Influenza Antigens, Vaccine Compositions, and Related Methods

Related Applications

[0001] The present application is related to and claims priority under 35 USC 119(e) to U.S.S.N. 60/773,378, filed February 13, 2006 (the '378 application) and to U.S.S.N. 60/813,955, filed June 15, 2006 (the '955 application); the entire contents of the '139 application and the '955 application are incorporated herein by reference.

Background of the Invention

[0001] Influenza has a long history characterized by waves of pandemics, epidemics, resurgences and outbreaks. Influenza is a highly contagious disease that could be equally devastating both in developing and developed countries. The influenza virus presents one of the major threats to the human population. In spite of annual vaccination efforts, influenza infections result in substantial morbidity and mortality. Although flu epidemics occur nearly every year, fortunately pandemics do not occur very often. However, recent flu strains have emerged such that we are again faced with the potential of an influenza pandemic. Avian influenza virus of the type H5N1, currently causing an epidemic in poultry in Asia as well as regions of eastern Europe, has persistently spread throughout the globe. The rapid spread of infection, as well as cross species transmission from birds to human subjects, increases the potential for outbreaks in human populations and the risk of a pandemic. The virus is highly pathogenic, resulting in a mortality rate of over fifty percent in birds as well as the few human cases which have been identified. If the virus were to achieve human to human transmission, it would have the potential to result in rapid, widespread illness and mortality.

[0002] The major defense against influenza is vaccination. Influenza viruses are segmented, negative-strand RNA viruses belonging to the family *Orthomyxoviridae*. The viral antigens are highly effective immunogens, capable of eliciting both systemic and mucosal antibody responses. Influenza virus hemagglutinin glycoprotein (HA) is generally considered the most important viral antigen with regard to the stimulation of neutralizing antibodies and vaccine design. The presence of viral neuraminidase (NA) has been shown to be important for generating multi-arm protective immune responses against the virus. Antivirals which inhibit neuraminidase activity have been

developed and may be an additional antiviral treatment upon infection. A third component considered useful in the development of influenza antivirals and vaccines is the ion channel protein M2.

[0003] Subtypes of the influenza virus are designated by different HA and NA resulting from antigenic shift. Furthermore, new strains of the same subtype result from antigenic drift, or mutations in the HA or NA molecules which generate new and different epitopes. Although 15 antigenic subtypes of HA have been documented, only three of these subtypes H1, H2, and H3, have circulated extensively in humans. Vaccination has become paramount in the quest for improved quality of life in both industrialized and underdeveloped nations. The majority of available vaccines still follow the basic principles of mimicking aspects of infection in order to induce an immune response that could protect against the relevant infection. However, generation of attenuated viruses of various subtypes and combinations can be time consuming and expensive. Emerging new technologies, in-depth understanding of a pathogen's molecular biology, pathogenesis, and its interactions with an individual's immune system have resulted in new approaches to vaccine development and vaccine delivery. Thus, while technological advances have improved the ability to produce improved influenza antigens vaccine compositions, there remains a need to provide additional sources of vaccines and new antigens for production of vaccines to address emerging subtypes and strains. Improved vaccine design and development for influenza virus subtypes, as well as methods of making and using such compositions of matter are needed which provide inexpensive and highly accessible sources of such therapeutic compositions.

Summary of the Invention

[0004] The present invention provides influenza antigens and vaccine components produced in plants. The present invention provides one or more influenza antigens generated as a fusion with a thermostable protein. The invention further provides vaccine compositions containing influenza antigens. Furthermore, the invention provides influenza vaccines comprising at least two different influenza antigens. In some embodiments, inventive compositions include one or more plant components. Still further provided are methods for production and use of the antigen and vaccine compositions of the invention.

Brief Description of the Drawing

[0005] *Figure 1.* Schematic of hemagglutinin (HA) protein and protein domains. The numbers 1, 2, and 3 in the upper left correspond to domains 1, 2, and 3 described herein. Domains 1, 2, and 2, 1 fold together to form a stem domain (SD). Domain 3 is a globular domain (GD). The ranges presented in items 1-6 correspond to amino acid positions of HA.

[0006] *Figure 2.* Map of the pET32 plasmid. The top left indicates the region between the T7 promoter and the T7 terminator lacking in modified plasmid used for cloning target antigen.

[0007] *Figure 3.* Schematic of the pET-PR-LicKM-KDEL and pET-PR-LicKM-VAC constructs inserted into a modified pET32a vector.

[0008] *Figure 4.* Schematic of the pBI121 vector organization.

[0009] *Figure 5.* Schematic organization of the derivation of the pBID4 plasmid from a pBI vector after excision of the GUS gene and the addition of a TMV-derived plasmid.

[0010] *Figure 6.* Schematic of the fusion of HA, domains of HA, and NA in lichenase sequence, with and without targeting sequences which were put into a vector.

[0011] *Figures 7A,B.* Lichenase assays of extracts of plants expressing LicKM and fusion proteins. (7A) Transient expression of lichenase in *Nicotiana benthamiana.* (7B) Zymogram of lichenase HA fusion proteins in plants (arrow).

[0012] *Figure 8.* Western analysis of extracts of plants expressing Lic-HA fusion proteins using anti-HA and anti-LicB antibodies.

[0013] *Figure 9.* Lichenase assays of extracts of plants expressing Lic-NA fusion proteins.

[0014] *Figure 10.* Western analysis of extracts of plants expressing Lic-HA fusion proteins.

[0015] *Figure 11.* Red blood cell hemagglutination assay with plant expressed HA lichenase fusion proteins.

[0016] *Figure 12.* Antibody response of mice immunized with test H5N1 influenza vaccine, with and without adjuvant.

[0017] *Figure 13.* Hemaggultination activity inhibition by serum dilutions obtained from mice immunized with H5N1 test vaccine, with and without adjuvant.

[0018] *Figures 14A-D.* Symptoms following H3N2 virus challenge in H3N2 influenza test vaccine and control treatment groups. (14A) Overall mean maximum results of clinical symptom scores. (14B) Overall mean maximum results of cell counts in nasal washes after virus challenge. (14C) Overall mean maximum results of weight loss in animals. (14D) Overall mean maximum of temperature change in animals.

[0019] *Figure 15.* Virus shedding following H3N2 virus challenge in H3N2 influenza test vaccine and control treatment groups. Group 1 depicts results from the negative control treatment group; Group 2 depicts results from animals treated with Test article 1 (CMB F1); Group 3 depicts results from animals treated with Test article 2 (CMB F2); Group 4 depicts results from animals treated with Test article 3 (CMB F3); and Group D depicts results from positive control treated animals. N refers to the number of animals assessed in each group (8 in each group).

[0020] *Figure 16.* Characterization of influenza A/Wyoming/3/03 virus antigens produced in plants. (16A) ELISA analysis of LicKM-(SD) and LicKM-(GD) using sheep serum raised against purified HA from influenza A/Wyoming/3/03 virus. Homologous virus (A/W/3/03) and plant-produced NA were used as positive and negative controls, respectively. (16B) Immunoblot analysis of LicKM-HA(SD) (lane 4) and LicKM-HA(GD) (lane 3) using rabbit serum raised against LicKM (anti-LicKM) and sheep serum raised against purified HA of influenza A/Wyoming/3/03 virus (anti-HA). LicKM (lane 2) and homologous virus (lane 1) were used as controls. (16C) ELISA analysis of NA using sheep sera raised against NIBRG-18 reassorted virus (anti-H7N2) and NIBRG-17 reassorted virus (anti-H7N1). Homologous virus (A/W/3/03) assessed using sheep serum to NIBRG-18 (anti-H7N2) was used as a positive control. (16D) Strain specific inhibition of neuraminidase activity following pre-incubation with sheep serum raised against NIBRG-18 (anti-H7N2) or NIBRG-17 (anti-H7N1). Mean enzymatic activity from three replicates are shown with standard deviations.

[0021] *Figure 17.* Hemagglutination inhibition titers of sera from ferrets immunized with VC1 plus adjuvant, VC2 no adjuvant, or VC2 plus adjuvant. Serum samples were collected prior to the first dose (Pre-imm), 14 days after the first dose (D1), 14 days after the second dose (D2), 10 days after the third dose (D3), and 4 days post-challenge (Post-Ch). Geometric mean titers with standard deviations are shown.

[0022] *Figure 18.* Post-challenge monitoring of ferrets immunized with VC1 plus adjuvant, VC2 no adjuvant, or VC2 plus adjuvant. Mean values with standard deviations are shown, and statistical analysis of data was conducted using ANOVA with the Bonferroni correction for multiple testing. Statistical significance was defined as a $p \leq 0.05$. (18A) Peak of virus shed post-infection. (18B) Maximum weight loss post-infection. (18C) Peak temperature rise post-infection. (18D) Peak of symptom scores post-infection. (18E) Peak of total leukocyte counts per ml of nasal wash samples post-infection.

