria, or viruses (Hammerschmidt, R., et al., "Protection of Cucumbers Against *Colletotrichum lagenarium* and *Cladosporium cucumerinum*," *Phytopathology* 66:790-3 (1976); Jenns, A. E., et al., "Localized Infection with Tobacco Necrosis Virus Protects Cucumber Against *Colletotrichum lagenarium*," *Physiological Plant Pathology* 11:207-12 (1977); Caruso, F. L., et al., "Induced Resistance of Cucumber to Anthracnose and Angular Leaf Spot by *Pseudomonas lachrymans* and *Colletotrichum Lagenarium*," *Physiological Plant Pathology* 14:191-201 (1979); Staub, T., et al., "Systemic Protection of Cucumber Plants Against Disease Caused by *Cladosporium cucumerinum* and *Colletotrichum lagenarium* by Prior Localized Infection with Either Fungus." *Physiological Plant Pathology*, 17:389-93 (1980); Bergstrom, G. C., et al., "Effects of Local Infection of Cucumber by *Colletotrichum lagenarium*, *Pseudomonas lachrymans* or Tobacco Necrosis Virus on Systemic Resistance to Cucumber Mosaic Virus," *Phytopathology* 72:922-6 (1982); Gessler, C., et al., "Induction of Resistance to Fusarium Wilt in Cucumber by Root and Foliar Pathogens." *Phytopathology* 72:1439-41 (1982); Basham, B., et al., "Tobacco Necrosis Virus Induces Systemic Resistance in Cucumbers Against *Sphaerotheca fuliginea*," *Physiological Plant Pathology* 23:137-44 (1983), which are hereby incorporated by reference). Non-specific protection induced by infection with *C. lagenarium* or tobacco necrosis virus was effective against at least 13 pathogens, including obligatory and facultative parasitic fungi, local lesion and systemic viruses, wilt fungi, and bacteria. Similarly, protection was induced by and was also effective against root pathogens. Other cucurbits, including watermelon and muskmelon have been systemically protected against *C. lagenarium* (Caruso, F. L., et al., "Protection of Watermelon and Muskmelon Against *Colletotrichum lagenarium* by *Colletotrichum lagenarium*," *Phytopathology* 67:1285-9 (1977), which is hereby incorporated by reference).

Systemic protection in tobacco has also been induced against a wide variety of diseases (Kuc, J., et al., "Immunization for Disease Resistance in Tobacco," *Recent Advances in Tobacco Science* 9:179-213 (1983), which is hereby incorporated by reference). Necrotic lesions caused by tobacco mosaic virus enhanced resistance in the upper leaves to disease caused by the virus (Ross, A. F., et al., "Systemic Acquired Resistance Induced by Localized Virus Infections in Plants," *Virology* 14:340-58 (1961); Ross, A. F., et al., "Systemic Effects of Local Lesion Formation." *In: Viruses of Plants* pp. 127-50 (1966), which are hereby incorporated by reference). *Phytophthora parasitica* var. *nicotianae*, *P. tabacina* and *Pseudomonas tabaci* and reduced reproduction of the aphid *Myzus persicae*

(McIntyre, J. L., et al., "Induction of Localized and Systemic Protection Against *Phytophthora Parasitica* var. *nicotianae* by Tobacco Mosaic Virus Infection of Tobacco Hypersensitive to the Virus." *Physiological Plant Pathology* 15:321-30 (1979); McIntyre, J. L., et al., "Effects of Localized Infections of *Nicotiana tabacum* by Tobacco Mosaic Virus on Systemic Resistance Against Diverse Pathogens and an Insect," *Phytopathology* 71:297-301 (1981), which are hereby incorporated by reference). Infiltration of heat-killed *P. tabaci* (Lovrekovich, L., et al., "Induced Reaction Against Wildfire Disease in Tobacco Leaves Treated with Heat-Killed Bacteria." *Nature* 205:823-4 (1965), which is hereby incorporated by reference), and *Pseudomonas solanacearum* (Sequeira, L., et al., "Interaction of Bacteria and Host Cell Walls: Its Relation to Mechanisms of Induced Resistance," *Physiological Plant Pathology* 10:43-50 (1977), which are hereby incorporated by reference), into tobacco leaves induced resistance against the same bacteria used for infiltration. Tobacco plants were also protected by the nematode *Pratylenchus penetrans* against *P. parasitica* var. *nicotiana* (McIntyre, J. L., et al., "Protection of Tobacco Against *Phytophthora parasitica* Var. *Nicotianae* by Cultivar-Nonpathogenic Races, Cell-Free Sonicates and *Pratylenchus Penetrans*," *Phytopathology* 68:235-9 (1978), which is hereby incorporated by reference).

Cruikshank, I. A. M., et al., "The Effect of Stem Infestation of Tobacco with *Peronospora tabacina* Adam on Foliage Reaction to Blue Mould." *Journal of the Australian Institute of Agricultural Science* 26:369-72 (1960), which is hereby incorporated by reference, were the first to report immunization of tobacco foliage against blue mould (i.e., *P. tabacina*) by stem injection with the fungus, which also involved dwarfing and premature senescence. It was recently discovered that injection external to the xylem not only alleviated stunting but also promoted growth and development. Immunized tobacco plants, in both glasshouse and field experiments, were approximately 40% taller, had a 40% increase in dry weight, 30% increase in fresh weight, and 4-6 more leaves than control plants (Tuzun, S., et al., "The Effect of Stem Injections with *Peronospora tabacina* and Metalaxyl Treatment on Growth of Tobacco and Protection Against Blue Mould in the Field." *Phytopathology* 74:804 (1984), which is hereby incorporated by reference). These plants flowered approximately 2-3 weeks earlier than control plants (Tuzun, S., et al., "Movement of a Factor in Tobacco Infected with *Peronospora tabacina* Adam which Systemically Protects Against Blue Mould," *Physiological Plant Pathology* 26:321-30 (1985), which is hereby incorporated by reference).

Systemic protection does not confer absolute immunity against infection, but reduces the severity of the disease and delays symptom development. Lesion number, lesion size, and extent of sporulation of fungal pathogens are all decreased. The diseased area may be reduced by more than 90%.

When cucumbers were given a 'booster' inoculation 3-6 weeks after the initial inoculation, immunization induced by *C. lagenarium* lasted through flowering and fruiting (Kuc, J., et al., "Aspects of the Protection of Cucumber Against *Colletotrichum lagenarium* by *Colletotrichum lagenarium*," *Phytopathology* 67:533-6 (1977), which is hereby incorporated by reference). Protection could not be induced once plants had set fruit. Tobacco plants were immunized for the growing season by stem injection with sporangia of *P. tabacina*. However, to prevent systemic blue mould development, this technique was only effective when the plants were above 20 cm in height.



Removal of the inducer leaf from immunized cucumber plants did not reduce the level of immunization of pre-existing expanded leaves. However, leaves which subsequently emerged from the apical bud were progressively less protected than their predecessors (Dean, R. A., et al., "Induced Systemic Protection in Cucumber: Time of Production and Movement of the 'Signal'," *Phytopathology* 76:966-70 (1986), which is hereby incorporated by reference). Similar results were reported by Ross, A. F., "Systemic Effects of Local Lesion Formation," *In: Viruses of Plants* pp. 127-50 (1966), which is hereby incorporated by reference, with tobacco (local lesion host) immunized against tobacco mosaic virus by prior infection with tobacco mosaic virus. In contrast, new leaves which emerged from scions excised from tobacco plants immunized by stem-injection with *P. tabacina* were highly protected (Tuzun, S., et al., "Transfer of Induced Resistance in Tobacco to Blue Mould (*Peronospora tabacina* Adam.) Via Callus," *Phytopathology* 75:1304 (1985), which is hereby incorporated by reference). Plants regenerated via tissue culture from leaves of immunized plants showed a significant reduction in blue mould compared to plants regenerated from leaves of non-immunized parents. Young regenerants only showed reduced sporulation. As plants aged, both lesion development and sporulation were reduced. Other investigators, however, did not reach the same conclusion, although a significant reduction in sporulation in one experiment was reported (Lucas, J. A., et al., "Nontransmissibility to Regenerants from Protected Tobacco Explants of Induced Resistance to *Peronospora hyoscyami*," *Phytopathology* 75:1222-5 (1985), which is hereby incorporated by reference).

Protection of cucumber and watermelon is effective in the glasshouse and in the field (Caruso, F. L., et al., "Field Protection of Cucumber Against *Colletotrichum lagenarium* by *C. Lagenarium*," *Phytopathology* 67:1290-2 (1977), which is hereby incorporated by reference). In one trial, the total lesion area of *C. lagenarium* on protected cucumber was less than 2% of the lesion areas on unprotected control plants. Similarly, only 1 of 66 protected, challenged plants died, whereas 47 of 69 unprotected, challenged watermelons died. In extensive field trials in Kentucky and Puerto Rico, stem injection of tobacco with sporangia of *P. tabacina* was at least as effective in controlling blue mould as the best fungicide, metalaxyl. Plants were protected 95-99%, based on the necrotic area and degree of sporulation, leading to a yield increase of 10-25% in cured tobacco.

Induced resistance against bacteria and viruses appears to be expressed as suppression of disease symptoms or pathogen multiplication or both (Caruso, F. L., et al., "Induced Resistance of Cucumber to Anthracnose and Angular Leaf Spot by *Pseudomonas lachrymans* and *Colletotrichum lagenarium*," *Physiological Plant Pathology* 14:191-201 (1979); Doss, M., et al., "Systemic Acquired Resistance of Cucumber to *Pseudomonas lachrymans* as Expressed in Suppression of Symptoms, but not in Multiplication of Bacteria," *Acta Phytopathologia Academiae Scientiarum Hungaricae* 16:(3-4), 269-72 (1981); Jenness, A. E., et al., "Non-Specific Resistance to Pathogens Induced Systemically by Local Infection of Cucumber with Tobacco Necrosis Virus, *Colletotrichum lagenarium* or *Pseudomonas lachrymans*," *Phytopathologia mediterranea* 18:129-34 (1979), which are hereby incorporated by reference).

As described above, research concerning systemic acquired resistance involves infecting plants with infectious pathogens. Although studies in this area are useful in understanding how systemic acquired resistance works, eliciting

such resistance with infectious agents is not commercially useful, because such plant-pathogen contact can weaken or kill plants. The present invention is directed to overcoming this deficiency.

#### SUMMARY OF THE INVENTION

The present invention relates to a method of imparting pathogen resistance to plants. This method involves applying a hypersensitive response elicitor polypeptide or protein in a non-infectious form to a plant under conditions where the polypeptide or protein contacts cells of the plant.

Another aspect of the present invention relates to a pathogen-resistant plant with cells in contact with non-infectious hypersensitive response elicitor polypeptide or protein.

Yet another aspect of the present invention relates to a composition for imparting pathogen resistance to plants. The composition includes a non-infectious, hypersensitive response elicitor polypeptide or protein and a carrier.

The present invention has the potential to: treat plant diseases which were previously untreatable; treat diseases systemically that one would not want to treat separately due to cost; and avoid the use of infectious agents to treat diseases. The present invention can impart resistance without using agents pathogenic to the plants being treated or to plants situated nearby those treated. Since the present invention involves use of a natural product that is fully biodegradable, the environment would not be contaminated.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the genetic organization of the gene cluster encoding the hypersensitive response elicitor polypeptide or protein for *Erwinia amylovora* (i.e. hrpN). The top line shows the restriction enzyme map of plasmid vector pCPP430, where E=Eco RI, B=Bam HI, and H=Hind III. The rectangles represent transcriptional units, and the arrows under the rectangles indicate the directions of transcription. The bigger arrow indicates the region necessary for ultimate translation of the hypersensitive response elicitor polypeptide or protein. pCPP430 hrpN is the derivative of pCPP430 in which hrpN is mutated by the insertion of transposon TnStac.

FIG. 2 is a map of plasmid vector pCPP9. Significant features are the mobilization (mob) site for conjugation; the cohesive site of  $\lambda$  (cos); and the partition region (par) for stable inheritance of the plasmid. B, BamHI; E, EcoRI; H, HindIII; P, PstI; S, SaII; Sm, SmaI; oriV, origin of replication; Spr, spectinomycin resistance; Smr, streptomycin resistance.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method of imparting pathogen resistance to plants. This method involves applying a hypersensitive response elicitor polypeptide or protein in a non-infectious form to all or part of a plant under conditions where the polypeptide or protein contacts all or part of the cells of the plant.

Another aspect of the present invention relates to a pathogen-resistant plant with cells in contact with a non-infectious hypersensitive response elicitor polypeptide or protein.

Yet another aspect of the present invention relates to a composition for imparting pathogen resistance to plants. The composition includes a non-infectious hypersensitive response elicitor polypeptide or protein and a carrier.

The hypersensitive response elicitor polypeptide or protein utilized in the present invention can correspond to hypersensitive response elicitor polypeptides or proteins derived from a wide variety of pathogens. Such polypeptides or proteins are able to elicit local necrosis in plant tissue contacted by the elicitor. Preferred pathogens include *Erwinia amylovora*, *Erwinia chrysanthemi*, *Pseudomonas syringae*, *Pseudomonas solanacearum*, *Xanthomonas campestris*, or mixtures thereof.

For purposes of the present invention, non-infectious forms of the hypersensitive response elicitor polypeptide or protein can induce a hypersensitive response without causing disease in the plant with which the polypeptide or protein is contacted. This can be achieved in a number of ways, including: 1) application of an isolated elicitor polypeptide or protein; 2) application of bacteria which do not cause disease and are transformed with genes encoding a hypersensitive response elicitor polypeptide or protein; and 3) application of bacteria which cause disease in some plant species (but not in those to which they are applied) and naturally contain a gene encoding the hypersensitive response elicitor polypeptide or protein.

In one embodiment of the present invention, the hypersensitive response elicitor polypeptides or proteins can be isolated from their corresponding organisms and applied to plants. Such isolation procedures are well known, as described in Arlat, M., F. Van Gijsegem, J. C. Huet, J. C. Pemollet, and C. A. Boucher, "PopA1, a Protein which Induces a Hypersensitive-like Response in Specific *Petunia* Genotypes is Secreted via the Hrp Pathway of *Pseudomonas solanacearum*," *EMBO J.* 13:543-553 (1994); He, S. Y., H. C. Huang, and A. Collmer, "*Pseudomonas syringae* pv. *syringae* Harpin<sub>Psu</sub>: a Protein that is Secreted via the Hrp Pathway and Elicits the Hypersensitive Response in Plants," *Cell* 73:1255-1266 (1993); and Wei, Z.-M., R. J. Laby, C. H. Zumoff, D. W. Bauer, S.-Y. He, A. Collmer, and S. V. Beer, "Harpin Elicitor of the Hypersensitive Response Produced by the Plant Pathogen *Erwinia amylovora*," *Science* 257:85-88 (1992), which are hereby incorporated by reference. See also pending U.S. patent application Ser. Nos. 08/200,024 and 08/062,024, which are hereby incorporated by reference. Preferably, however, the isolated hypersensitive response elicitor polypeptides or proteins of the present invention are produced recombinantly and purified as described below.

In other embodiments of the present invention, the hypersensitive response elicitor polypeptide or protein of the present invention can be applied to plants by applying bacteria containing genes encoding the hypersensitive response elicitor polypeptide or protein. Such bacteria must be capable of secreting or exporting the polypeptide or protein so that the elicitor can contact plant cells. In these embodiments, the hypersensitive response elicitor polypeptide or protein is produced by the bacteria in planta or just prior to introduction of the bacteria to the plants.

In one embodiment of the bacterial application mode of the present invention, the bacteria do not cause the disease and have been transformed (e.g., recombinantly) with genes encoding a hypersensitive response elicitor polypeptide or protein. For example, *E. coli*, which do not elicit a hypersensitive response in plants, can be transformed with genes encoding a hypersensitive response elicitor polypeptide or protein and then applied to plants. Bacterial species (other than *E. coli*) can also be used in this embodiment of the present invention.

In another embodiment of the bacterial application mode of the present invention, the bacteria do cause disease and

naturally contain a gene encoding a hypersensitive response elicitor polypeptide or protein. Examples of such bacteria are noted above. However, in this embodiment these bacteria are applied to plants which are not susceptible to the disease carried by the bacteria. For example, *Erwinia amylovora* causes disease in apple or pear but not in tomato. However, such bacteria will elicit a hypersensitive response in tomato. Accordingly, in accordance with this embodiment of the present invention, *Erwinia amylovora* can be applied to tomato to impart pathogen resistance without causing disease in that species.

The hypersensitive response elicitor polypeptide or protein from *Erwinia chrysanthemi* has an amino acid sequence corresponding to SEQ. ID. No. 1 as follows:

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Met Gln Ile Thr Ile Lys Ala His Ile Gly Gly Asp Leu Gly Val Ser
1          5          10          15
Gly Leu Gly Ala Gln Gly Leu Lys Gly Leu Asn Ser Ala Ala Ser Ser
20          20          25          30
Leu Gly Ser Ser Val Asp Lys Leu Ser Ser Thr Ile Asp Lys Leu Thr
35          40          45
Ser Ala Leu Thr Ser Met Met Phe Gly Gly Ala Leu Ala Gln Gly Leu
25          50          55          60
Gly Ala Ser Ser Lys Gly Leu Gly Met Ser Asn Gln Leu Gly Gln Ser
65          70          75          80
Phe Gly Asn Gly Ala Gln Gly Ala Ser Asn Leu Leu Ser Val Pro Lys
30          85          90          95
Ser Gly Gly Asp Ala Leu Ser Lys Met Phe Asp Lys Ala Leu Asp Asp
100          105          110
Leu Leu Gly His Asp Thr Val Thr Lys Leu Thr Asn Gln Ser Asn Gln
35          115          120          125
Leu Ala Asn Ser Met Leu Asn Ala Ser Gln Met Thr Gln Gly Asn Met
130          135          140
Asn Ala Phe Gly Ser Gly Val Asn Asn Ala Leu Ser Ser Ile Leu Gly
40          145          150          155          160
Asn Gly Leu Gly Gln Ser Met Ser Gly Phe Ser Gln Pro Ser Leu Gly
165          170          175
Ala Gly Gly Leu Gln Gly Leu Ser Gly Ala Gly Ala Phe Asn Gln Leu
45          180          185          190
Gly Asn Ala Ile Gly Met Gly Val Gly Gln Asn Ala Ala Leu Ser Ala
195          200          205
Leu Ser Asn Val Ser Thr His Val Asp Gly Asn Asn Arg His Phe Val
50          210          215          220
Asp Lys Glu Asp Arg Gly Met Ala Lys Glu Ile Gly Gln Phe Met Asp
225          230          235          240
Gln Tyr Pro Glu Ile Phe Gly Lys Pro Glu Tyr Gln Lys Asp Gly Trp
55          245          250          255
Ser Ser Pro Lys Thr Asp Asp Lys Ser Trp Ala Lys Ala Leu Ser Lys
260          265          270
Pro Asp Asp Asp Gly Met Thr Gly Ala Ser Met Asp Lys Phe Arg Gln
60          275          280          285
Ala Met Gly Met Ile Lys Ser Ala Val Ala Gly Asp Thr Gly Asn Thr
290          295          300
Asn Leu Asn Leu Arg Gly Ala Gly Gly Ala Ser Leu Gly Ile Asp Ala
65          305          310          315          320

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Ala Val Val Gly Asp Lys Ile Ala Asn Met Ser Leu Gly Lys Leu Ala  
325 330 335

Gly Leu Ser Asn Ala Leu Asn Asp Met Leu Gly Gly Ser Leu Asn Thr  
100 105 110

Asn Ala

5 Leu Gly Ser Lys Gly Gly Asn Asn Thr Thr Ser Thr Thr Asn Ser Pro  
115 120 125

This hypersensitive response elicitor polypeptide or protein has a molecular weight of 34 kDa, is heat stable, has a glycine content of greater than 16%, and contains substantially no cysteine. The *Erwinia chrysanthemi* hypersensitive response elicitor polypeptide or protein is encoded by a DNA molecule having a nucleotide sequence corresponding to SEQ. ID. No. 2 as follows:

Leu Asp Gln Ala Leu Gly Ile Asn Ser Thr Ser Gln Asn Asp Asp Ser  
130 135 140

10 Thr Ser Gly Thr Asp Ser Thr Ser Asp Ser Ser Asp Pro Met Gln Gln  
145 150 155 160

CGATTTTACC	CGGGTGAACG	TGCTATGACC	GACAGCATCA	CGGTATTGCA	CACCGTACG	60
GCGTTTATGG	CCGCGATGAA	CCGGCATCAG	GCGGCGCGCT	GGTCCGCCGA	ATCCGGCGCT	120
GAICTGGTAT	TCAGTTTGG	GGACACCGGG	CGTGAAC TCA	TGATGCAGAT	TCAGCCGGGG	180
CAGCAATACT	CCGGCATGTT	GCCGACCGTG	CTCGCTCGTC	GTTATCAGCA	GGCGGCAGAG	240
TGCGATGGCT	GCCATCTGTG	CCTGAACGGC	AGCGATGTAT	TGATCCTCTG	GTGGCCGCTG	300
CCGTCGGATC	CCGGCACTTA	TCCGCAAGTG	ATCGAACGTT	TGTTTGAAC	GGCGGGAATG	360
ACGTTGCCGT	CGCTATCCAT	AGCACCGACG	GCGCGTCCGC	AGACAGGGAA	CGGACGCGCC	420
CGATCAITAA	GATAAAGCGG	GCITTTTTTA	TTGCAAAACG	GTAACGGTGA	GGAACCGTTT	480
CACCGTCGGC	GTCACTCAGT	AACAAGTATC	CATCATGATG	CCTACATCGG	GATCGGCGTG	540
GGCATCCGTT	GCAGATACTT	TTGCGAACAC	CTGACATGAA	TGAGGAAACG	AAATATGCA	600
AAITACGATC	AAAGCGCACA	TCCGGCGTGA	TTTGGGCGTC	TCCGGTCTGG	GGCTGGGTGC	660
TCAGGGACTG	AAAGGACTGA	ATTCGCGGCG	TTCATCGCTG	GGTTCACGCG	TGGATAAACT	720
GAGCAGCACC	ATCGATAAGT	TGACCTCCGC	GCTGACTTCG	ATGATGTTTG	GCGGCGCGCT	780
GGCGCAGGGG	CTGGGCGCCA	GCTCGAAGGG	GCTGGGGATG	AGCAATCAAC	TGGGCCAGTC	840
TTTCGGCAAT	GGCGCGCAGG	GTGCGAGCAA	CCTGCTATCC	GTACCGAAAT	CCGGCGGCGA	900
TGCGTTGTCA	AAAATGTTTG	ATAAAGCGCT	GGACGATCTG	CTGGGTCATG	ACACCGTGAC	960
CAAGCTGACT	AACCAGAGCA	ACCAACTGGC	TAATTCATATG	CTGAACGCCA	GCCAGATGAC	1020
CCAGGGTAAT	ATGAATCGGT	TCGGCAGCGG	TGTGAACAAC	GCACGTCTGT	CCATCTCGG	1080
CAACGGTCTC	GGCCAGTCGA	TGAGTGGCTT	CTCTAGCCT	TCTCTGGGGG	CAGGGCGCTT	1140
GCGAGGCCTG	AGCGGCGCGG	GTGCAITCAA	CCAGTGGGT	AAITGCCATCG	GCAITGGCGCT	1200
GGGGCAGAAT	AAATCTGGG	ATAAAGCCT	TAACGTCAAG	ACCCACGTAG	ACGGTAAACA	1260
CCGCCACTTT	GTAGATAAAG	AAGATCGCGG	CATGGCGAAA	GAGATCGGCC	AGTTTATGGA	1320
TCAGTATCCG	GAATATTTCC	GTAACCAGAA	ATACCAGAAA	GATGGCTGGA	GTTCCCGGAA	1380
CGCGGACGAC	AAATCTGGG	C1AAAGCCT	GAGTAAACCG	GATGATGACG	GTATGACCGG	1440
CGCCAGCATG	GACAAATCC	GTCAGGCGAT	GGGTATGATC	AAAAGCGCGG	TGGCGGGTGA	1500
TACCGGCAAT	ACCAACTGA	ACCTGCGTGG	C1CGGGCGGT	GCAITCGCTGG	G1ATCGATGC	1560
GGCTGTCTGC	GGCGATAAAA	TAGCCAACAT	GTCCTGGGT	AAGCTGGCCA	ACGCCTGATA	1620
ATCTGTGCTG	GCCTGATAAA	GCGGAAACGA	AAAAAGAGAC	GGGGAAGCCT	G1CTCTTTTC	1680
TTATTATGCG	GTTTATGCGG	TTACCTGGAC	CGGTTAATCA	TCGTCATCGA	TCTGGTACAA	1740
ACGCACAITT	TCCCGTTCAT	TCCGCTCGTT	ACGCGCCACA	ATCGCGATGG	CATCTTCCTC	1800
GTCCGCTCAGA	TTGCGCGGCT	GATGGGGAAC	GCCGGGTGGA	ATATAGAGAA	ACTCGCCGGC	1860
CAGATGGAGA	CACGTCTGCG	ATAAATCTGT	GCCGTAACGT	GTTTCTATCC	GCCCTTTTAG	1920
CAGATAGATT	GCGGTTTCGT	AATCAACATG	GTAATGCGGT	TCCGCTGTGT	CGCCGGCCGG	1980
GATCACCACA	ATAITCATAG	AAAGCTGTCT	TGCACCTACC	GTATCGCGGG	AGATACCGAC	2040
AAAATAGGGC	AGTTTTGCGG	TGGTATCCGT	GGGTGTTC	GGCTGACAA	TCTTGAGTTG	2100
GTTCTGATC	ATCTTTCTCC	ATCTGGGCGA	CCTGATCGGT	T		2141