Detailed Description of the Invention

[0023] The invention relates to influenza antigens useful in the preparation of vaccines against influenza infection, and fusion proteins comprising such influenza antigens operably linked to thermostable protein. The invention relates to methods of production of provided antigens, including but not limited to, production in plant systems. Further, the invention relates to vectors, fusion proteins, plant cells, plants and vaccine compositions comprising the antigens and fusion proteins of the invention. Still further provided are methods of inducing immune response against influenza infection in a subject comprising administering vaccine compositions of the invention to a subject.

Influenza Antigens

[0024] Influenza antigen proteins of the present invention include any immunogenic protein or peptide capable of eliciting an immune response against influenza virus. Generally, immunogenic proteins of interest include influenza antigens (*e.g.*, influenza proteins, fusion proteins, *etc.*), immunogenic portions thereof, or immunogenic variants thereof and combinations of any of the foregoing.

[0025] Influenza antigens for use in accordance with the present invention may include full-length influenza proteins or fragments of influenza proteins, and/or fusion proteins comprising full-length influenza proteins or fragments of influenza proteins. Where fragments of influenza proteins are utilized, whether alone or in fusion proteins, such fragments retain immunological activity (*e.g.*, cross-reactivity with anti-influenza antibodies). Based on their capacity to induce immunoprotective response against viral infection, hemagglutinin and neuraminidase are primary antigens of interest in generating vaccines. Additional antigens, such as the membrane ion channel M2 may be useful in production of vaccines (*e.g.*, combination vaccines) in order to improve efficacy of immunoprotection.

[0026] Thus, the invention provides plant cells and plants expressing a heterologous protein (*e.g.*, an influenza antigen (*e.g.*, influenza protein or a fragment thereof, a fusion protein comprising an influenza protein or fragment thereof). A heterologous protein of the invention can comprise any influenza antigen of interest, including, but not limited to hemagglutinin (HA), neuraminidase (NA), membrane ion channel M2 (M2), a portion of hemagglutinin (HA), a portion of neuraminidase (NA) and a portion of membrane ion channel (M2), or fusion proteins, fragments, or combinations of hemagglutinin (HA), neuraminidase (NA), membrane ion channel M2 (M2), a portion of

hemagglutinin (HA), a portion of neuraminidase (NA) and/or a portion of membrane ion channel (M2).

[0027] Amino acid sequences of a variety of different influenza HA, NA and M2 proteins (*e.g.*, from different subtypes, or strains or isolates) are known in the art and are available in public databases such as GenBank. Exemplary full length protein sequences for HA and NA of two influenza subtypes of particular interest today, as well as sequence for M2 are provided below:

V: Vietnam H5N1

[0028] HA (HAV) SEQ ID NO.: 1

AKAGVQSVKMEKIVLLFAIVSLVKSDQICIGYHANNSTEQVDTIMEKNVTVTHAQDILEKTH
NGKLCDLDGVKPLILRDCSVAGWLLGNPMCDEFINVPEWSYIVEKANPVNDLCYPGDFND
YEELKHLLSRINHFEKIQIIPKSSWSSHEASLGVSSACPYQGKSSFFRNVVWLIKKNSTYPTIK
RSYNNTNQEDLLVLWGIHHPNDAAEQTKLYQNPTTYISVGTSTLNQRLVPRIATRSKVNGQ
SGRMEFFWTILKPNDAINFESNGNFIAPEYAYKIVKKGDSTIMKSELEYGNCNTKCQTPMGA
INSSMPFHNIHPLTIGECPKYVKSNRLVLATGLRNSPQRERRRKKRGLFGAIAGFIEGGWQG
MVDGWYGYHHSNEQGSGYAADKESTQKAIDGVTNKVNSIIDKMNTQFEAVGREFNNLER
RIENLNKKMEDGFLDVWTYNAELLVLMENERTLDFHDSNVKNLYDKVRLQLRDNAKELG
NGCFEFYHKCDNECMESVRNGTYDYPQYSEEARLKREEISGVKLESIGIYQILSIYSTVASSL
ALALMVAGLSLWMCSNGSLQCRICI

[0029] NA (NAV) SEQ ID NO.: 2:

*MNPNQKIITIGSICMVTGIVS*LMLQIGNMISIWVSHSIHTGNQHQSEPISNTNLLTEKAVASVKL
AGNSSLCPINGWAVYSKDNSIRIGSKGDVFVIREPFISCSHLECRTFFLTQGALLNDKHSNGT
VKDRSPHRTLMSCPVGEAPSPYNSRFESVAWSASACHDGTSWLTIGISGPDNGAVAVLKYN
GIITDTIKSWRNNILRTQESECACVNGSCFTVMTDGPSNGQASHKIFKMEKGKVVKSVELDA
PNYHYEECSCYPDAGEITCVCRDNWHGSNRPWVSFNQNLEYQIGYICSGVFGDNPRPNDGT
GSCGPVSSNGAGGVKGFSFKYGNGVWIGRTKSTNSRSGFEMIWDPNGWTETDSSFSVKQDI
VAITDWSGYSGSFVQHPELTGLDCIRPCFWVELIRGRPKESTIWTSGSSISFCGVNSDTVGWS
WPDGAELPFTIDK

W: Wyoming H3N2

[0030] HA (HAW) SEQ ID NO.: 3:

MKTIIALSYILCLVFSQKLPGNDNSTATLCLGHHAVPNGTIVKTITNDQIEVTNATELVQSSST

GGICDSPHQILDGENCTLIDALLGDPQCDGFQNKKWDLFVERSKAYSNC*YPYDVPDYA*SLRS
LVASSGTLEFNNESFNWAGVTQNGTSSACKRRSNKSFFSRLNWLTHLKYKYPALNVTMPN
NEKFDKLYIWGVHHPVTDSDQISLYAQASGRITVSTKRSQQTVIPNIGYRPRVRDISSRISIYW
TIVKPGDILLINSTGNLIAPRGYFKIRSGKSSIMRSDAPIGKCNSECITPNGSIPNDKPFQNVNRI
TYGAC*PRYVKQNTLKLAT*GMRNVPEKQTRGIFGAIAGFIENGWEGMVDGWYGFRHQNSEGT
GQAADLKSTQAAINQINGKLNRLIGKTNEKFHQIEKEFSEVEGRIQDLEKYVEDTKIDLWSY
NAELLVALENQHTIDLTDSEMNKLFERTKKQLRENAEDMGNGCFKIYHKCDNACIESIRNG
TYDHDVYRDEALNNRFQIKGVELKSGYKDWILWISFAISCFLLCVALLGFIMWACQKGNIR
CNICI

[0031] NA (NAW) SEQ ID NO.: 4:
MNPNQKIITIGSVSLTISTICFFMQIAILITTVTLHFKQYEFNSPPNNQVMLCEPTIIERNITEIVY
LTNTTIEKEICPKLAEYRNWSKPQCNITGFAPFSKDNSIRLSAGGDIWVTREPYVSCDPDKCY
QFALGQGTTLNNVHSNDTVHDRTPYRTLLMNELGVPFHLGTKQVCIAWSSSSCHDGKAWL
HVCVTGDDENATASFIYNGRLVDSIVSWSKKILRTQESECVCINGTCTVVMTDGSASGKAD
TKILFIEEGKIVHTSTLSGSAQHVEECSCYPRYPGVRCVCRDNWKGSNRPIVDINIKDYSIVSS
YVCSGLVGDTPRKNDSSSSSHCLDPNNEEGGHGVKGWAFDDGNDVWMGRTISEKLRSGYE
TFKVIEGWSNPNSKLQINRQVIVDRGNRSGYSGIFSVEGKSCINRCFYVELIRGRKQETEVLW
TSNSIVVFCGTSGTYGTGSWPDGADINLMPI

[0032] Influenza Hong Kong M2 protein SEQ ID NO.: 5:
LTEVETPIRNEWGCRCNDSSDP

Influenza proteins

Hemagglutinin

[0033] In certain embodiments, full length hemagglutinin (HA) is utilized in vaccine compositions of the invention. In some embodiments one or more domains of HA is used. In certain embodiments, two or three or more domains are utilized, as one or more separate polypeptides or linked together in one or more fusion polypeptides. Certain exemplary embodiments provide influenza antigen comprising full length, domain 1-2 and domain 2-1 (referred to herein as HA1_2), or domain 3 of HA.