The hypersensitive response elicitor polypeptide or protein derived from *Erwinia amylovora* has an amino acid sequence corresponding to SEQ. ID. No. 3 as follows:

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Met Ser Leu Asn Thr Ser Gly Leu Gly Ala Ser Thr Met Gln Ile Ser  
1 5 10 15

Leu Leu Lys Met Phe Ser Glu Ile Met Gln Ser Leu Phe Gly Asp Gly  
50 165 170 175

Ile Gly Gly Ala Gly Gly Asn Asn Gly Leu Leu Gly Thr Ser Arg Gln  
20 25 30

Gln Asp Gly Thr Gln Gly Ser Ser Ser Gly Gly Lys Gln Pro Thr Glu  
180 185 190

Asn Ala Gly Leu Gly Gly Asn Ser Ala Leu Gly Leu Gly Gly Gly Asn  
35 40 45

Gly Glu Gln Asn Ala Tyr Lys Lys Gly Val Thr Asp Ala Leu Ser Gly  
55 195 200 205

Gln Asn Asp Thr Val Asn Gln Leu Ala Gly Leu Leu Thr Gly Met Met  
50 55 60

Leu Met Gly Asn Gly Leu Ser Gln Leu Leu Gly Asn Gly Gly Leu Gly  
210 215 220

Met Met Met Ser Met Met Gly Gly Gly Gly Leu Met Gly Gly Gly Leu  
65 70 75 80

Gly Gly Gln Gly Gly Asn Ala Gly Thr Gly Leu Asp Gly Ser Ser Leu  
60 225 230 235 240

Gly Gly Gly Leu Gly Asn Gly Leu Gly Gly Ser Gly Gly Leu Gly Glu  
85 90 95

Gly Gly Lys Gly Leu Gln Asn Leu Ser Gly Pro Val Asp Tyr Gln Gln  
245 250 255

Leu Gly Asn Ala Val Gly Thr Gly Ile Gly Met Lys Ala Gly Ile Gln  
65 260 265 270

11

-continued

Ala Leu Asn Asp Ile	Gly Thr His Arg His Ser Ser Thr Arg Ser Phe	Pro
275	280	385
Val Asn Lys Gly Asp Arg Ala Met Ala Lys Glu Ile Gly Gln Phe Met		5
290	295	300
Asp Gln Tyr Pro Glu Val Phe Gly Lys Pro Gln Tyr Gln Lys Gly Pro		
305	310	315
Gly Gln Glu Val Lys Thr Asp Asp Lys Ser Trp Ala Lys Ala Leu Ser		10
	325	330
Lys Pro Asp Asp Asp Gly Met Thr Pro Ala Ser Met Glu Gln Phe Asn		
	340	345
Lys Ala Lys Gly Met Ile Lys Arg Pro Met Ala Gly Asp Thr Gly Asn		15
	355	360
Gly Asn Leu Gln His Ala Val Pro Val Val Leu Arg Trp Val Leu Met		
	370	375
		380

12

-continued

This hypersensitive response elicitor polypeptide or protein has a molecular weight of about 37 kDa, it has a pI of approximately 4.3, and is heat stable at 100° C. for at least 10 minutes. This hypersensitive response elicitor polypeptide or protein has substantially no cysteine. The hypersensitive response elicitor polypeptide or protein derived from *Erwinia amylovora* is more fully described in Wei, Z.-M., R. J. Laby, C. H. Zumoff, D. W. Bauer, S.-Y. He, A. Collmer, and S. V. Beer, "Harpin, Elicitor of the Hypersensitive Response Produced by the Plant Pathogen *Erwinia amylovora*," *Science* 257:85-88 (1992), which is hereby incorporated by reference. The DNA molecule encoding this polypeptide or protein has a nucleotide sequence corresponding to SEQ. ID. No. 4 as follows:

ATGAGTCTGA	ATACAAGTGG	GCTGGGAGCG	TCAACGATGC	AAATTCTAT	CGGCGGTGCG	60
GGCGGAAATA	ACGGGTTGCT	GGGTACCACT	CGCCAGAATG	CTGGGTTGGG	TGGCAATTCT	120
GCACTGGGGC	TGGGCGGCGG	TAATCAAAT	GATACCGTCA	ATCAGCTGGC	TGGCTIACCT	180
ACCGGCATGA	TGATGATGAT	GAGCATGATG	GGCGGTGGTG	GGCTGATGGG	CGGTGGCTTA	240
GGCGGTGGCT	TAGGTAATGG	CTTGGGTGGC	TCAGGTGGCC	TGGCGAAGG	ACTGTCGAAC	300
GCGCTGAACG	ATATGTTAGG	CGGTTCGCTG	AACACGCTGG	GCTCGAAAGG	CGGCAACAAT	360
ACCACTCAA	CAACAAATTC	CCCGCTGGAC	CAGGCGCTGG	GTATTAATC	AACGTCCCAA	420
AACGACGATT	CCACCTCCGG	CACAGAITCC	ACCTCAGACT	CCAGCGACCC	GATGCAGCAG	480
CTGCTGAAGA	TGTTCAAGCGA	GATAATGCAA	AGCCTGTTTG	GTGATGGGCA	AGATGGCACC	540
CAGGGCAGTT	CCTCTGGGGG	CAAGCAGCCG	ACCGAAGGCG	AGCAGAACGC	CTATAAAAAA	600
GGAGTCACTG	ATGCGCTGTC	GGGCCTGATG	GGTAAATGGTC	TGAGCCAGCT	CCTTGGCAAC	660
GGGGGACTGG	GAGGTGGTCA	GGGCGTAAT	GCTGGCACGG	GTCTTGACGG	TTCGTGCGTG	720
GGCGGCAAAG	GGCTGCAAAA	CCTGAGCGGG	CCGGTGGACT	ACCAGCAGTT	AGGTAACGCC	780
GTGGGTACCG	GTATCGGTAT	GAAAGCGGGC	AITCAGGCGC	TGAATGATAT	CGGTACGCAC	840
AGGCACAGTT	CAACCCGTTT	TTTCGTCAAT	AAAGCGGATC	GGGCGATGGC	GAAAGGAAATC	900
GGTCAAGTCA	TGGACCAAGTA	TCCTGAGGTG	TTTGGCAAAGC	CGCAGTACCA	GAAAGGCCCG	960
GGTCAGGAGG	TGAAAACCGA	TGACAAATCA	TGGGCAAAAAG	CACTGAGCAA	GCCAGATGAC	1020
GACCGAATGA	CACCAGCCAG	TATGGAGCAG	TTCAACAAAG	CCAAGGGCAT	GATCAAAAAGG	1080
CCCATGGCCG	GTGATACCGG	CAACGGCAAC	CTGCAGCACG	CGGTGCCGGT	GGTTCCTCGC	1140
TGGGTATTGA	TGCCATGA					1158

The hypersensitive response elicitor polypeptide or protein derived from *Pseudomonas syringae* has an amino acid sequence corresponding to SEQ. ID. No. 5 as follows:

Met	Gln	Ser	Leu	Ser	Leu	Asn	Ser	Ser	Ser	Leu	Gln	Thr	Pro	Ala	Met
1				5					10					15	
Ala	Leu	Val	Leu	Val	Arg	Pro	Glu	Ala	Glu	Thr	Thr	Gly	Ser	Thr	Ser
			20					25					30		
Ser	Lys	Ala	Leu	Gln	Glu	Val	Val	Val	Lys	Leu	Ala	Glu	Glu	Leu	Met
		35					40					45			
Arg	Asn	Gly	Gln	Leu	Asp	Asp	Ser	Ser	Pro	Leu	Gly	Lys	Leu	Leu	Ala
	50					55					60				
Lys	Ser	Met	Ala	Ala	Asp	Gly	Lys	Ala	Gly	Gly	Gly	Ile	Glu	Asp	Val
					70					75					80
Ile	Ala	Ala	Leu	Asp	Lys	Leu	Ile	His	Glu	Lys	Leu	Gly	Asp	Asn	Phe
				85					90					95	
Gly	Ala	Ser	Ala	Asp	Ser	Ala	Ser	Gly	Thr	Gly	Gln	Gln	Asp	Leu	Met
			100					105					110		
Thr	Gln	Val	Leu	Asn	Gly	Leu	Ala	Lys	Ser	Met	Leu	Asp	Asp	Leu	Leu
			115				120					125			

-continued

Thr	Lys	Gln	Asp	Gly	Gly	Thr	Ser	Phe	Ser	Glu	Asp	Asp	Met	Pro	Met
	130					135					140				
Leu	Asn	Lys	Ile	Ala	Gln	Phe	Met	Asp	Asp	Asn	Pro	Ala	Gln	Phe	Pro
145					150					155					160
Lys	Pro	Asp	Ser	Gly	Ser	Trp	Val	Asn	Glu	Leu	Lys	Glu	Asp	Asn	Phe
				165					170					175	
Leu	Asp	Gly	Asp	Glu	Thr	Ala	Ala	Phe	Arg	Ser	Ala	Leu	Asp	Ile	Ile
			180					185					190		
Gly	Gln	Gln	Leu	Gly	Asn	Gln	Gln	Ser	Asp	Ala	Gly	Ser	Leu	Ala	Gly
		195					200					205			
Thr	Gly	Gly	Gly	Leu	Gly	Thr	Pro	Ser	Ser	Phe	Ser	Asn	Asn	Ser	Ser
	210					215					220				
Val	Met	Gly	Asp	Pro	Leu	Ile	Asp	Ala	Asn	Thr	Gly	Pro	Gly	Asp	Ser
225					230					235					240
Gly	Asn	Thr	Arg	Gly	Glu	Ala	Gly	Gln	Leu	Ile	Gly	Glu	Leu	Ile	Asp
				245					250					255	
Arg	Gly	Leu	Gln	Ser	Val	Leu	Ala	Gly	Gly	Gly	Leu	Gly	Thr	Pro	Val
			260					265					270		
Asn	Thr	Pro	Gln	Thr	Gly	Thr	Ser	Ala	Asn	Gly	Gly	Gln	Ser	Ala	Gln
		275					280					285			
Asp	Leu	Asp	Gln	Leu	Leu	Gly	Gly	Leu	Leu	Leu	Lys	Gly	Leu	Glu	Ala
	290					295					300				
Thr	Leu	Lys	Asp	Ala	Gly	Gln	Thr	Gly	Thr	Asp	Val	Gln	Ser	Ser	Ala
305					310					315					320
Ala	Gln	Ile	Ala	Thr	Leu	Leu	Val	Ser	Thr	Leu	Leu	Gln	Gly	Thr	Arg
				325					330					335	
Asn	Gln	Ala	Ala	Ala											
			340												

This hypersensitive response elicitor polypeptide or protein has a molecular weight of 34–35 kDa. It is rich in glycine (about 13.5%) and lacks cysteine and tyrosine. Further information about the hypersensitive response elicitor derived from *Pseudomonas syringae* is found in He, S. Y., H. C. Huang, and A. Collmer, "*Pseudomonas syringae* pv.

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*syringae* Harpin<sub>PSs</sub>: a Protein that is Secreted via the Hrp Pathway and Elicits the Hypersensitive Response in Plants." *Cell* 73:1255–1266 (1993), which is hereby incorporated by reference. The DNA molecule encoding the hypersensitive response elicitor from *Pseudomonas syringae* has a nucleotide sequence corresponding to SEQ. ID. No. 6 as follows:

ATGCAGAGTC	TCAGTCTTAA	CAGCAGCTCG	CTGCAAACCC	CGGCAATGGC	CCTTGTCCTG	60
GTACGTCCTG	AAGCCGAGAC	GACTGGCAGT	ACGTCGAGCA	AGGCGCTTCA	GGAAAGTTGTC	120
GTGAAGCTGG	CCGAGGAACT	GATGCGCAAT	GGTCAACTCG	ACGACAGCTC	GCCAITGGGA	180
AAACTGTITGG	CCAAGTCGAT	GGCCGCGAT	GGCAAGGCGG	GCGGCGGTAT	TGAGGATGTC	240
ATCGTGTGCG	TGGACAAGCT	GATCCATGAA	AAGCTCGGTG	ACAACCTTCG	CGCGTCTGCG	300
GACAGCGCCT	CGGGTACCGG	ACAGCAGGAC	CTGATGACTC	AGGTGCTCAA	TGGCCTGGCC	360
AAGTCGATGC	TCGATGATCT	TCTGACCAAG	CAGGATGGCG	GGACAAGCTT	CTCCGAAGAC	420
GATATGCCGA	TGCTGAACAA	GATCGGCGAG	TTCATGGATG	ACAATCCCGC	ACAGTTTCCC	480
AAGCCGGACT	CGGGCTCCTG	GGTGAACGAA	CTCAAGGAAG	ACAACCTTCT	TGATGGCGAC	540
GAAACGGCTG	CGTCCGTTT	GGCACTCGAC	ATCATTGGCC	AGCAACTGGG	TAATCAGCAG	600
AGTGACGCTG	GCAGTCTGGC	AGGGACGGGT	GGAGGTCTGG	GCCTCCGAG	CAGTTTTTCC	660
AACAACCTGT	CCGTGATGGG	TGATCCGCTG	ATCGACGCCA	ATACCGTCC	CGGTGACAGC	720
GGCAATACCC	GTGGTGAAGC	GGGGCAACTG	ATCGGCGAGC	TTATCGACCG	TGGCCTGCAA	780
TCGGTATTGG	CCGGTGGTGG	ACTGGGCACA	CCCGTAAACA	CCCCGCAGAC	CGGTACGTCG	840
GCGAATGGCG	GACAGTCCCG	TCAGGATCTT	GATCAGTTGC	TGGGCGGCTT	GCTGTCTAAG	900
GGCTGGAGG	CAACGCTCAA	GGATGCCGGG	CAAACAGGCA	CCGACGTGCA	GTGAGCGCT	960
GCGCAAATCG	CCACCTTGCT	GGTCAGTACG	CTGCTGCAAG	GCACCCGCAA	TCAGGCTGCA	1020
GCCTGA						1026

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The hypersensitive response elicitor polypeptide or protein derived from *Pseudomonas solanacearum* has an amino acid sequence corresponding to SEQ. ID. No. 7 as follows:

Met	Ser	Val	Gly	Asn	Ile	Gln	Ser	Pro	Ser	Asn	Leu	Pro	Gly	Leu	Gln
1				5					10					15	

-continued

Asn	Leu	Asn	Leu	Asn	Thr	Asn	Thr	Asn	Ser	Gln	Gln	Ser	Gly	Gln	Ser
			20					25					30		
Val	Gln	Asp	Leu	Ile	Lys	Gln	Val	Glu	Lys	Asp	Ile	Leu	Asn	Ile	Ile
		35					40					45			
Ala	Ala	Leu	Val	Gln	Lys	Ala	Ala	Gln	Ser	Ala	Gly	Gly	Asn	Thr	Gly
	50					55					60				
Asn	Thr	Gly	Asn	Ala	Pro	Ala	Lys	Asp	Gly	Asn	Ala	Asn	Ala	Gly	Ala
65					70					75					80
Asn	Asp	Pro	Ser	Lys	Asn	Asp	Pro	Ser	Lys	Ser	Gln	Ala	Pro	Gln	Ser
				85					90					95	
Ala	Asn	Lys	Thr	Gly	Asn	Val	Asp	Asp	Ala	Asn	Asn	Gln	Asp	Pro	Met
			100					105					110		
Gln	Ala	Leu	Met	Gln	Leu	Leu	Glu	Asp	Leu	Val	Lys	Leu	Leu	Lys	Ala
		115					120					125			
Ala	Leu	His	Met	Gln	Gln	Pro	Gly	Gly	Asn	Asp	Lys	Gly	Asn	Gly	Val
	130					135					140				
Gly	Gly	Ala	Asn	Gly	Ala	Lys	Gly	Ala	Gly	Gly	Gln	Gly	Gly	Leu	Ala
145					150					155					160
Glu	Ala	Leu	Gln	Glu	Ile	Glu	Gln	Ile	Leu	Ala	Gln	Leu	Gly	Gly	Gly
				165					170					175	
Gly	Ala	Gly	Ala	Gly	Gly	Ala	Gly	Gly	Gly	Val	Gly	Gly	Ala	Gly	Gly
			180					185					190		
Ala	Asp	Gly	Gly	Ser	Gly	Ala	Gly	Gly	Ala	Gly	Gly	Ala	Asn	Gly	Ala
		195					200					205			
Asp	Gly	Gly	Asn	Gly	Val	Asn	Gly	Asn	Gln	Ala	Asn	Gly	Pro	Gln	Asn
	210					215						220			
Ala	Gly	Asp	Val	Asn	Gly	Ala	Asn	Gly	Ala	Asp	Asp	Gly	Ser	Glu	Asp
225				230						235					240
Gln	Gly	Gly	Leu	Thr	Gly	Val	Leu	Gln	Lys	Leu	Met	Lys	Ile	Leu	Asn
				245					250					255	
Ala	Leu	Val	Gln	Met	Met	Gln	Gln	Gly	Gly	Leu	Gly	Gly	Gly	Asn	Gln
			260					265					270		
Ala	Gln	Gly	Gly	Ser	Lys	Gly	Ala	Gly	Asn	Ala	Ser	Pro	Ala	Ser	Gly
		275					280					285			
Ala	Asn	Pro	Gly	Ala	Asn	Gln	Pro	Gly	Ser	Ala	Asp	Asp	Gln	Ser	Ser
	290					295					300				
Gly	Gln	Asn	Asn	Leu	Gln	Ser	Gln	Ile	Met	Asp	Val	Val	Lys	Glu	Val
305				310						315					320
Val	Gln	Ile	Leu	Gln	Gln	Met	Leu	Ala	Ala	Gln	Asp	Gly	Gly	Ser	Gln
				325					330					335	
Gln	Ser	Thr	Ser	Thr	Gln	Pro	Met								
			340												

It is encoded by a DNA molecule having a nucleotide sequence corresponding SEQ. ID. No. 8 as follows:

ATGTCAGTCG	GAAACATCCA	GAGCCCGTCG	AACCTCCCGG	GTCTGCAGAA	CCTGAACCTC	60
AACACCAACA	CCAACAGCCA	GCAATCGGGC	CAGTCCGTGC	AAGACCTGAT	CAAGCAGGTC	120
GAGAAGGACA	TCCTCAACAT	CATCGCAGCC	CTCGTGCAGA	AGGCCGCACA	GTCCGCGGGC	180
GGCAACACCG	GTAACACCGG	CAACGCGCCG	GCGAAGGACG	GCAATGCCAA	CGCGGGCGCC	240
AACGACCCGA	GCAAGAACGA	CCCGAGCAAG	AGCCAGGCTC	CGCAGTCGGC	CAACAAGACC	300
GGCAACGTCG	ACGACGCCAA	CAACCAGGAT	CCGATGCAAG	CGCTGATGCA	GCTGCTGGAA	360
GACCTGGTGA	AGCTGCTGAA	GGCGGCCCTG	CACATGCAGC	AGCCCGGCGG	CAATGACAAG	420
GGCAACGGCG	TGGGCGGTGC	CAACGGCGCC	AAGGTTGCCG	GCGCCAGGG	CGGCTGGCC	480
GAAGCGCTGC	AGGAGATCGA	GCAGATCCTC	GCCAGCTCG	GCGCGGGCGG	TGCTGGCGCC	540
GGCGCGCGCG	GTGGCGGTGT	CGGCGGTGCT	GGTGGCGCGG	ATGGCGGCTC	CGGTGCGGGT	600
GGCGCAGGCG	GTGCGAACGG	CGCCGACGGC	GGCAATGGCG	TGAACGGCAA	CCAGGCGAAC	660
GGCCCGCAGA	ACGCAGGCGA	TGTCAACGGT	GCCAACGGCG	CGGATGACGG	CAGCGAAGAC	720

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CAGGGCGGCC	TCACCGGCGT	GCTGCAAAAG	CTGATGAAGA	TCCTGAACGC	GCTGGTGCAG	780
ATGATGCAGC	AAGGCGGCGT	CGGCGGCGGC	AACCAGGGCGC	AGGGCGGCTC	GAAGGGTGCC	840
GGCAACGCCT	CGCCGGCTTC	CGGCGCGAAC	CCGGCGCGGA	ACCAGCCCGG	TTCGGCGGAT	900
GATCAATCGT	CCGGCCAGAA	CAATCTGCAA	TCCCAGATCA	TGGATGTGGT	GAAGGAGGTC	960
GTCCAGATCC	TGCAGCAGAT	GCTGGCGGCG	CAGAACGGCG	GCAGCCAGCA	GTCCACCTCG	1020
ACGCAGCCGA	TGTAA					1035

Further information regarding the hypersensitive response elicitor polypeptide or protein derived from *Pseudomonas solanacearum* is set forth in Arlat, M., F. Van Gijsegem, J. C. Huet, J. C. Pemollet, and C. A. Boucher, "PopA1, a Protein which Induces a Hypersensitive-like Response in Specific Petunia Genotypes, is Secreted via the Hrp Pathway of *Pseudomonas solanacearum*," *EMBO J.* 13:543-533 (1994), which is hereby incorporated by reference.

The hypersensitive response elicitor polypeptide or protein from *Xanthomonas campestris* pv. *glycines* has an amino acid sequence corresponding to SEQ. ID. No. 9 as follows:

Thr	Leu	Ile	Glu	Leu	Met	Ile	Val	Val	Ala	Ile	Ile	Ala	Ile	Leu	Ala
1				5					10					15	
Ala	Ile	Ala	Leu	Pro	Ala	Tyr	Gln	Asp	Tyr						
			20					25							

This sequence is an amino terminal sequence having 26 residues only from the hypersensitive response elicitor polypeptide or protein of *Xanthomonas campestris* pv. *glycines*. It matches with fimbrial subunit proteins determined in other *Tanthomouas campestris* pathogens.

The above elicitors are exemplary. Other elicitors can be identified by growing bacteria that elicit a hypersensitive response under which genes encoding an elicitor are expressed. Cell-free preparations from culture supernatants can be tested for elicitor activity (i.e. local necrosis) by using them to infiltrate appropriate plant tissues.

It is also possible to use fragments of the above hypersensitive response elicitor polypeptides or proteins as well as fragments of full length elicitors from other pathogens, in the method of the present invention.

Suitable fragments can be produced by several means. In the first, subclones of the gene encoding a known elicitor protein are produced by conventional molecular genetic manipulation by subcloning gene fragments. The subclones then are expressed in vitro or in vivo in bacterial cells to yield a smaller protein or a peptide that can be tested for elicitor activity according to the procedure described below.

As an alternative, fragments of an elicitor protein can be produced by digestion of a full-length elicitor protein with proteolytic enzymes like chymotrypsin or Staphylococcus proteinase A, or trypsin. Different proteolytic enzymes are likely to cleave elicitor proteins at different sites based on the amino acid sequence of the elicitor protein. Some of the fragments that result from proteolysis may be active elicitors of resistance.

In another approach, based on knowledge of the primary structure of the protein, fragments of the elicitor protein gene may be synthesized by using the PCR technique together with specific sets of primers chosen to represent particular portions of the protein. These then would be cloned into an appropriate vector for increase and expression of a truncated peptide or protein.

Variants may also (or alternatively) be modified by, for example, the deletion or addition of amino acids that have

minimal influence on the properties, secondary structure and hydrophobic nature of the polypeptide. For example, a polypeptide may be conjugated to a signal (or leader) sequence at the N-terminal end of the protein which co-translationally or post-translationally directs transfer of the protein. The polypeptide may also be conjugated to a linker or other sequence for ease of synthesis, purification or identification of the polypeptide.

The protein or polypeptide of the present invention is preferably produced in purified form (preferably at least about 80%, more preferably 90%, pure) by conventional techniques. Typically, the protein or polypeptide of the

present invention is secreted into the growth medium of recombinant *E. coli*. To isolate the protein, the *E. coli* host cell carrying a recombinant plasmid is propagated, homogenized, and the homogenate is centrifuged to remove bacterial debris. The supernatant is then subjected to sequential ammonium sulfate precipitation. The fraction containing the polypeptide or protein of the present invention is subjected to gel filtration in an appropriately sized dextran or polyacrylamide column to separate the proteins. If necessary, the protein fraction may be further purified by HPLC.

The DNA molecule encoding the hypersensitive response elicitor polypeptide or protein can be incorporated in cells using conventional recombinant DNA technology. Generally, this involves inserting the DNA molecule into an expression system to which the DNA molecule is heterologous (i.e. not normally present). The heterologous DNA molecule is inserted into the expression system or vector in proper sense orientation and correct reading frame. The vector contains the necessary elements for the transcription and translation of the inserted protein-coding sequences.

U.S. Pat. No. 4,237,224 to Cohen and Boyer, which is hereby incorporated by reference, describes the production of expression systems in the form of recombinant plasmids using restriction enzyme cleavage and ligation with DNA ligase. These recombinant plasmids are then introduced by means of transformation and replicated in unicellular cultures including procaryotic organisms and eucaryotic cells grown in tissue culture.