[0034] *HA Vietnam [H5N1]:*

[0035] H5N1 HA signal peptide SEQ ID NO.: 6: AKAGVQSVKMEKIVLLFAIVSLVKS

[0036] H5N1 HA domain 1-2 SEQ ID NO.: 7:
DQICIGYHANNSTEQVDTIMEKNVTVTHAQDILEKTHNGKL

[0037] H5N1 HA domain 3 SEQ ID NO.: 33:
CDLDGVKPLILRDCSVAGWLLGNPMCDEFINVPEWSYIVEKANPVNDLCYPGDFNDYEELK
HLLSRINHFEKIQIIPKSSWSSHEASLGVSSACPYQGKSSFFRNVVWLIKKNSTYPTIKRSYNN
TNQEDLLVLWGIHHPNDAAEQTKLYQNPTTYISVGTSTLNQRLVPRIATRSKVNGQSGRME
FFWTILKPNDAINFESNGNFIAPEYAYKIVKKGDSTIMKSELEYGNC

[0038] H5N1 HA domain 2-1 SEQ ID NO.: 8:
NTKCQTPMGAINSSMPFHNIHPLTIGECPKYVKSNRLVLATGLRNSPQRERRRKKRGLFGAI
AGFIEGGWQGMVDGWYGYHHSNEQGSGYAADKESTQKAIDGVTNKVNSIIDKMNTQFEA
VGREFNNLERRIENLNKKMEDGFLDVWTYNAELLVLMENERTLDFHDSNVKNLYDKVRL
QLRDNAKELGNGCFEFYHKCDNECMESVRNGTYDYPQYSEEARLKREEISGVKLESIGIYQI

[0039] H5N1 HA transmembrane domain SEQ ID NO.: 9:
LSIYSTVASSLALALMVAGLSLWMCSNGSLQCRICI

[0040] *HA A/Wyoming (H3N2)*

[0041] H3N2 HA signal peptide SEQ ID NO.: 10: MKTIIALSYILCLVFS

[0042] H3N2 HA domain 1-2 SEQ ID NO.: 11:
QKLPGNDNSTATLCLGHHAVPNGTIVKTITNDQIEVTNATELVQSSSTGGI

[0043] H3N2 HA domain 3 SEQ ID NO.: 12:
CDSPHQILDGENCTLIDALLGDPQCDGFQNKKWDLFVERSKAYSNC*YPYDVPDYA*SLRSLVA
SSGTLEFNNESFNWAGVTQNGTSSACKRRSNKSFFSRLNWLTHLKYKYPALNVTMPNNEK
FDKLYIWGVHHPVTDSDQISLYAQASGRITVSTKRSQQTVIPNIGYRPRVRDISSRISIYWTIV
KPGDILLINSTGNLIAPRGYFKIRSGKSSIMRSDAPIGKC

[0044] H3N2 HA domain 2-1 SEQ ID NO.: 13:
NSECITPNGSIPNDKPFQNVNRITYGAC*PRYVKQNTLKLAT*GMRNVPEKQTRGIFGAIAGFIEN
GWEGMVDGWYGFRHQNSEGTGQAADLKSTQAAINQINGKLNRLIGKTNEKFHQIEKEFSE
VEGRIQDLEKYVEDTKIDLWSYNAELLVALENQHTIDLTDSEMNKLFERTKKQLRENAEDM
GNGCFKIYHKCDNACIESIRNGTYDHDVYRDEALNNRFQIKGVELKSGYKDWIL

[0045] H3N2 HA transmembrane domain SEQ ID NO.: 14:
WISFAISCFLLCVALLGFIMWACQKGNIRCNICI

[0046] In certain embodiments, full length neuraminidase (NA) antigen is utilized in vaccine antigens of the invention. In some embodiments, a domain of NA is used. In certain embodiments two or three or more domains are provided in antigens of the invention. Certain exemplary embodiments provide influenza antigen comprising full length NA, lacking anchor peptide sequence.

Neuraminidase

[0047] *NA Vietnam*

[0048] H5N1 NA anchor peptide SEQ ID NO.: 15: *MNPNQKIITIGSICMVTGIVS*

[0049] H5N1 NA SEQ ID NO.: 16:

LMLQIGNMISIWVSHSIHTGNQHQSEPISNTNLLTEKAVASVKLAGNSSLCPINGWAVYSKD
NSIRIGSKGDVFVIREPFISCSHLECRTFFLTQGALLNDKHSNGTVKDRSPHRTLMSCPVGEA
PSPYNSRFESVAWSASACHDGTSWLTIGISGPDNGAVAVLKYNGIITDTIKSWRNNILRTQES
ECACVNGSCFTVMTDGPSNGQASHKIFKMEKGKVVKSVELDAPNYHYEECSCYPDAGEIT
CVCRDNWHGSNRPWVSFNQNLEYQIGYICSGVFGDNPRPNDGTGSCGPVSSNGAGGVKGF
SFKYGNGVWIGRTKSTNSRSGFEMIWDPNGWTETDSSFSVKQDIVAITDWSGYSGSFVQHP
ELTGLDCIRPCFWVELIRGRPKESTIWTSGSSISFCGVNSDTVGWSWPDGAELPFTIDK

[0050] H3N2 NA anchor peptide SEQ ID NO.: 17:

MNPNQKIITIGSVSLTISTICFFMQIAILITTVTLHF

[0051] H3N2 NA SEQ ID NO.: 18:

KQYEFNSPPNNQVMLCEPTIIERNITEIVYLTNTTIEKEICPKLAEYRNWSKPQCNITGFAPFS
KDNSIRLSAGGDIWVTREPYVSCDPDKCYQFALGQGTTLNNVHSNDTVHDRTPYRTLLMN
ELGVPFHLGTKQVCIAWSSSSCHDGKAWLHVCVTGDDENATASFIYNGRLVDSIVSWSKKI
LRTQESECVCINGTCTVVMTDGSASGKADTKILFIEEGKIVHTSTLSGSAQHVEECSCYPRYP
GVRCVCRDNWKGSNRPIVDINIKDYSIVSSYVCSGLVGDTPRKNDSSSSSHCLDPNNEEGGH
GVKGWAFDDGNDVWMGRTISEKLRSGYETFKVIEGWSNPNSKLQINRQVIVDRGNRSGYS
GIFSVEGKSCINRCFYVELIRGRKQETEVLWTSNSIVVFCGTSGTYGTGSWPDGADINLMPI

[0052] While sequences of exemplary influenza antigens are provided herein, and domains depicted for each of HA and NA and M2 have been provided for exemplary strains, it will be appreciated that any sequence having immunogenic characteristics of a domain of HA and/or NA and/or M2 may alternatively be employed. One skilled in the art will readily be capable of generating sequences having at least 75%, 80%, 85%, or 90% or more identity to provided antigens. In certain embodiments, influenza antigens comprise proteins including those having at least 95%, 96%, 97%, 98%, or more identity to a domain of HA and/or NA and/or M2, or a portion of a domain

of HA and/or NA and/or M2, wherein the antigen protein retains immunogenic activity. For example sequences having sufficient identity to influenza antigen(s) which retain immunogenic characteristics are capable of binding with antibodies which react with domains (antigen(s)) provided herein. Immunogenic characteristics often include three dimensional presentation of relevant amino acids or side groups. One skilled in the art can readily identify sequences with modest differences in sequence (*e.g.*, with difference in boundaries and/or some sequence alternatives, that, nonetheless preserve immunogenic characteristics). For instance, sequences whose boundaries are near to (*e.g.*, within about 15 amino acids, 14 amino acids, 13 amino acids, 12 amino acids, 11 amino acids, 10 amino acids, 9 amino acids, 8 amino acids, 7 amino acids 6 amino acids, 5 amino acids 4 amino acids, 3 amino acids, 2 amino acids, or 1 amino acid) of domain boundaries designated herein at either end of designated amino acid sequence may be considered to comprise relevant domain in accordance with the present invention. Thus, the invention contemplates use of a sequence of influenza antigen to comprise residues approximating the domain designation. For example, domain(s) of HA have been engineered and expressed as an in-frame fusion protein as an antigen of the invention (see Exemplification herein). Further, one will appreciate that any domains, partial domains or regions of amino acid sequence of influenza antigen (*e.g.*, HA, NA, M2) which are immunogenic can be generated using constructs and methods provided herein. Still further, domains or subdomains can be combined, separately and/or consecutively for production of influenza antigens.

[0053] As exemplary antigens, we have utilized sequences from hemagglutinin, neuraminidase, and M2 of particular subtypes as described in detail herein. Various subtypes of influenza virus exist and continue to be identified as new subtypes emerge. It will be understood by one skilled in the art that the methods and compositions provided herein may be adapted to utilize sequences of additional subtypes. Such variation is contemplated and encompassed within the methods and compositions provided herein.

Influenza Poplypeptide Fusions with Thermostable Proteins

[0054] In certain aspects of the invention, provided are influenza antigen(s) comprising fusion polypeptides which comprise an influenza protein (or a fragment or variant thereof) operably linked to a thermostable protein. Inventive fusion polypeptides can be produced in any available expression system known in the art. In certain embodiments, inventive fusion proteins are produced in a plant or portion thereof (*e.g.*, plant, plant cell, root, sprout, *etc.*).