Recombinant genes may also be introduced into viruses, such as vaccinia virus. Recombinant viruses can be generated by transection of plasmids into cells infected with virus.

Suitable vectors include, but are not limited to, the following viral vectors such as lambda vector system gt11, gt WES.tB, Charon 4, and plasmid vectors such as pBR322, pBR325, pACYC177, pACYC184, pUC8, pUC9, pUC18, pUC19, pLG339, pR290, pKC37, pKC101, SV 40, pBlue-script II SK ± or KS ± (see "Stratagene Cloning Systems" Catalog (1993) from Stratagene, La Jolla, Calif. which is

hereby incorporated by reference), pQE, pIH821, pGEX, pET series (see F. W. Studier et al., "Use of T7 RNA Polymerase to Direct Expression of Cloned Genes," *Gene Expression Technology* vol. 185 (1990), which is hereby incorporated by reference), and any derivatives thereof. Recombinant molecules can be introduced into cells via transformation, particularly transduction, conjugation, mobilization, or electroporation. The DNA sequences are cloned into the vector using standard cloning procedures in the art, as described by Maniatis et al., *Molecular Cloning: A Laboratory Manual*, Cold Springs Laboratory, Cold Springs Harbor, New York (1982), which is hereby incorporated by reference.

A variety of host-vector systems may be utilized to express the protein-encoding sequence(s). Primarily, the vector system must be compatible with the host cell used. Host-vector systems include but are not limited to the following: bacteria transformed with bacteriophage DNA, plasmid DNA, or cosmid DNA; microorganisms such as yeast containing yeast vectors; mammalian cell systems infected with virus (e.g., vaccinia virus, adenovirus, etc.); insect cell systems infected with virus (e.g., baculovirus); and plant cells infected by bacteria. The expression elements of these vectors vary in their strength and specificities. Depending upon the host-vector system utilized, any one of a number of suitable transcription and translation elements can be used.

Different genetic signals and processing events control many levels of gene expression (e.g., DNA transcription and messenger RNA (mRNA) translation).

Transcription of DNA is dependent upon the presence of a promoter which is a DNA sequence that directs the binding of RNA polymerase and thereby promotes mRNA synthesis. The DNA sequences of eucaryotic promoters differ from those of procaryotic promoters. Furthermore, eucaryotic promoters and accompanying genetic signals may not be recognized in or may not function in a procaryotic system, and, further, procaryotic promoters are not recognized and do not function in eucaryotic cells.

Similarly, translation of mRNA in procaryotes depends upon the presence of the proper procaryotic signals which differ from those of eucaryotes. Efficient translation of mRNA in procaryotes requires a ribosome binding site called the Shine-Dalgarno ("SD") sequence on the mRNA. This sequence is a short nucleotide sequence of mRNA that is located before the start codon, usually AUG, which encodes the amino-terminal methionine of the protein. The SD sequences are complementary to the 3'-end of the 16S rRNA (ribosomal RNA) and probably promote binding of mRNA to ribosomes by duplexing with the rRNA to allow correct positioning of the ribosome. For a review on maximizing gene expression, see Roberts and Lauer, *Methods in Enzymology*, 68:473 (1979), which is hereby incorporated by reference.

Promoters vary in their "strength" (i.e. their ability to promote transcription). For the purposes of expressing a cloned gene, it is desirable to use strong promoters in order to obtain a high level of transcription and, hence, expression of the gene. Depending upon the host cell system utilized, any one of a number of suitable promoters may be used. For instance, when cloning in *E. coli*, its bacteriophages, or plasmids, promoters such as the T7 phage promoter, lac promoter, trp promoter, recA promoter, ribosomal RNA promoter, the PR and PL promoters of coliphage lambda and others, including but not limited, to lacUV5, ompF, bla, lpp, and the like, may be used to direct high levels of transcription of adjacent DNA segments. Additionally, a hybrid

trp-lacUV5 (tac) promoter or other *E. coli* promoters produced by recombinant DNA or other synthetic DNA techniques may be used to provide for transcription of the inserted gene.

Bacterial host cell strains and expression vectors may be chosen which inhibit the action of the promoter unless specifically induced. In certain operations, the addition of specific inducers is necessary for efficient transcription of the inserted DNA. For example, the lac operon is induced by the addition of lactose or IPTG (isopropylthio-beta-D-galactoside). A variety of other operons, such as trp, pro, etc., are under different controls.

Specific initiation signals are also required for efficient gene transcription and translation in procaryotic cells. These transcription and translation initiation signals may vary in "strength" as measured by the quantity of gene specific messenger RNA and protein synthesized, respectively. The DNA expression vector, which contains a promoter, may also contain any combination of various "strong" transcription and/or translation initiation signals. For instance, efficient translation in *E. coli* requires a Shine-Dalgarno (SD) sequence about 7-9 bases 5' to the initiation codon (ATG) to provide a ribosome binding site. Thus, any SD-ATG combination that can be utilized by host cell ribosomes may be employed. Such combinations include but are not limited to the SD-ATG combination from the cro gene or the N gene of coliphage lambda, or from the *E. coli* tryptophan E, D, C, B or A genes. Additionally, any SD-ATG combination produced by recombinant DNA or other techniques involving incorporation of synthetic nucleotides may be used.

Once the isolated DNA molecule encoding the hypersensitive response elicitor polypeptide or protein has been cloned into an expression system, it is ready to be incorporated into a host cell. Such incorporation can be carried out by the various forms of transformation noted above, depending upon the vector/host cell system. Suitable host cells include, but are not limited to, bacteria, virus, yeast, mammalian cells, insect, plant, and the like.

The method of the present invention can be utilized to treat a wide variety of plants to impart pathogen resistance. Suitable plants include dicots and monocots. More particularly, useful crop plants can include: rice, wheat, barley, rye, cotton, sunflower, peanut, corn, potato, sweet potato, bean, pea, chicory, lettuce, endive, cabbage, cauliflower, broccoli, turnip, radish, spinach, onion, garlic, eggplant, pepper, celery, carrot, squash, pumpkin, zucchini, cucumber, apple, pear, melon, strawberry, grape, raspberry, pineapple, soybean, tobacco, tomato, sorghum, and sugarcane. Examples of suitable ornamental plants are: *Arabidopsis thaliana*, Saintpaulia, petunia, pelargonium, poinsettia, chrysanthemum, carnation, and zinnia.

The method of imparting pathogen resistance to plants in accordance with the present invention is useful in imparting resistance to a wide variety of pathogens including viruses, bacteria, and fungi.

Resistance, inter alia, to the following viruses can be achieved by the method of the present invention: *Tobacco mosaic virus* and *tomato mosaic virus*.

Resistance, inter alia, to the following bacteria can also be imparted to plants in accordance with the present invention: *Pseudomonas solanacearum*, *Pseudomonas syringae* pv. *tabaci*, and *Xanthomonas campestris* pv. *pelargonii*.

Plants can be made resistant, inter alia, to the following fungi by use of the method of the present invention: *Fusarium oxysporum* and *Phytophthora infestans*.

The method of the present invention can be carried out through a variety of procedures for applying the hypersen-



sitive response elicitor polypeptide or protein to all or part of the plant being treated. This may (but need not) involve infiltration of the hypersensitive response elicitor polypeptide or protein into the plant. Suitable application methods include high or low pressure spraying, injection, and leaf abrasion proximate to when elicitor application takes place. Other suitable application procedures can be envisioned by those skilled in the art provided they are able to effect contact of the hypersensitive response elicitor polypeptide or protein with cells of the plant.

The hypersensitive response elicitor polypeptide or protein can be applied to plants in accordance with the present invention alone or in a mixture with other materials.

One aspect of the present invention involves a composition for imparting pathogen resistance to plants containing a hypersensitive response elicitor polypeptide or protein in a carrier. Suitable carriers include water or aqueous solutions. In this embodiment, the composition contains greater than 500 nM hypersensitive response elicitor polypeptide or protein.

Although not required, this composition may contain additional additives including fertilizer, insecticide, fungicide, and mixtures thereof. Suitable fertilizers include  $(\text{NH}_4)_2\text{NO}_3$ . An example of a suitable insecticide is Malathion. Useful fungicides include Captan.

Other suitable additives include buffering agents, wetting agents, and abrading agents. These materials can be used to facilitate the process of the present invention.

## EXAMPLES

### Example 1

#### Harpin-induced Resistance of Tomato Against the Southern Bacterial Wilt Disease (*Pseudomonas solanacearum*)

Two-week-old tomato seedlings, grown in 8×15 cm flats in the greenhouse were treated as follows: 20 plants were used for each of the six treatments, which were designated A through F, and are described as follows:

- (A) About 100  $\mu\text{l}$  of a 200  $\mu\text{g}/\text{ml}$  crude harpin (i.e. hypersensitive response elicitor polypeptide or protein) preparation (Z-M. Wei, "Harpin. Elicitor of the Hypersensitive Response Produced by the Plant Pathogen *Erwinia amylovora*," *Science* 257:85-88 (1992), which is hereby incorporated by reference) was infiltrated into the lowest true leaf of each of the seedlings.
- (B) The same harpin preparation as used in (A) was sprayed with 400-mesh carborundum onto the leaf surface of the seedlings and then gently rubbed in with the thumb.
- (C) *E. coli* DH5(pCPP430)(See FIG. 1 for map of plasmid vector pCPP430) was grown in LB medium to  $\text{OD}_{620}=0.7$ . The culture was centrifuged and then resuspended in 5 mM of potassium phosphate buffer pH 6.5. About 100  $\mu\text{l}$  of cell suspension was infiltrated into each leaf of the seedlings.
- (D) *E. coli* DH5(pCPP430::hrpN) (See FIG. 1 for map of plasmid vector pCPP430::hrpN) was used as in (C). The cells were grown, and the suspension and the amount of inoculum used were the same as described in (C).
- (E) For *E. coli* DH5(pCPP9) (See FIG. 2), the cells were grown and the suspension and the amount of inoculum used were the same as described in (C).
- (F) Infiltration of leaves with 5mM potassium phosphate buffer was as described in (C).

The challenge pathogenic bacterium, *Pseudomonas solanacearum* strain K60, was grown in King's medium B to  $\text{OD}_{620}=0.7$  (about  $10^8$  cfu/ml). The culture was centrifuged and resuspended in 100 volume of 5 mM potassium phosphate buffer to a final concentration of about  $1 \times 10^6$  cfu/ml.

Three days after the tomato seedlings were treated with harpin or bacteria, they were pulled up and about one cm of roots were cut off with scissors. The seedlings were then dipped into the suspension of *P. solanacearum* K60 for 3 min. The inoculated plants were replanted into the same pots. The plants were left in a greenhouse, and the disease incidence was recorded 7 days after inoculation.

#### A. Effect of treatment with harpin

After 24 hours, only those leaf portions that had been infiltrated with harpin or *E. coli* DH5(pCPP430) had collapsed. Leaves sprayed with harpin and carborundum showed only spotty necrosis.

#### B. Effect of treatment with harpin on the development of Southern Bacterial Wilt

None of the 20 harpin-infiltrated plants showed any symptoms one week after inoculation with *P. solanacearum* K60 (Table 1). One out of the 20 plants showed stunting symptoms. However, 7 of the 20 buffer-infiltrated plants showed stunting symptoms. Treatment with *E. coli* DH5 (pCPP430<sup>-</sup>) (a transposon-induced mutant unable to elicit the hypersensitive collapse) or *E. coli* DH5(pCPP9) did not show significant difference compared to the plants treated with buffer. These results suggest that harpin or *E. coli* DH5(pCPP430), which produces harpin, induced resistance in the tomato plants to southern bacterial wilt caused by *P. solanacearum* K60.

TABLE 1

Disease incidence of tomato seedlings 7 and 14 days after inoculation with *P. solanacearum* K60.

Treatment	Number of Plants			
	Day 7		Day 14	
	Stunted	Healthy	Stunted	Healthy
A. Harpin infiltration	0	20	2	18
B. Harpin spray	1	19	3	17
C. <i>E. coli</i> DH5 (pCPP430)	2	18	3	17
D. <i>E. coli</i> DH5 (pCPP430 <sup>-</sup> )	4	16	7	13
E. <i>E. coli</i> DH5 (pCPP9)	5	15	6 + 1 wilted	13
F. Buffer	7	13	8 + 1 wilted	11
No pathogen	0	20	0	20

Four weeks after inoculation, plants treated with the harpin or *E. coli* DH5(pCPP430) were taller and broader as compared to those treated with buffer. The average heights of 10 plants that had been infiltrated with harpin or buffer are given in Table 2.

TABLE 2

Heights (cm) of tomato plants four weeks after inoculation with *Pseudomonas solanacearum* K60, following treatment with harpin or buffer.