[0055] Enzymes or other proteins which are not found naturally in humans or animal cells are particularly appropriate for use in fusion polypeptides of the present invention. Thermostable proteins that, when fused, confer thermostability to a fusion product are useful. Thermostability allows produced protein to maintain conformation, and maintain produced protein at room temperature This feature facilitates easy, time efficient and cost effective recovery of a fusion polypeptide. A representative family of thermostable enzymes useful in accordance with the invention is the glucanohydrolase family. These enzymes specifically cleave 1,4-β glucosidic bonds that are adjacent to 1,3-β linkages in mixed linked polysaccharides (Hahn *et al.*, 1994 *Proc. Natl. Acad. Sci., USA*, 91:10417). Such enzymes are found in cereals, such as oat and barley, and are also found in a number of fungal and bacterial species, including *C. thermocellum* (Goldenkova *et al.*, 2002, *Mol. Biol.* 36:698). Thus, desirable thermostable proteins for use in fusion polypeptides of the present invention include glycosidase enzymes. Exemplary thermostable glycosidase proteins include those represented by GenBank accession numbers selected from those set forth in Table A, the contents of each of which are incorporated herein by reference by entire incorporation of the GenBank accession information for each referenced number. Exemplary thermostable enzymes of use in fusion proteins of the invention include *Clostridium thermocellum* P29716, *Brevibacillus brevis* P37073, and *Rhodthermus marinus* P45798, each of which are incorporated herein by reference to their GenBank accession numbers. Representative fusion proteins illustrated in the Examples utilize modified thermostable enzyme isolated from *Clostridium thermocellum*, however, any thermostable protein may be similarly utilized in accordance with the present invention.

Table A: Thermostable glycosidase proteins

P29716	(Beta-glucanase *Clostridium thermocellum*)
P37073	(Beta-glucanase *Brevibacillus brevis*)
1MVE_A	(Beta-glucanase *Fibrobacter succinogenes*)
P07883	(Extracellular agarase *Streptomyces coelicolor*)
P23903	(Glucan endo-13-beta-glucosidase A1 *Bacillus circulans*)
P27051	(Beta-glucanase *Bacillus licheniformis*)
P45797	(Beta-glucanase *Paenibacillus polymyxa* (*Bacillus polymyxa*))
P37073	(Beta-glucanase *Brevibacillus brevis*)
P45798	(Beta-glucanase *Rhodothermus marinus*)
P38645	(Beta-glucosidase *Thermobispora bispora*)
P40942	(Celloxylanase *Clostridium stercorarium*)
P14002	(Beta-glucosidase *Clostridium thermocellum*)
O33830	(Alpha-glucosidase *Thermotoga maritima*)
O43097	(Xylanase *Thermomyces lanuginosus*)

P54583	(Endo-glucanase E1 *Acidothermus cellulolyticus*)
P14288	(Beta-galactosidase *Sulfolobus acidocaldarius*)
O52629	(Beta-galactosidase *Pyrococcus woesei*)
P29094	(Oligo-16-glucosidase *Geobacillus thermoglucosidasius*)
P49067	(Alpha-amylase *Pyrococcus furiosus*)
JC7532	(Cellulase *Bacillus* species)
Q60037	(Xylanase A *Thermotoga maritima*)
P33558	(Xylanase A *Clostridium stercorarium*)
P05117	(Polygalacturonase-2 precursor *Solanum lycopersicum*)
P04954	(Cellulase D *Clostridium thermocellum*)
Q4J929	(N-glycosylase *Sulfolobus acidocaldarius*)
O33833	(Beta-fructosidase *Thermotoga maritima*)
P49425	(Endo-14-beta-mannosidase *Rhodothermus marinus*)
P06279	(Alpha-amylase *Geobacillus stearothermophilus*)
P45702 P45703 P40943	(Xylanase *Geobacillus stearothermophilus*)
P09961	(Alpha-amylase 1 *Dictyoglomus thermophilum*)
Q60042	(Xylanase A *Thermotoga neapolitana*)
AAN05438 AAN05439	(Beta-glycosidase *Thermus thermophilus*)
AAN05437	(Sugar permease *Thermus thermophilus*)
AAN05440	(Beta-glycosidase *Thermus filiformis*)
AAD43138	(Beta-glycosidase *Thermosphaera aggregans*)

[0056] When designing fusion proteins and polypeptides in accordance with the invention, it is desirable, of course, to preserve immunogenicity of the antigen. Still further, it is desirable in certain aspects of the invention to provide constructs which provide thermostability of a fusion protein. This feature facilitates easy, time efficient and cost effective recovery of a target antigen. In certain aspects, antigen fusion partners may be selected which provide additional advantages, including enhancement of immunogenicity, potential to incorporate multiple vaccine determinants, yet lack prior immunogenic exposure to vaccination subjects. Further beneficial qualities of fusion peptides of interest include proteins which provide ease of manipulation for incorporation of one or more antigens, as well as proteins which have potential to confer ease of production, purification, and/or formulation for vaccine preparations. One of ordinary skill in the art will appreciate that three dimensional presentation can affect each of these beneficial characteristics. Preservation of immunity or preferential qualities therefore may affect, for example, choice of fusion partner and/or choice of fusion location (*e.g.*, N-terminus, C-terminus, internal, combinations thereof). Alternatively or additionally, preferences may affects length of segment selected for fusion, whether it be length of antigen, or length of fusion partner selected.

[0057] The present inventors have demonstrated successful fusion of a variety of antigens with a thermostable protein. For example, we have used the thermo-stable carrier molecule LicB, also referred to as lichenase, for production of fusion proteins. LicB is 1,3-1,4-β glucanase (LicB) from *Clostridium thermocellum* (GenBank accession: X63355 [gi:40697]). LicB belongs to a family of globular proteins. Based on the three dimensional structure of LicB, its N- and C-termini are situated close to each other on the surface, in close proximity to the active domain. LicB also has a loop structure exposed on the surface that is located far from the active domain. We have generated constructs such that the loop structure and N- and C-termini of protein can be used as insertion sites for influenza antigen polypeptides. Influenza antigen polypeptides can be expressed as N- or C-terminal fusions or as inserts into the surface loop. Importantly, LicB maintains its enzymatic activity at low pH and at high temperature (up to 75°C). Thus, use of LicB as a carrier molecule contributes advantages, including likely enhancement of target specific immunogenicity, potential to incorporate multiple vaccine determinants, and straightforward formulation of vaccines that may be delivered nasally, orally or parenterally. Furthermore, production of LicB fusions in plants should reduce the risk of contamination with animal or human pathogens. See examples provided herein.

[0058] Fusion proteins of the invention comprising influenza antigen may be produced in any of a variety of expression systems, including both *in vitro* and *in vivo* systems. One skilled in the art will readily appreciate that optimization of nucleic acid sequences for a particular expression system is often desirable. For example, in the exemplification provided herein, optimized sequence for expression of influenza antigen-LicB fusions in plants is provided. See Example 1. Thus, any relevant nucleic acid encoding influenza antigen(s) fusion protein(s) and fragments thereof in accordance with the invention is intended to be encompassed within nucleic acid constructs of the invention.

[0059] For production in plant systems, transgenic plants expressing influenza antigen(s) (*e.g.*, influenza protein(s) or fragments or fusions thereof) may be utilized. Alternatively or additionally, transgenic plants may be produced using methods well known in the art to generate stable production crops. Additionally, plants utilizing transient expression systems may be utilized for production of influenza antigen(s). When utilizing plant expression systems, whether transgenic or transient expression in plants is utilized, any of nuclear expression, chloroplast expression, mitochondrial expression, or viral expression may be taken advantage of according to the applicability of the system to antigen desired. Furthermore, additional expression systems for production of antigens and fusion proteins in accordance with the present invention may be utilized.

For example, mammalian expression systems (*e.g.*, mammalian cell lines (*e.g.*, CHO, *etc.*)), bacterial expression systems (*e.g.*, *E. coli*), insect expression systems (*e.g.*, baculovirus), yeast expression systems, and *in vitro* expression systems (*e.g.*, reticulate lysates) may be used for expression of antigens and fusion proteins of the invention.

Production of Influenza Antigens

[0060] In accordance with the present invention, influenza antigens (including influenza protein(s), fragments, variants, and/or fusions thereof) may be produced in any desirable system; production is not limited to plant systems. Vector constructs and expression systems are well known in the art and may be adapted to incorporate use of influenza antigens provided herein. For example, influenza antigens (including fragments, variants, and/or fusions) can be produced in known expression systems, including mammalian cell systems, transgenic animals, microbial expression systems, insect cell systems, and plant systems, including transgenic and transient plant systems. Particularly where influenza antigens are produced as fusion proteins, it may be desirable to produce such fusion proteins in non-plant systems.