Infiltrated with Buffer Not inoculated	Infiltrated with Harpin Inoculated with K60	Infiltrated with Buffer Inoculated with K60
36	32	11
41	29	21
35	38	33
34	35	12

TABLE 2-continued

Heights (cm) of tomato plants four weeks after inoculation with <i>Pseudomonas solanacearum</i> K60, following treatment with harpin or buffer.		
Infiltrated with Buffer Not inoculated	Infiltrated with Harpin Inoculated with K60	Infiltrated with Buffer Inoculated with K60
39	37	15
35	33	32
36	22	25
35	35	15
41	40	37
37	29	38
Average	36.9	33
		23.9

## Example 2

**Harpin-induced Resistance of Tomato against Southern Bacterial Wilt Disease *Pseudomonas solanacearum***

All the methods used for infiltration and inoculation were the same as described in Example 1, except that the concentration of *P. solanacearum* K60 was about  $5 \times 10^4$  cfu/ml.

The buffer-infiltrated plants showed symptoms 15 days after inoculation with *P. solanacearum* K60. Six out of 20 plants showed stunting symptoms after 15 days; 2 plants were wilted after 21 days. The wilted plants eventually died. However, none of the 20 harpin-treated plants showed stunting symptoms. Three weeks after inoculation, 3 of the 20 harpin-treated plants showed stunting symptoms. It is possible that after three weeks, the plants may have lost their induced resistance. As in the first experiment, the overall girth and heights of the harpin-treated plants were greater than those treated with buffer.

## Example 3

**Harpin-induced Resistance of Tomato against Southern Bacterial Wilt Disease *Pseudomonas solanacearum***

This experiment was similar to Example 1, except that additional inoculum of *Pseudomonas solanacearum* K60 was added to the pots containing the treated tomato plants.

Harpin was infiltrated into two-week-old tomato seedlings. Two panels of each plant were infiltrated with about 200  $\mu$ l harpin suspended in 5 mM of potassium phosphate buffer at the concentration about 200  $\mu$ g/ml. A total of 20 tomato seedlings were infiltrated. The same number of tomato seedlings were infiltrated with buffer. After two days, the plants were inoculated with *Pseudomonas solanacearum* K60 by root-dipping. The harpin- or buffer-infiltrated plants were pulled from the soil mix and small amounts of roots were cut off with scissors and then the remaining roots were dipped into a suspension of *P. solanacearum* K60 for three minutes. The concentration of the bacterial cell suspension was about  $5 \times 10^8$  cfu/ml. The seedlings were replanted into the same pot. An additional 3 ml of bacterial suspension was added to the soil of each individual 4-inch diameter pot. Disease incidence was scored after one week. All the experiments were done in the greenhouse with limited temperature control.

After three weeks, 11 of the 20 buffer-infiltrated tomato plants had died and 2 plants that had wilted recovered, but remained severely stunted. Only 4 plants grew normally compared with non-inoculated tomatoes. However, 15 of the

harpin-treated plants appeared healthy; three plants were stunted and two plants were wilted 3 weeks after inoculation. These results are summarized below in Table 3.

TABLE 3

Harpin-induced resistance of tomato against bacterial wilt disease caused by <i>P. solanacearum</i>			
Treatment	Weeks After Inoculation		
	1	2	3
<b>Harpin</b>			
Healthy	20	17	15
Wilted	0	1	2
Stunted	0	2	3
<b>Buffer</b>			
Healthy	8	5	4
Wilted	8	12	13
Stunted	4	3	3

## Example 4

**Harpin-induced Resistance of Tobacco to Tobacco Mosaic Virus**

One panel of a lower leaf of four-week old tobacco seedlings (cultivar, Xanthi, with N gene) were infiltrated with *E. amylovora* harpin at the concentration of 200  $\mu$ g/ml. After three days, the plants were challenged with tobacco mosaic virus ("TMV"). Two concentrations of the virus (5  $\mu$ g and 100  $\mu$ g/ml) were used. About 50  $\mu$ l of the virus suspension was deposited on one upper tobacco leaf. The leaf was dusted with 400-mesh carborundum and the leaves gently rubbed. Each concentration was tested on three plants. Necrotic lesions were counted 4 days after inoculation and on two subsequent days and the mean number on three leaves is reported (Table 4). It was difficult to distinguish the individual lesions by Day 10 because some of the necrotic lesions had merged together. Therefore, the number of lesions recorded seemed less than those recorded on Day 7. The size of the necrotic lesions in buffer-treated leaves was much larger than the harpin-treated leaves.

TABLE 4

Harpin-induced resistance of tobacco against TMV from inoculation with 5 $\mu$ g/ml of virus			
Treatment	Mean Number of Lesions/Leaf		
	Day 4	Day 7	Day 10
Harpin	21	32	35
Buffer	67	102	76

There was no significant difference in the number of local lesions that developed on the harpin-treated and buffer-treated tobacco when the tobacco mosaic virus inoculum concentration was 100  $\mu$ g/ml.

## Example 5

**Harpin-induced Resistance of Tomato to Fusarium Wilt Disease**

Six-week-old tomato plants were treated with harpin as described for Example 3. The fungal pathogen, *Fusarium oxysporum*, was grown on Lima Bean Agar medium for 5

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days at 27° C. Two entire agar plates with mycelia were blended for 2 minutes in 20 ml of 5 mM potassium phosphate buffer. The roots of harpin- or buffer-treated tomato plants were wounded by plunging a wooden stake into the soil of the pots. Then, 3 ml of the fungal suspension was poured into the soil of each 4-inch pot. The inoculated plants remained in a controlled environment chamber at 24° C. with 16 hours of light per day. Disease incidence was recorded 7 days after inoculation. Each treatment was applied to 10 plants. The results are shown below in Table 5.

TABLE 5

Effect of harpin or buffer treatment on Fusarium wilt disease of tomato				
Treatment	Number of plants (of 10) showing wilt symptoms at the indicated time post-inoculation			
	Day 7	Day 10	Day 15	Day 20
Harpin	1	2	4	4 (1 dead)
Buffer	3	6	7	7 (4 dead)

## Example 6

#### Harpin-Induced Resistance of Tobacco Against Wildfire Disease (*Pseudomonas syringae* pv. *tabaci*).

Harpin was infiltrated into single panels of the lower leaves of 4-week-old tobacco plants (20 cm high). After three days, suspensions of *Pseudomonas syringae* pv. *tabaci* were infiltrated into single panels of upper leaves. Four days later, disease incidence was recorded, as set forth in Table 6.

TABLE 6

Symptoms of infection by Wildfire disease in tobacco leaves inoculated with <i>Pseudomonas syringae</i> pv. <i>tabaci</i> following treatment of lower leaves with harpin.		
Concentration of <i>P.s. tabaci</i>	Treated with Harpin	Not treated with Harpin
10 <sup>4</sup> cfu/ml	no symptoms	necrosis and water-soaking
10 <sup>5</sup> cfu/ml	no symptoms	necrosis and water-soaking
10 <sup>6</sup> cfu/ml	no symptoms	necrosis and water-soaking
10 <sup>7</sup> cfu/ml	no symptoms	necrosis and water-soaking
10 <sup>8</sup> cfu/ml	necrosis	necrosis and water-soaking

## Example 7

#### Harpin-induced Resistance of Geranium (*Pelargonium hortorum*) Against Bacterial Leaf Spot (*Xanthomonas campestris* pv. *pelargonii*)

This experiment was done with rooted cuttings of geranium growing in individual 4" or 6" pots in an artificial soil mix in a greenhouse. Two lower leaves on each plant were infiltrated with either 0.05M potassium phosphate buffer, pH 6.5 (control), or harpin or a suspension of *Escherichia coli* DH5(pCPP430) (the entire cloned *hrp* gene cluster of *E. amylovora*). Two to seven days following infiltration, all the plants were inoculated with a pure culture of the bacterial leaf spot pathogen, *Xanthomonas campestris* pv. *pelargonii*. A suspension of the bacteria (5×10<sup>6</sup> cfu/ml) was atomized over both upper and lower leaf surfaces of the plants at low pressure. Each treatment was applied to two plants (designated "A" and "B" in Table 7). The plants were

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maintained in a closed chamber for 48 hours with supplemental misting supplied by cool-mist foggers. Then, the plants were maintained on the greenhouse bench subject to ambient humidity and temperature of 23° C. to 32° C. for 10 days before disease development was assessed.

TABLE 7

Effect of harpin and the *hrp* gene cluster of *Erwinia amylovora* on the development of bacterial leaf spot of geranium.

Treatment	Time between treatment and inoculation with <i>Xanthomonas campestris</i> pv. <i>pelargonii</i>									
	7 Days Plant		5 Days Plant		4 Days Plant		3 Days Plant		2 days Plant	
	A	B	A	B	A	B	A	B	A	B
Buffer	3*	5	5	4	3	2	4	3	4	5
Harpin	0	0	0	0	0	0	1	0	0	0
DH5 (pCPP430)	0	0	NT	NT	0	0	0	1	1	0

\*Numbers in table are the number of leaves showing disease symptoms (pronounced necrosis, chlorosis, or wilting) 10 days following inoculation.

## Example 8

#### Activity of several harpins in inducing resistance to Wildfire Disease caused by *Pseudomonas syringae* pv. *tabaci*

Tobacco plants (*Nicotiana tabacum* var. Xanthi) were grown in the greenhouse. At 4 weeks of age, harpin preparations were infiltrated into a single panel of two lower leaves of each plant. Twelve plants were treated with each harpin preparation, and three were treated with the same potassium phosphate buffer that was used to prepare the harpins. The hypersensitive necrosis developed within 24 hours in the panels of the leaves infiltrated with the harpin preparations, but not with buffer.

At 7, 10, 11, and 12 days after harpin treatment, all plants were inoculated with suspensions of 10<sup>4</sup> to 10<sup>6</sup> cells/ml of *Pseudomonas syringae* pv. *tabaci* by infiltrating panels on upper leaves. Plants were incubated in the greenhouse for 7 days before disease development was evaluated. The results are tabulated as follows in Table 8:

TABLE 8

Harpin source	Days between treatment and inoculation											
	12			11			10			7		
log [Inoc.]	4	5	6	4	5	6	4	5	6	4	5	6
None (buffer)	+	+	++	+	+	++	+	+	++	+	+	++
<i>P. syringae</i>	-	-	+	-	-	+	-	-	+	-	-	+
<i>E. chrysanthemi</i>	-	-	+	-	-	+	-	-	+	-	-	+
<i>E. amylovora</i>	-	-	+	-	-	+	-	-	+	-	-	+

- = No symptoms,

+ = Necrosis with yellow halo, typical of wildfire disease

++ = Severe necrosis with yellow halo, typical of wildfire disease

The results indicate that the harpin preparations from the three bacteria are effective in inducing resistance to the wildfire pathogen. Plants treated with either harpin exhibited no symptoms with the two lower inoculum concentrations used. At the higher concentration, symptoms were more severe on buffer-treated plants than harpin-treated plants.

## Example 9

Harpin induced resistance against the Late Blight disease caused by *Phytophthora infestans*

The late blight pathogen affects potatoes and tomatoes primarily. It was responsible for the infamous Irish potato famine. The activity of harpin in inducing resistance to this pathogen was tested on tomato seedlings grown in the greenhouse. Three-week old seedlings (cultivar 'Mama Mia', about 6 to 8 inches high) were treated with harpin and subsequently inoculated with *Phytophthora infestans*. Two panels of a lower leaf of each plant were infiltrated with a solution of harpin, a suspension of *Escherichia coli* DH5 (pCPP430), which produces and secretes harpin, or potassium phosphate buffer.

Two, three, or four days following infiltration, the plants were inoculated with a mycelial suspension of *Phytophthora infestans*. The strain U.S. 7 was used, which is highly virulent to tomato. The mycelial suspension was made by blending gently the contents of two barley-meal agar plates on and in which the fungus had grown for 2 weeks at 21° C. The suspension was brushed onto the top and undersides of one leaf per treated plant with an artist's broad paint brush.

The treated and inoculated plants were incubated in a specially constructed mist chamber designed to maintain a temperature of 20°-23° C. in the greenhouse, while maintaining high relative humidity. The moisture was provided by several cool-mist foggers operating at maximum rate on purified water. Disease incidence was evaluated 13 days

following inoculation with *Phytophthora infestans*, and the results are tabulated in Table 9. Each treatment was applied to four individual plants.

TABLE 9

Numbers of lesion of late blight that were present on tomato leaves 13 days after inoculation.

Treatment	Days between treatment and inoculation											
	4				3				2			
	Plant											
	A	B	C	D	A	B	C	D	A	B	C	D
Buffer	3	2	0	0	1	2	2	0	0	0	4	1
Harpin	0	0	1	0	0	0	0	1	2	1	0	0
DH5(pCPP430)	0	0	0	1	0	2	2	1	0	1	1	0

Treatment with harpin reduced the number of lesions that developed on plants at all intervals between treatment and inoculation. The number of late blight lesions that developed also was reduced by prior treatment with DH5(pCPP430), which produces and secretes harpin.