[0061] In some embodiments of the invention, influenza antigens are desirably produced in plant systems. Plants are relatively easy to manipulate genetically, and have several advantages over alternative sources such as human fluids, animal cell lines, recombinant microorganisms and transgenic animals. Plants have sophisticated post-translational modification machinery for proteins that is similar to that of mammals (although it should be noted that there are some differences in glycosylation patterns between plants and mammals). This enables production of bioactive reagents in plant tissues. Also, plants can economically produce very large amounts of biomass without requiring sophisticated facilities. Moreover, plants are not subject to contamination with animal pathogens. Like liposomes and microcapsules, plant cells are expected to provide protection for passage of antigen to the gastrointestinal tract.

[0062] Plants may be utilized for production of heterologous proteins via use of various production systems. One such system includes use of transgenic/genetically-modified plants where a gene encoding target product is permanently incorporated into the genome of the plant. Transgenic systems may generate crop production systems. A variety of foreign proteins, including many of mammalian origin and many vaccine candidate antigens, have been expressed in transgenic plants and shown to have functional activity. (Tacket *et al.*, 2000, *J. Infect. Dis.*, 182:302; and Thanavala *et al.*, 2005, *Proc. Natl. Acad. Sci., USA*, 102:3378). Additionally, administration of unprocessed

transgenic plants expressing hepatitis B major surface antigen to non-immunized human volunteers resulted in production of immune response (Kapusta *et al.*, 1999, *FASEB J.*, 13:1796).

[0063] One system for expressing polypeptides in plants utilizes plant viral vectors engineered to express foreign sequences (*e.g.*, transient expression). This approach allows for use of healthy non-transgenic plants as rapid production systems. Thus, genetically engineered plants and plants infected with recombinant plant viruses can serve as "green factories" to rapidly generate and produce specific proteins of interest. Plant viruses have certain advantages that make them attractive as expression vectors for foreign protein production. Several members of plant RNA viruses have been well characterized, and infectious cDNA clones are available to facilitate genetic manipulation. Once infectious viral genetic material enters a susceptible host cell, it replicates to high levels and spreads rapidly throughout the entire plant. There are several approaches to producing target polypeptides using plant viral expression vectors, including incorporation of target polypeptides into viral genomes. One approach involves engineering coat proteins of viruses that infect bacteria, animals or plants to function as carrier molecules for antigenic peptides. Such carrier proteins have the potential to assemble and form recombinant virus-like particles displaying desired antigenic epitopes on their surface. This approach allows for time-efficient production of vaccine candidates, since the particulate nature of a vaccine candidate facilitates easy and cost-effective recovery from plant tissue. Additional advantages include enhanced target-specific immunogenicity, the potential to incorporate multiple vaccine determinants, and ease of formulation into vaccines that can be delivered nasally, orally or parenterally. As an example, spinach leaves containing recombinant plant viral particles carrying epitopes of virus fused to coat protein have generated immune response upon administration (Modelska *et al.*, 1998, *Proc. Natl. Acad. Sci., USA*, 95:2481; and Yusibov *et al.*, 2002, *Vaccine*, 19/20:3155).

Plant expression systems

[0064] Any plant susceptible to incorporation and/or maintenance of heterologus nucleic acid and capable of producing heterologous protein may be utilized in accordance with the present invention. In general, it will often be desirable to utilize plants that are amenable to growth under defined conditions, for example in a greenhouse and/or in aqueous systems. It may be desirable to select plants that are not typically consumed by human beings or domesticated animals and/or are not typically part of the human food chain, so that they may be grown outside without concern that expressed polynucleotide may be undesirably ingested. In some embodiments, however, it will be

desirable to employ edible plants. In particular embodiments, it will be desirable to utilize plants that accumulate expressed polypeptides in edible portions of a plant.

[0065] Often, certain desirable plant characteristics will be determined by the particular polynucleotide to be expressed. To give but a few examples, when a polynucleotide encodes a protein to be produced in high yield (as will often be the case, for example, when antigen proteins are to be expressed), it will often be desirable to select plants with relatively high biomass (*e.g.*, tobacco, which has additional advantages that it is highly susceptible to viral infection, has a short growth period, and is not in the human food chain). Where a polynucleotide encodes antigen protein whose full activity requires (or is inhibited by) a particular post-translational modification, the ability (or inability) of certain plant species to accomplish relevant modification (*e.g.*, a particular glycosylation) may direct selection. For example, plants are capable of accomplishing certain post-translational modifications (*e.g.*, glycosylation), however, plants will not generate sialation patterns which is found in mammalian post-translational modification. Thus, plant production of antigen may result in production of a different entity than the identical protein sequence produced in alternative systems.

[0066] In certain embodiments of the invention, crop plants, or crop-related plants are utilized. In certain specific embodiments, edible plants are utilized.

[0067] Plants for use in accordance with the present invention include Angiosperms, Bryophytes (*e.g.*, Hepaticae, Musci, *etc.*), Pteridophytes (*e.g.*, ferns, horsetails, lycopods), Gymnosperms (*e.g.*, conifers, cycase, Ginko, Gnetales), and Algae (*e.g.*, Chlorophyceae, Phaeophyceae, Rhodophyceae, Myxophyceae, Xanthophyceae, and Euglenophyceae). Exemplary plants are members of the family Leguminosae (Fabaceae; *e.g.*, pea, alfalfa, soybean); Gramineae (Poaceae; *e.g.*, corn, wheat, rice); Solanaceae, particularly of the genus *Lycopersicon* (*e.g.*, tomato), *Solanum* (*e.g.*, potato, eggplant), *Capsium* (*e.g.*, pepper), or *Nicotiana* (*e.g.*, tobacco); Umbelliferae, particularly of the genus *Daucus* (*e.g.*, carrot), *Apium* (*e.g.*, celery), or *Rutaceae* (*e.g.*, oranges); Compositae, particularly of the genus *Lactuca* (*e.g.*, lettuce); Brassicaceae (Cruciferae), particularly of the genus *Brassica* or *Sinapis*. In certain aspects, plants of the invention may be plants of the *Brassica* or *Arabidopsis* genus. Some exemplary Brassicaceae family members include *Brassica campestris, B. carinata, B. juncea, B. napus, B. nigra, B. oleraceae,B. tournifortii, Sinapis alba,* and *Raphanus sativus.* Some suitable plants that are amendable to transformation and are edible as sprouted seedlings include alfalfa, mung bean, radish, wheat, mustard, spinach, carrot, beet, onion, garlic, celery, rhubarb, a leafy plant

such as cabbage or lettuce, watercress or cress, herbs such as parsley, mint, or clovers, cauliflower, broccoli, soybean, lentils, edible flowers such as sunflower *etc.*

[0068] *Introducing Vectors Into Plants*

[0069] In general, vectors may be delivered to plants according to known techniques. For example, vectors themselves may be directly applied to plants (*e.g.*, via abrasive inoculations, mechanized spray inoculations, vacuum infiltration, particle bombardment, or electroporation). Alternatively or additionally, virions may be prepared (*e.g.*, from already infected plants), and may be applied to other plants according to known techniques.

[0070] A wide variety of viruses are known that infect various plant species, and can be employed for polynucleotide expression according to the present invention (see, for example, in *The Classification and Nomenclature of Viruses*, "Sixth Report of the International Committee on Taxonomy of Viruses" (Ed. Murphy *et al.*), Springer Verlag: New York, 1995, the entire contents of which are incorporated herein by reference; Grierson *et al.*, *Plant Molecular Biology*, Blackie, London, pp. 126-146, 1984; Gluzman *et al.*, *Communications in Molecular Biology: Viral Vectors*, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, pp. 172-189, 1988; and Mathew, *Plant Viruses Online* (http://image.fs.uidaho.edu/vide/). In certain embodiments of the invention rather than delivering a single viral vector to a plant cell, multiple different vectors are delivered which, together, allow for replication (and, optionally cell-to-cell and/or long distance movement) of viral vector(s). Some or all of the proteins may be encoded by the genome of transgenic plants. In certain aspects, described in further detail herein, these systems include one or more viral vector components.

[0071] Vector systems that include components of two heterologous plant viruses in order to achieve a system that readily infects a wide range of plant types and yet poses little or no risk of infectious spread. An exemplary system has been described previously (see, *e.g.*, PCT Publication WO 00/25574 and U.S. Patent Publication 2005/0026291, both of which are incorporated herein by reference. As noted herein, in particular aspects of the present invention, viral vectors are applied to plants (*e.g.*, plant, portion of plant, sprout, *etc.*), for example, through infiltration or mechanical inoculation, spray, *etc.* Where infection is to be accomplished by direct application of a viral genome to a plant, any available technique may be used to prepare the genome. For example, many viruses that are usefully employed in accordance with the present invention have ssRNA genomes. ssRNA may be prepared by transcription of a DNA copy of the genome, or by replication of an RNA copy, either *in vivo* or *in vitro*. Given the readily availability of easy-to-use *in vitro* transcription

systems (*e.g.*, SP6, T7, reticulocyte lysate, *etc.*), and also the convenience of maintaining a DNA copy of an RNA vector, it is expected that inventive ssRNA vectors will often be prepared by *in vitro* transcription, particularly with T7 or SP6 polymerase.

[0072] In certain embodiments of the invention rather than introducing a single viral vector type into a plant, multiple different viral vectors are introduced. Such vectors may, for example, trans-complement each other with respect to functions such as replication, cell-to-cell movement, and/or long distance movement. Vectors may contain different polynucleotides encoding influenza antigen of the invention. Selection for plant(s) or portions thereof that express multiple polypeptides encoding one or more influenza antigen(s) may be performed as described above for single polynucleotides or polypeptides.

[0073] *Plant Tissue Expression Systems*

[0074] As discussed above, in accordance with the present invention, influenza antigens may be produced in any desirable system. Vector constructs and expression systems are well known in the art and may be adapted to incorporate use of influenza antigens provided herein. For example, transgenic plant production is known and generation of constructs and plant production may be adapted according to known techniques in the art. In some embodiments, transient expression systems in plants is desirable. Two of these systems include production of clonal roots and clonal plant systems, and derivatives thereof, as well as production of sprouted seedlings systems.

[0075] Clonal Plants

[0076] Clonal roots maintain RNA viral expression vectors and stably produce target protein uniformly in an entire root over extended periods of time and multiple subcultures. In contrast to plants, where a target gene is eliminated via recombination during cell-to-cell or long distance movement, in root cultures the integrity of a viral vector is maintained and levels of target protein produced over time are similar to those observed during initial screening. Clonal roots allow for ease of production of heterologous protein material for oral formulation of antigen and vaccine compositions. Methods and reagents for generating a variety of clonal entities derived from plants which are useful for production of antigen (*e.g.*, antigen proteins of the invention) have been described previously and are known in the art (see, for example, PCT Publication WO 05/81905, which is incorporated herein by reference). Clonal entities include clonal root lines, clonal root cell lines, clonal plant cell lines, and clonal plants capable of production of antigen (*e.g.*, antigen proteins of the invention). The invention further provides methods and reagents for expression of antigen polynucleotide and polypeptide products in clonal cell lines derived from various plant tissues (*e.g.*,

roots, leaves), and in whole plants derived from single cells (clonal plants). Such methods are typically based on use of plant viral vectors of various types.

[0077] For example, in one aspect, the invention provides methods of obtaining a clonal root line that expresses a polynucleotide encoding an influenza antigen of the invention comprising steps of: (i) introducing a viral vector that comprises a polynucleotide encoding an influenza antigen of the invention into a plant or portion thereof; and (ii) generating one or more clonal root lines from a plant. Clonal root lines may be generated, for example, by infecting a plant or plant portion (*e.g.*, a harvested piece of leaf) with an *Agrobacterium* (*e.g.*, *A. rhizogenes*) that causes formation of hairy roots. Clonal root lines can be screened in various ways to identify lines that maintain virus, lines that express a polynucleotide encoding an influenza antigen of the invention at high levels, *etc.* The invention further provides clonal root lines, *e.g.*, clonal root lines produced according to inventive methods and further encompasses methods of expressing polynucleotides and producing polypeptide(s) encoding influenza antigen(s) of the invention using clonal root lines.

[0078] The invention further provides methods of generating a clonal root cell line that expresses a polynucleotide encoding an influenza antigen of the invention comprising steps of: (i) generating a clonal root line, cells of which contain a viral vector whose genome comprises a polynucleotide encoding an influenza antigen of the invention; (ii) releasing individual cells from a clonal root line; and (iii) maintaining cells under conditions suitable for root cell proliferation. The invention provides clonal root cell lines and methods of expressing polynucleotides and producing polypeptides using clonal root cell lines.

[0079] In one aspect, the invention provides methods of generating a clonal plant cell line that expresses a polynucleotide encoding an influenza antigen of the invention comprising steps of: (i) generating a clonal root line, cells of which contain a viral vector whose genome comprises a polynucleotide encoding an influenza antigen of the invention; (ii) releasing individual cells from a clonal root line; and (iii) maintaining cells in culture under conditions appropriate for plant cell proliferation. The invention further provides methods of generating a clonal plant cell line that expresses a polynucleotide encoding an influenza antigen of the invention comprising steps of: (i) introducing a viral vector that comprises a polynucleotide encoding an influenza antigen of the invention into cells of a plant cell line maintained in culture; and (ii) enriching for cells that contain viral vector. Enrichment may be performed, for example, by (i) removing a portion of cells from the culture; (ii) diluting removed cells so as to reduce cell concentration; (iii) allowing diluted cells to

proliferate; and (iv) screening for cells that contain viral vector. Clonal plant cell lines may be used for production of an influenza antigen in accordance with the present invention.

[0080] The invention includes a number of methods for generating clonal plants, cells of which contain a viral vector that comprises a polynucleotide encoding influenza antigen of the invention. For example, the invention provides methods of generating a clonal plant that expresses a polynucleotide encoding influenza antigen of the invention comprising steps of: (i) generating a clonal root line, cells of which contain a viral vector whose genome comprises a polynucleotide encoding influenza antigen of the invention; (ii) releasing individual cells from a clonal root line; and (iii) maintaining released cells under conditions appropriate for formation of a plant. The invention further provides methods of generating a clonal plant that expresses a polynucleotide encoding influenza antigen of the invention comprising steps of: (i) generating a clonal plant cell line, cells of which contain a viral vector whose genome comprises a polynucleotide encoding an influenza antigen of the invention; and (ii) maintaining cells under conditions appropriate for formation of a plant. In general, clonal plants according to the invention can express any polynucleotide encoding an influenza antigen of the invention. Such clonal plants can be used for production of a antigen polypeptide.

[0081] As noted above, the present invention provides systems for expressing a polynucleotide or polynucleotide(s) encoding influenza antigen(s) of the invention in clonal root lines, clonal root cell lines, clonal plant cell lines (*e.g.*, cell lines derived from leaf, stem, *etc.*), and in clonal plants. A polynucleotide encoding an influenza antigen of the invention is introduced into an ancestral plant cell using a plant viral vector whose genome includes polynucleotide encoding an influenza antigen of the invention operably linked to (*i.e.*, under control of) a promoter. A clonal root line or clonal plant cell line is established from a cell containing virus according to any of several techniques further described below. The plant virus vector or portions thereof can be introduced into a plant cell by infection, by inoculation with a viral transcript or infectious cDNA clone, by electroporation, by T-DNA mediated gene transfer, *etc.*

[0082] The following sections describe methods for generating clonal root lines, clonal root cell lines, clonal plant cell lines, and clonal plants that express a polynucleotide encoding an influenza antigen of the invention are then described. A "root line" is distinguished from a "root cell line" in that a root line produces actual rootlike structures or roots while a root cell line consists of root cells that do not form rootlike structures. Use of the term "line" is intended to indicate that cells of the line can proliferate and pass genetic information on to progeny cells. Cells of a cell line typically

proliferate in culture without being part of an organized structure such as those found in an intact plant. Use of the term "root line" is intended to indicate that cells in the root structure can proliferate without being part of a complete plant. It is noted that the term "plant cell" encompasses root cells. However, to distinguish the inventive methods for generating root lines and root cell lines from those used to directly generate plant cell lines from non-root tissue (as opposed to generating clonal plant cell lines from clonal root lines or clonal plants derived from clonal root lines), the terms "plant cell" and "plant cell line" as used herein generally refer to cells and cell lines that consist of non-root plant tissue. Plant cells can be, for example, leaf, stem, shoot, flower part, *etc.* It is noted that seeds can be derived from clonal plants generated as derived herein. Such seeds may contain viral vector as will plants obtained from such seeds. Methods for obtaining seed stocks are well known in the art (see, for example, U.S Patent Publication 2004/093643).

[0083] Clonal Root Lines

[0084] The present invention provides systems for generating a clonal root line in which a plant viral vector is used to direct expression of a polynucleotide encoding an influenza antigen of the invention. One or more viral expression vector(s) including a polynucleotide encoding an influenza antigen of the invention operably linked to a promoter is introduced into a plant or a portion thereof according to any of a variety of known methods. For example, plant leaves can be inoculated with viral transcripts. Vectors themselves may be directly applied to plants (*e.g.*, via abrasive inoculations, mechanized spray inoculations, vacuum infiltration, particle bombardment, or electroporation). Alternatively or additionally, virions may be prepared (*e.g.*, from already infected plants), and may be applied to other plants according to known techniques.