Although the invention has been described in detail for the purpose of illustration, it is understood that such detail is solely for that purpose, and variations can be made therein by those skilled in the art without departing from the spirit and scope of the invention which is defined by the following claims.

## SEQUENCE LISTING

## ( 1 ) GENERAL INFORMATION:

( i i i ) NUMBER OF SEQUENCES: 9

## ( 2 ) INFORMATION FOR SEQ ID NO:1:

## ( i ) SEQUENCE CHARACTERISTICS:

- ( A ) LENGTH: 338 amino acids  
 ( B ) TYPE: amino acid  
 ( C ) STRANDEDNESS:  
 ( D ) TOPOLOGY: linear

## ( i i ) MOLECULE TYPE: protein

## ( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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 35          40          45
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Asn	Ala														

## ( 2 ) INFORMATION FOR SEQ ID NO:2:

- ( i ) SEQUENCE CHARACTERISTICS:  
 ( A ) LENGTH: 2141 base pairs  
 ( B ) TYPE: nucleic acid  
 ( C ) STRANDEDNESS: single  
 ( D ) TOPOLOGY: linear

( i i ) MOLECULE TYPE: DNA (genomic)

( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:2:

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( 2 ) INFORMATION FOR SEQ ID NO:3:

( i ) SEQUENCE CHARACTERISTICS:

- ( A ) LENGTH: 385 amino acids
- ( B ) TYPE: amino acid
- ( C ) STRANDEDNESS:
- ( D ) TOPOLOGY: linear

( ii ) MOLECULE TYPE: protein

( xi ) SEQUENCE DESCRIPTION: SEQ ID NO:3:

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				85					90					95		
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Thr	Ser	Gly	Thr	Asp	Ser	Thr	Ser	Asp	Ser	Ser	Asp	Pro	Met	Gln	Gln
	145				150					155					160
Leu	Leu	Lys	Met	Phe	Ser	Glu	Ile	Met	Gln	Ser	Leu	Phe	Gly	Asp	Gly
				165					170					175	
Gln	Asp	Gly	Thr	Gln	Gly	Ser	Ser	Ser	Gly	Gly	Lys	Gln	Pro	Thr	Glu
			180					185					190		
Gly	Glu	Gln	Asn	Ala	Tyr	Lys	Lys	Gly	Val	Thr	Asp	Ala	Leu	Ser	Gly
		195					200					205			
Leu	Met	Gly	Asn	Gly	Leu	Ser	Gln	Leu	Leu	Gly	Asn	Gly	Gly	Leu	Gly
	210					215					220				
Gly	Gly	Gln	Gly	Gly	Asn	Ala	Gly	Thr	Gly	Leu	Asp	Gly	Ser	Ser	Leu
	225				230					235					240
Gly	Gly	Lys	Gly	Leu	Gln	Asn	Leu	Ser	Gly	Pro	Val	Asp	Tyr	Gln	Gln
				245					250					255	
Leu	Gly	Asn	Ala	Val	Gly	Thr	Gly	Ile	Gly	Met	Lys	Ala	Gly	Ile	Gln
			260					265					270		
Ala	Leu	Asn	Asp	Ile	Gly	Thr	His	Arg	His	Ser	Ser	Thr	Arg	Ser	Phe
		275					280					285			
Val	Asn	Lys	Gly	Asp	Arg	Ala	Met	Ala	Lys	Glu	Ile	Gly	Gln	Phe	Met
	290					295				300					
Asp	Gln	Tyr	Pro	Glu	Val	Phe	Gly	Lys	Pro	Gln	Tyr	Gln	Lys	Gly	Pro
	305				310					315					320
Gly	Gln	Glu	Val	Lys	Thr	Asp	Asp	Lys	Ser	Trp	Ala	Lys	Ala	Leu	Ser
				325					330					335	
Lys	Pro	Asp	Asp	Asp	Gly	Met	Thr	Pro	Ala	Ser	Met	Glu	Gln	Phe	Asn
			340					345					350		
Lys	Ala	Lys	Gly	Met	Ile	Lys	Arg	Pro	Met	Ala	Gly	Asp	Thr	Gly	Asn
	355						360					365			
Gly	Asn	Leu	Gln	His	Ala	Val	Pro	Val	Val	Leu	Arg	Trp	Val	Leu	Met
	370					375					380				
Pro															
385															

## ( 2 ) INFORMATION FOR SEQ ID NO:4:

- ( i ) SEQUENCE CHARACTERISTICS:  
 ( A ) LENGTH: 1158 base pairs  
 ( B ) TYPE: nucleic acid  
 ( C ) STRANDEDNESS: single  
 ( D ) TOPOLOGY: linear

( ii ) MOLECULE TYPE: DNA (genomic)

( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:4:

```

ATGAGTCTGA ATACAAGTGG GCTGGGAGCG TCAACGATGC AAATTTCTAT CGGCGGTGCG      60
GGCGGAAATA ACGGTTGCT GGGTACCAGT CGCCAGAATG CTGGGTTGGG TGGCAATTCT      120
GCACTGGGGC TGGGCGGCGG TAATCAAAAT GATACCGTCA ATCAGCTGGC TGGCTTACTC      180
ACCGGCATGA TGATGATGAT GAGCATGATG GCGGGTGGTG GGCTGATGGG CGGTGGCTTA      240
GGCGGTGGCT TAGGTAATGG CTTGGGTGGC TCAGGTGGCC TGGGCGAAGG ACTGTGGAAC      300
GCGCTGAACG ATATGTTAGG CGGTTGCTG AACACGCTGG GCTCGAAAGG CGGCAACAAT      360

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ACCACTTCAA	CAACAAATTC	CCCGCTGGAC	CAGGCGCTGG	GTATTAACTC	AACGTCCCAA	420
AACGACGATT	CCACCTCCGG	CACAGATTCC	ACCTCAGACT	CCAGCGACCC	GATGCAGCAG	480
CTGCTGAAGA	TGTTACAGCGA	GATAATGCAA	AGCCTGTTTG	GTGATGGGCA	AGATGGCACC	540
CAGGGCAGTT	CCTCTGGGGG	CAAGCAGCCG	ACCGAAGGCG	AGCAGAACGC	CTATAAAAAA	600
GGAGTCACTG	ATGCGCTGTC	GGGCCTGATG	GGTAATGGTC	TGAGCCAGCT	CCTTGGCAAC	660
GGGGGACTGG	GAGGTGGTCA	GGGCGGTAAT	GCTGGCACGG	GTCTTGACGG	TTCGTGCGTG	720
GGCGGCAAAG	GGCTGCAAAA	CCTGAGCGGG	CCGGTGGACT	ACCAGCAGTT	AGGTAACGCC	780
GTGGGTACCG	GTATCGGTAT	GAAAGCGGGC	ATTCAGGCGC	TGAATGATAT	CGGTACGCAC	840
AGGCACAGTT	CAACCCGTTT	TTTCGTCAAT	AAAGGCGATC	GGGCGATGGC	GAAAGGAAATC	900
GGTCAGTTCA	TGGACCAGTA	TCCTGAGGTG	TTTGGCAAGC	CGCAGTACCA	GAAAAGGCCCG	960
GGTCAGGAGG	TGAAAACCGA	TGACAAATCA	TGGGCAAAAAG	CACTGAGCAA	GCCAGATGAC	1020
GACGGAATGA	CACCAGCCAG	TATGGAGCAG	TTCAACAAAAG	CCAAGGGCAT	GATCAAAAAGG	1080
CCCATGGCGG	GTGATACCGG	CAACGGCAAC	CTGCAGCAGC	CGGTGCCGGT	GGTTCTTCGC	1140
TGGGTATTGA	TGCCATGA					1158

## ( 2 ) INFORMATION FOR SEQ ID NO:5:

## ( i ) SEQUENCE CHARACTERISTICS:

- ( A ) LENGTH: 341 amino acids
- ( B ) TYPE: amino acid
- ( C ) STRANDEDNESS:
- ( D ) TOPOLOGY: linear

## ( i i ) MOLECULE TYPE: protein

## ( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:5:

Met	Gln	Ser	Leu	Ser	Leu	Asn	Ser	Ser	Ser	Leu	Gln	Thr	Pro	Ala	Met	
1				5					10					15		
Ala	Leu	Val	Leu	Val	Arg	Pro	Glu	Ala	Glu	Thr	Thr	Gly	Ser	Thr	Ser	
			20					25					30			
Ser	Lys	Ala	Leu	Gln	Glu	Val	Val	Val	Lys	Leu	Ala	Glu	Glu	Leu	Met	
		35				40						45				
Arg	Asn	Gly	Gln	Leu	Asp	Asp	Ser	Ser	Pro	Leu	Gly	Lys	Leu	Leu	Ala	
	50				55						60					
Lys	Ser	Met	Ala	Ala	Asp	Gly	Lys	Ala	Gly	Gly	Gly	Ile	Glu	Asp	Val	
65				70					75					80		
Ile	Ala	Ala	Leu	Asp	Lys	Leu	Ile	His	Glu	Lys	Leu	Gly	Asp	Asn	Phe	
			85					90						95		
Gly	Ala	Ser	Ala	Asp	Ser	Ala	Ser	Gly	Thr	Gly	Gln	Gln	Asp	Leu	Met	
			100					105					110			
Thr	Gln	Val	Leu	Asn	Gly	Leu	Ala	Lys	Ser	Met	Leu	Asp	Asp	Leu	Leu	
		115					120					125				
Thr	Lys	Gln	Asp	Gly	Gly	Thr	Ser	Phe	Ser	Glu	Asp	Asp	Met	Pro	Met	
	130					135					140					
Leu	Asn	Lys	Ile	Ala	Gln	Phe	Met	Asp	Asp	Asn	Pro	Ala	Gln	Phe	Pro	
145					150					155				160		
Lys	Pro	Asp	Ser	Gly	Ser	Trp	Val	Asn	Glu	Leu	Lys	Glu	Asp	Asn	Phe	
				165					170					175		
Leu	Asp	Gly	Asp	Glu	Thr	Ala	Ala	Phe	Arg	Ser	Ala	Leu	Asp	Ile	Ile	
			180					185					190			
Gly	Gln	Gln	Leu	Gly	Asn	Gln	Gln	Ser	Asp	Ala	Gly	Ser	Leu	Ala	Gly	
		195					200						205			



-continued

Thr	Gly	Gly	Gly	Leu	Gly	Thr	Pro	Ser	Ser	Phe	Ser	Asn	Asn	Ser	Ser
	210					215					220				
Val	Met	Gly	Asp	Pro	Leu	Ile	Asp	Ala	Asn	Thr	Gly	Pro	Gly	Asp	Ser
225					230					235					240
Gly	Asn	Thr	Arg	Gly	Glu	Ala	Gly	Gln	Leu	Ile	Gly	Glu	Leu	Ile	Asp
				245					250					255	
Arg	Gly	Leu	Gln	Ser	Val	Leu	Ala	Gly	Gly	Gly	Leu	Gly	Thr	Pro	Val
			260					265					270		
Asn	Thr	Pro	Gln	Thr	Gly	Thr	Ser	Ala	Asn	Gly	Gly	Gln	Ser	Ala	Gln
		275					280					285			
Asp	Leu	Asp	Gln	Leu	Leu	Gly	Gly	Leu	Leu	Leu	Lys	Gly	Leu	Glu	Ala
	290					295					300				
Thr	Leu	Lys	Asp	Ala	Gly	Gln	Thr	Gly	Thr	Asp	Val	Gln	Ser	Ser	Ala
305					310					315					320
Ala	Gln	Ile	Ala	Thr	Leu	Leu	Val	Ser	Thr	Leu	Leu	Gln	Gly	Thr	Arg
				325					330					335	
Asn	Gln	Ala	Ala	Ala											
				340											

## ( 2 ) INFORMATION FOR SEQ ID NO:6:

## ( i ) SEQUENCE CHARACTERISTICS:

- ( A ) LENGTH: 1026 base pairs
- ( B ) TYPE: nucleic acid
- ( C ) STRANDEDNESS: single
- ( D ) TOPOLOGY: linear

## ( i i ) MOLECULE TYPE: DNA (genomic)

## ( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:6:

ATGCAGAGTC	TCAGTCTTAA	CAGCAGCTCG	CTGCAAACCC	CGGCAATGGC	CCTTGTCTCTG	60
GTACGTCTCTG	AAGCCGAGAC	GACTGGCAGT	ACGTCGAGCA	AGGCGCTTCA	GGAAGTTGTC	120
GTGAAGCTGG	CCGAGGAACT	GATGCGCAAT	GGTCAACTCG	ACGACAGCTC	GCCATTGGGA	180
AAACTGTTGG	CCAAGTCGAT	GGCCGCAGAT	GGCAAGGCGG	GCGGCGGTAT	TGAGGATGTC	240
ATCGCTGCGC	TGGACAAGCT	GATCCATGAA	AAGCTCGGTG	ACAACCTTCGG	CGCGTCTGCG	300
GACAGCGCCT	CGGGTACCGG	ACAGCAGGAC	CTGATGACTC	AGGTGCTCAA	TGGCCTGGCC	360
AAGTCGATGC	TCGATGATCT	TCTGACCAAG	CAGGATGGCG	GGACAAGCTT	CTCCGAAGAC	420
GATATGCCGA	TGCTGAACAA	GATCGCGCAG	TTCATGGATG	ACAATCCCGC	ACAGTTTCCC	480
AAGCCGGACT	CGGGCTCCTG	GGTGAACGAA	CTCAAGGAAAG	ACAACCTTCCT	TGATGGCGAC	540
GAAACGGCTG	CGTTCGTTTC	GGCACTCGAC	ATCATTGGCC	AGCAACTGGG	TAATCAGCAG	600
AGTGACGCTG	GCAGTCTGGC	AGGGACGGGT	GGAGGTCTGG	GCACTCCGAG	CAGTTTTTCC	660
AACAACCTCGT	CCGTGATGGG	TGATCCGCTG	ATCGACGCCA	ATACCGGTCC	CGGTGACAGC	720
GGCAATACCC	GTGGTGAAGC	GGGGCAACTG	ATCGGCGAGC	TTATCGACCG	TGGCCTGCAA	780
TCGGTATTGG	CCGGTGGTGG	ACTGGGCACA	CCCGTAAACA	CCCCGCAGAC	CGGTACGTCG	840
GCGAATGGCG	GACAGTCCGC	TCAGGATCTT	GATCAGTTGC	TGGGCGGCTT	GCTGCTCAAG	900
GGCCTGGAGG	CAACGCTCAA	GGATGCCGGG	CAAACAGGCA	CCGACGTGCA	GTCGAGCGCT	960
GCGCAAATCG	CCACCTTGCT	GGTCAGTACG	CTGCTGCAAG	GCACCCGCAA	TCAGGCTGCA	1020
GCCTGA						1026

## ( 2 ) INFORMATION FOR SEQ ID NO:7:

-continued

## ( i ) SEQUENCE CHARACTERISTICS:

- ( A ) LENGTH: 344 amino acids
- ( B ) TYPE: amino acid
- ( C ) STRANDEDNESS:
- ( D ) TOPOLOGY: linear

## ( i i ) MOLECULE TYPE: protein

## ( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:7:

```

Met Ser Val Gly Asn Ile Gln Ser Pro Ser Asn Leu Pro Gly Leu Gln
1          5          10          15
Asn Leu Asn Leu Asn Thr Asn Thr Asn Ser Gln Gln Ser Gly Gln Ser
20          25          30
Val Gln Asp Leu Ile Lys Gln Val Glu Lys Asp Ile Leu Asn Ile Ile
35          40          45
Ala Ala Leu Val Gln Lys Ala Ala Gln Ser Ala Gly Gly Asn Thr Gly
50          55          60
Asn Thr Gly Asn Ala Pro Ala Lys Asp Gly Asn Ala Asn Ala Gly Ala
65          70          75
Asn Asp Pro Ser Lys Asn Asp Pro Ser Lys Ser Gln Ala Pro Gln Ser
85          90          95
Ala Asn Lys Thr Gly Asn Val Asp Asp Ala Asn Asn Gln Asp Pro Met
100         105         110
Gln Ala Leu Met Gln Leu Leu Glu Asp Leu Val Lys Leu Leu Lys Ala
115         120         125
Ala Leu His Met Gln Gln Pro Gly Gly Asn Asp Lys Gly Asn Gly Val
130         135         140
Gly Gly Ala Asn Gly Ala Lys Gly Ala Gly Gly Gln Gly Gly Leu Ala
145         150         155
Glu Ala Leu Gln Glu Ile Glu Gln Ile Leu Ala Gln Leu Gly Gly Gly
165         170         175
Gly Ala Gly Ala Gly Gly Ala Gly Gly Gly Val Gly Gly Ala Gly Gly
180         185         190
Ala Asp Gly Gly Ser Gly Ala Gly Gly Ala Gly Gly Ala Asn Gly Ala
195         200         205
Asp Gly Gly Asn Gly Val Asn Gly Asn Gln Ala Asn Gly Pro Gln Asn
210         215         220
Ala Gly Asp Val Asn Gly Ala Asn Gly Ala Asp Asp Gly Ser Glu Asp
225         230         235
Gln Gly Gly Leu Thr Gly Val Leu Gln Lys Leu Met Lys Ile Leu Asn
245         250         255
Ala Leu Val Gln Met Met Gln Gln Gly Gly Leu Gly Gly Gly Asn Gln
260         265         270
Ala Gln Gly Gly Ser Lys Gly Ala Gly Asn Ala Ser Pro Ala Ser Gly
275         280         285
Ala Asn Pro Gly Ala Asn Gln Pro Gly Ser Ala Asp Asp Gln Ser Ser
290         295         300
Gly Gln Asn Asn Leu Gln Ser Gln Ile Met Asp Val Val Lys Glu Val
305         310         315
Val Gln Ile Leu Gln Gln Met Leu Ala Ala Gln Asn Gly Gly Ser Gln
325         330         335
Gln Ser Thr Ser Thr Gln Pro Met
340

```

## ( 2 ) INFORMATION FOR SEQ ID NO:8:

## ( i ) SEQUENCE CHARACTERISTICS:

-continued

( A ) LENGTH: 1035 base pairs  
 ( B ) TYPE: nucleic acid  
 ( C ) STRANDEDNESS: single  
 ( D ) TOPOLOGY: linear

( i i ) MOLECULE TYPE: DNA (genomic)

( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:8:

```

ATGTCAGTCG GAAACATCCA GAGCCCGTCG AACCTCCCGG GTCIGCAGAA CCTGAACCTC      60
AACACCAACA CCAACAGCCA GCAATCGGGC CAGTCCGTGC AAGACCTGAT CAAGCAGGTC      120
GAGAAGGACA TCCTCAACAT CATCGCAGCC CTCGTGCAGA AGGCCGCACA GTCGGCGGGC      180
GGCAACACCG GTAACACCGG CAACCGCGCCG GCGAAGGACG GCAATGCCAA CGCGGGCGCC      240
AACGACCCGA GCAAGAACGA CCCGAGCAAAG AGCCAGGCTC CGCAGTCGGC CAACAAGACC      300
GGCAACGTCG ACGACGCCAA CAACCAGGAT CCGATGCAAAG CGCTGATGCA GCTGCTGGAA      360
GACCTGGTGA AGCTGCTGAA GGCGGCCCTG CACATGCAGC AGCCCGGCGG CAATGACAAG      420
GGCAACGGCG TGGGCGGTGC CAACGGCGCC AAGGGTGCCG GCGGCCAGGG CGGCCTGGCC      480
GAAGCGCTGC AGGAGATCGA GCAGATCCTC GCCCAGCTCG GCGGCGGCGG TGCTGGCGCC      540
GGCGGCGCGG GTGGCGGTGT CCGCGGTGCT GGTGGCGCGG ATGGCGGCTC CGGTGCGGGT      600
GGCGCAGGCG GTGCGAACGG CGCCGACGGC GGCAATGGCG TGAACGGCAA CCAGGCGAAC      660
GGCCCGCAGA ACGCAGGCGA TGTC AACGGT GCCAACGGCG CGGATGACGG CAGCGAAGAC      720
CAGGGCGGCG TCACCGGCGT GCTGCAAAAAG CTGATGAAGA TCCTGAACGC GCTGGTGCAG      780
ATGATGCAGC AAGGCGGCCT CGGCGGCGGC AACCAGGCGC AGGGCGGCTC GAAGGGTGCC      840
GGCAACGCCT CGCCGGCTTC CGGCGCGAAC CCGGGCGCGA ACCAGCCCGG TTCGGCGGAT      900
GATCAATCGT CCGGCCAGAA CAATCTGCAA TCCCAGATCA TGGATGTGGT GAAGGAGGTC      960
GTCCAGATCC TGCAGCAGAT GCTGGCGGCG CAGAACGGCG GCAGCCAGCA GTCCACCTCG     1020
ACGCAGCCGA TG TAA                                                                1035
  
```

( 2 ) INFORMATION FOR SEQ ID NO:9:

( i ) SEQUENCE CHARACTERISTICS:

( A ) LENGTH: 26 amino acids  
 ( B ) TYPE: amino acid  
 ( C ) STRANDEDNESS:  
 ( D ) TOPOLOGY: linear

( i i ) MOLECULE TYPE: peptide

( x i ) SEQUENCE DESCRIPTION: SEQ ID NO:9:

```

Thr Leu Ile Glu Leu Met Ile Val Val Ala Ile Ile Ala Ile Leu Ala
1           5           10           15
Ala Ile Ala Leu Pro Ala Tyr Gln Asp Tyr
20           25
  
```

What is claimed:

1. A method of imparting pathogen resistance to plants comprising:

applying externally to a plant a hypersensitive response eliciting bacterium, which does not cause disease in that plant, or a hypersensitive response eliciting polypeptide or protein, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from a pathogen selected from the group consisting of *Erwinia amylovora*, *Erwinia chrysanthemi*, *Pseudomonas syringae*, *Pseudomonas solanacearum*, *Xanthomonas campestris*, and mixtures thereof.

55

2. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from *Erwinia chrysanthemi*.

3. A method according to claim 2, wherein the hypersensitive response eliciting polypeptide or protein has an amino acid sequence corresponding to SEQ. ID. No. 1.

4. A method according to claim 2, wherein the hypersensitive response eliciting polypeptide or protein has a molecular weight of 34 kDa.

5. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from *Erwinia amylovora*.

6. A method according to claim 5, wherein the hypersensitive response eliciting polypeptide or protein has an amino acid sequence corresponding to SEQ. ID. No. 3.

7. A method according to claim 5, wherein the hypersensitive response eliciting polypeptide or protein has a molecular weight of 37 kDa.

8. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from *Pseudomonas syringae*.

9. A method according to claim 8, wherein the hypersensitive response eliciting polypeptide or protein has an amino acid sequence corresponding to SEQ. ID. No. 5.

10. A method according to claim 8, wherein the hypersensitive response eliciting polypeptide or protein has a molecular weight of 34–35 kDa.

11. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from *Pseudomonas solanacearum*.

12. A method according to claim 11, wherein the hypersensitive response eliciting polypeptide or protein has an amino acid sequence corresponding to SEQ. ID. No. 7.

13. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein corresponds to that derived from *Xanthomonas campestris*.

14. A method according to claim 13, wherein the hypersensitive response eliciting polypeptide or protein has an amino acid sequence corresponding to SEQ. ID. No. 9.

15. A method according to claim 1, wherein the plant is selected from the group consisting of dicots and monocots.

16. A method according to claim 15, wherein the plant is selected from the group consisting of rice, wheat, barley, rye, cotton, sunflower, peanut, corn, potato, sweet potato, bean, pea, chicory, lettuce, endive, cabbage, cauliflower, broccoli, turnip, radish, spinach, onion, garlic, eggplant, pepper, celery, carrot, squash, pumpkin, zucchini, cucumber, apple, pear, melon, strawberry, grape, raspberry, pineapple, soybean, tobacco, tomato, sorghum, and sugarcane.

17. A method according to claim 15, wherein the plant is selected from the group consisting of *Arabidopsis thaliana*,

Saintpaulia, petunia, pelargonium, poinsettia, chrysanthemum, carnation, and zinnia.

18. A method according to claim 1, wherein the pathogen to which the plant is resistant is selected from the group consisting of a viruses, bacteria, fungi, and combinations thereof.

19. A method according to claim 1, wherein said applying is carried out by spraying.

20. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein is applied to plants as a composition further comprising a carrier.

21. A method according to claim 20, wherein the carrier is selected from the group consisting of water and aqueous solutions.

22. A method according to claim 20, wherein the composition contains greater than 500 nM of the hypersensitive response eliciting polypeptide or protein.

23. A method according to claim 20, wherein the composition further contains additives selected from the group consisting of fertilizer, insecticide, fungicide, and mixtures thereof.

24. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein is in isolated form.

25. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein is applied as bacteria which do not cause disease and are transformed with a gene encoding the hypersensitive response eliciting polypeptide or protein.

26. A method according to claim 1, wherein the hypersensitive response eliciting polypeptide or protein is applied as bacteria which cause disease in some plant species, but not in those subjected to said applying, and contain a gene encoding the hypersensitive response eliciting polypeptide or protein.

\* \* \* \* \*