[0085] Where infection is to be accomplished by direct application of a viral genome to a plant, any available technique may be used to prepare viral genome. For example, many viruses that are usefully employed in accordance with the present invention have ssRNA genomes. ssRNA may be prepared by transcription of a DNA copy of the genome, or by replication of an RNA copy, either *in vivo* or *in vitro*. Given the readily available, easy-to-use *in vitro* transcription systems (*e.g.*, SP6, T7, reticulocyte lysate, *etc.*), and also the convenience of maintaining a DNA copy of an RNA vector, it is expected that inventive ssRNA vectors will often be prepared by *in vitro* transcription, particularly with T7 or SP6 polymerase. Infectious cDNA clones can be used. *Agrobacterially* mediated gene transfer can be used to transfer viral nucleic acids such as viral vectors (either entire viral genomes or portions thereof) to plant cells using, *e.g.*, agroinfiltration, according to methods known in the art.

[0086] A plant or plant portion may then be then maintained (*e.g.*, cultured or grown) under conditions suitable for replication of viral transcript. In certain embodiments of the invention virus spreads beyond the initially inoculated cell, *e.g.*, locally from cell to cell and/or systemically from an initially inoculated leaf into additional leaves. However, in some embodiments of the invention virus does not spread. Thus viral vector may contain genes encoding functional MP and/or CP, but may be lacking one or both of such genes. In general, viral vector is introduced into (infects) multiple cells in the plant or portion thereof.

[0087] Following introduction of viral vector into a plant, leaves are harvested. In general, leaves may be harvested at any time following introduction of a viral vector. However, it may be desirable to maintain a plant for a period of time following introduction of a viral vector into the plant, *e.g.*, a period of time sufficient for viral replication and, optionally, spread of virus from the cells into which it was initially introduced. A clonal root culture (or multiple cultures) is prepared, *e.g.*, by known methods further described below.

[0088] In general, any available method may be used to prepare a clonal root culture from a plant or plant tissue into which a viral vector has been introduced. One such method employs genes that exist in certain bacterial plasmids. These plasmids are found in various species of *Agrobacterium* that infect and transfer DNA to a wide variety of organisms. As a genus, *Agrobacteria* can transfer DNA to a large and diverse set of plant types including numerous dicot and monocot angiosperm species and gymnosperms (see, for example, Gelvin, 2003, *Microbiol. Mol. Biol. Rev.*, 67:16, and references therein, all of which are incorporated herein by reference). The molecular basis of genetic transformation of plant cells is transfer from bacterium and integration into plant nuclear genome of a region of a large tumor-inducing (Ti) or rhizogenic (Ri) plasmid that resides within various *Agrobacterial* species. This region is referred to as the T-region when present in the plasmid and as T-DNA when excised from plasmid. Generally, a single-stranded T-DNA molecule is transferred to a plant cell in naturally occurring *Agrobacterial* infection and is ultimately incorporated (in double-stranded form) into the genome. Systems based on Ti plasmids are widely used for introduction of foreign genetic material into plants and for production of transgenic plants.

[0089] Infection of plants with various *Agrobacterial* species and transfer of T-DNA has a number of effects. For example, *A. tumefaciens* causes crown gall disease while *A. rhizogenes* causes development of hairy roots at the site of infection, a condition known as "hairy root disease." Each root arises from a single genetically transformed cell. Thus root cells in roots are clonal, and

each root represents a clonal population of cells. Roots produced by *A. rhizogenes* infection are characterized by a high growth rate and genetic stability (Giri *et al.*, 2000, *Biotech. Adv.*, 18:1, and references therein, all of which are incorporated herein by reference). In addition, such roots are able to regenerate genetically stable plants (Giri 2000, *supra*).

[0090] In general, the present invention encompasses use of any strain of *Agrobacteria*, particularly *A. rhizogenes* strains, that is capable of inducing formation of roots from plant cells. As mentioned above, a portion of the Ri plasmid (Ri T-DNA) is responsible for causing hairy root disease. While transfer of this portion of the Ri plasmid to plant cells can conveniently be accomplished by infection with *Agrobacteria* harboring the Ri plasmid, the invention encompasses use of alternative methods of introducing the relevant region into a plant cell. Such methods include any available method of introducing genetic material into plant cells including, but not limited to, biolistics, electroporation, PEG-mediated DNA uptake, Ti-based vectors, *etc.* The relevant portions of Ri T-DNA can be introduced into plant cells by use of a viral vector. Ri genes can be included in the same vector that contains a polynucleotide encoding an influenza antigen of the invention or in a different viral vector, which can be the same or a different type to that of the vector that contains a polynucleotide encoding an influenza antigen of the invention. It is noted that the entire Ri T-DNA may not be required for production of hairy roots, and the invention encompasses use of portions of Ri T-DNA, provided that such portions contain sufficient genetic material to induce root formation, as known in the art. Additional genetic material, *e.g.*, genes present within the Ri plasmid but not within T-DNA, may be transferred to a plant cell in accordance with the invention, particularly genes whose expression products facilitate integration of T-DNA into the plant cell DNA.

[0091] In order to prepare a clonal root line in accordance with certain embodiments of the invention, harvested leaf portions are contacted with *A. rhizogenes* under conditions suitable for infection and transformation. Leaf portions are maintained in culture to allow development of hairy roots. Each root is clonal, *i.e.*, cells in the root are derived from a single ancestral cell into which Ri T-DNA was transferred. In accordance with the invention, a portion of such ancestral cells will contain a viral vector. Thus cells in a root derived from such an ancestral cell may contain viral vector since it will be replicated and will be transmitted during cell division. Thus a high proportion (*e.g.* at least 50%, at least 75%, at least 80%, at least 90%, at least 95%), all (100%), or substantially all (at least 98%) of cells will contain viral vector. It is noted that since viral vector is inherited by daughter cells within the clonal root, movement of viral vector within the root is not necessary to maintain viral vector throughout the root. Individual clonal hairy roots may be removed from the

leaf portion and further cultured. Such roots are also referred to herein as root lines. Isolated clonal roots continue to grow following isolation.

[0092] A variety of different clonal root lines have been generated using inventive methods. These root lines were generated using viral vectors containing polynucleotide(s) encoding an influenza antigen of the invention (*e.g.*, encoding influenza polypeptide(s), or fragments or fusion proteins thereof). Root lines were tested by Western blot. Root lines displayed a variety of different expression levels of various polypeptides. Root lines displaying high expression were selected and further cultured. These root lines were subsequently tested again and shown to maintain high levels of expression over extended periods of time, indicating stability. Expression levels were comparable to or greater than expression in intact plants infected with the same viral vector used to generate clonal root lines. In addition, stability of expression of root lines was superior to that obtained in plants infected with the same viral vector. Up to 80% of such virus-infected plants reverted to wild type after 2 – 3 passages. (Such passages involved inoculating plants with transcripts, allowing infection (local or systemic) to become established, taking a leaf sample, and inoculating fresh plants that are subsequently tested for expression).

[0093] Root lines may be cultured on a large scale for production of antigen of the invention polypeptides as discussed further below. It is noted that clonal root lines (and cell lines derived from clonal root lines) can generally be maintained in medium that does not include various compounds, *e.g.*, plant growth hormones such as auxins, cytokinins, *etc.*, that are typically employed in culture of root and plant cells. This feature greatly reduces expense associated with tissue culture, and the inventors expect that it will contribute significantly to economic feasibility of protein production using plants.

[0094] Any of a variety of methods may be used to select clonal roots that express a polynucleotide encoding influenza antigen(s) of the invention. Western blots, ELISA assays, *etc.*, can be used to detect an encoded polypeptide. In the case of detectable markers such as GFP, alternative methods such as visual screens can be performed. If a viral vector that contains a polynucleotide that encodes a selectable marker is used, an appropriate selection can be imposed (*e.g.*, leaf material and/or roots derived therefrom can be cultured in the presence of an appropriate antibiotic or nutritional condition and surviving roots identified and isolated). Certain viral vectors contain two or more polynucleotide(s) encoding influenza antigen(s) of the invention, *e.g.*, two or more polynucleotides encoding different polypeptides. If one of these is a selectable or detectable marker, clonal roots that are selected or detected by selecting for or detecting expression of the

marker will have a high probability of also expressing a second polynucleotide. Screening for root lines that contain particular polynucleotides can also be performed using PCR and other nucleic acid detection methods.

[0095] Alternatively or additionally, clonal root lines can be screened for presence of virus by inoculating host plants that will form local lesions as a result of virus infection (*e.g.*, hypersensitive host plants). For example, 5 mg of root tissue can be homogenized in 50 ul of phosphate buffer and used to inoculate a single leaf of a tobacco plant. If virus is present in root cultures, within two to three days characteristic lesions will appear on infected leaves. This means that root line contains recombinant virus that carries a polynucleotide encoding an influenza antigen of the invention (a target gene). If no local lesions are formed, there is no virus, and the root line is rejected as negative. This method is highly time and cost efficient. After initially screening for the presence of virus, roots that contain virus may be subjected to secondary screening, *e.g.*, by Western blot or ELISA to select high expressers. Additional screens, *e.g.*, screens for rapid growth, growth in particular media or under particular environmental conditions, *etc.*, can be applied. These screening methods may, in general, be applied in the development of any of clonal root lines, clonal root cell lines, clonal plant cell lines, and/or clonal plants described herein.

[0096] As will be evident to one of ordinary skill in the art, a variety of modifications may be made to the description of the inventive methods for generating clonal root lines that contain a viral vector. Such modifications are within the scope of the invention. For example, while it is generally desirable to introduce viral vector into an intact plant or portion thereof prior to introduction of Ri T-DNA genes, in certain embodiments of the invention the Ri-DNA is introduced prior to introducing viral vector. In addition, it is possible to contact intact plants with *A. rhizogenes* rather than harvesting leaf portions and then exposing them to bacterium.

[0097] Other methods of generating clonal root lines from single cells of a plant or portion thereof that harbor a viral vector can be used (*i.e.*, methods not using *A. rhizogenes* or genetic material from the Ri plasmid). For example, treatment with certain plant hormones or combinations of plant hormones is known to result in generation of roots from plant tissue.

[0098] Clonal Cell Lines Derived from Clonal Root Lines

[0099] As described above, the invention provides methods for generating clonal root lines, wherein cells in root lines contain a viral vector. As is well known in the art, a variety of different cell lines can be generated from roots. For example, root cell lines can be generated from individual root cells obtained from a root using a variety of known methods. Such root cell lines may be

obtained from various different root cell types within the root. In general, root material is harvested and dissociated (*e.g.*, physically and/or enzymatically digested) to release individual root cells, which are then further cultured. Complete protoplast formation is generally not necessary. If desired, root cells can be plated at very dilute cell concentrations, so as to obtain root cell lines from single root cells. Root cell lines derived in this manner are clonal root cell lines containing viral vector. Such root cell lines therefore exhibit stable expression of a polynucleotide encoding an influenza antigen of the invention. Clonal plant cell lines can be obtained in a similar manner from clonal roots, *e.g.*, by culturing dissociated root cells in the presence of appropriate plant hormones. Screens and successive rounds of enrichment can be used to identify cell lines that express a polynucleotide encoding an influenza antigen of the invention at high levels. However, if the clonal root line from which the cell line is derived already expresses at high levels, such additional screens may be unnecessary.

[00100] As in the case of the clonal root lines, cells of a clonal root cell line are derived from a single ancestral cell that contains viral vector and will, therefore, also contain viral vector since it will be replicated and will be transmitted during cell division. Thus a high proportion (*e.g.* at least 50%, at least 75%, at least 80%, at least 90%, at least 95%), all (100%), or substantially all (at least 98%) of cells will contain viral vector. It is noted that since viral vector is inherited by daughter cells within a clonal root cell line, movement of viral vector among cells is not necessary to maintain viral vector. Clonal root cell lines can be used for production of a polynucleotide encoding influenza antigen of the invention as described below.

[00101] Clonal Plant Cell Lines

[00102] The present invention provides methods for generating a clonal plant cell line in which a plant viral vector is used to direct expression of a polynucleotide encoding an influenza antigen of the invention. According to the inventive method, one or more viral expression vector(s) including a polynucleotide encoding an influenza antigen of the invention operably linked to a promoter is introduced into cells of a plant cell line that is maintained in cell culture. A number of plant cell lines from various plant types are known in the art, any of which can be used. Newly derived cell lines can be generated according to known methods for use in practicing the invention. A viral vector is introduced into cells of a plant cell line according to any of a number of methods. For example, protoplasts can be made and viral transcripts then electroporated into cells. Other methods of introducing a plant viral vector into cells of a plant cell line can be used.

[00103] A method for generating clonal plant cell lines in accordance with the invention and a viral vector suitable for introduction into plant cells (*e.g.*, protoplasts) can be used as follows: Following introduction of viral vector, a plant cell line may be maintained in tissue culture. During this time viral vector may replicate, and polynucleotide(s) encoding an influenza antigen(s) of the invention may be expressed. Clonal plant cell lines are derived from culture, *e.g.*, by a process of successive enrichment. For example, samples may be removed from culture, optionally with dilution so that the concentration of cells is low, and plated in Petri dishes in individual droplets. Droplets are then maintained to allow cell division.

[00104] It will be appreciated that droplets may contain a variable number of cells, depending on the initial density of the culture and the amount of dilution. Cells can be diluted such that most droplets contain either 0 or 1 cell if it is desired to obtain clonal cell lines expressing a polynucleotide encoding an influenza antigen of the invention after only a single round of enrichment. However, it can be more efficient to select a concentration such that multiple cells are present in each droplet and then screen droplets to identify those that contain expressing cells. In general, any appropriate screening procedure can be employed. For example, selection or detection of a detectable marker such as GFP can be used. Western blots or ELISA assays can be used. Individual droplets (100 ul) contain more than enough cells for performance of these assays. Multiple rounds of enrichment are performed to isolate successively higher expressing cell lines. Single clonal plant cell lines (*i.e.*, populations derived from a single ancestral cell) can be generated by further limiting dilution using standard methods for single cell cloning. However, it is not necessary to isolate individual clonal lines. A population containing multiple clonal cell lines can be used for expression of a polynucleotide encoding one or more influenza antigen(s) of the invention.

[00105] In general, certain considerations described above for generation of clonal root lines apply to the generation of clonal plant cell lines. For example, a diversity of viral vectors containing one or more polynucleotide(s) encoding an influenza antigen(s) of the invention can be used as can combinations of multiple different vectors. Similar screening methods can be used. As in the case of clonal root lines and clonal root cell lines, cells of a clonal plant cell line are derived from a single ancestral cell that contains viral vector and will, therefore, also contain viral vector since it will be replicated and will be transmitted during cell division. Thus a high proportion(*e.g.* at least 50%, at least 75%, at least 80%, at least 90%, at least 95%), all (100%), or substantially all (at least 98%) of cells will contain viral vector. It is noted that since viral vector is inherited by daughter cells within a clonal plant cell line, movement of viral vector among cells is not necessary to maintain viral

vector. The clonal plant cell line can be used for production of a polypeptide encoding an influenza antigen of the invention as described below.

[00106] Clonal Plants

[00107] Clonal plants can be generated from clonal roots, clonal root cell lines, and/or clonal plant cell lines produced according to various methods described above. Methods for the generation of plants from roots, root cell lines, and plant cell lines such as clonal root lines, clonal root cell lines, and clonal plant cell lines described herein are well known in the art (see, *e.g.*, Peres *et al.*, 2001, *Plant Cell, Tissue, Organ Culture*, 65:37; and standard reference works on plant molecular biology and biotechnology cited elsewhere herein). The invention therefore provides a method of generating a clonal plant comprising steps of (i) generating a clonal root line, clonal root cell line, or clonal plant cell line according to any of the inventive methods described above; and (ii) generating a whole plant from a clonal root line, clonal root cell line, or clonal plant. Clonal plants may be propagated and grown according to standard methods.

[00108] As in the case of clonal root lines, clonal root cell lines, and clonal plant cell lines, cells of a clonal plant are derived from a single ancestral cell that contains viral vector and will, therefore, also contain viral vector since it will be replicated and will be transmitted during cell division. Thus a high proportion(*e.g.* at least 50%, at least 75%, at least 80%, at least 90%, at least 95%), all (100%), or substantially all (at least 98%) of cells will contain viral vector. It is noted that since viral vector is inherited by daughter cells within the clonal plant, movement of viral vector is not necessary to maintain viral vector.

[00109] *Sprouts and Sprouted Seedling Plant Expression Systems*

[00110] Systems and and reagents for generating a variety of sprouts and sprouted seedlings which are useful for production of influenza antigen(s) according to the present invention have been described previously and are known in the art (see, for example, PCT Publication WO 04/43886, which is incorporated herein by reference). The present invention further provides sprouted seedlings, which may be edible, as a biomass containing an influenza antigen. In certain aspects, biomass is provided directly for consumption of antigen containing compositions. In some aspects, biomass is processed prior to consumption, for example, by homogenizing, crushing, drying, or extracting. In certain aspects, influenza antigen is purified from biomass and formulated into a pharmaceutical composition.

[00111] Additionally provided are methods for producing influenza antigen(s) in sprouted seedlings that can be consumed or harvested live (*e.g.*, sprouts, sprouted seedlings of the *Brassica*

genus). In certain aspects, the present invention involves growing a seed to an edible sprouted seedling in a contained, regulatable environment (*e.g.*, indoors, in a container, *etc.*). A seed can be a genetically engineered seed that contains an expression cassette encoding an influenza antigen, which expression is driven by an exogenously inducible promoter. A variety of exogenously inducible promoters can be used that are inducible, for example, by light, heat, phytohormones, nutrients, *etc.*

[00112] In related embodiments, the present invention provides methods of producing influenza antigen(s) in sprouted seedlings by first generating a seed stock for a sprouted seedling by transforming plants with an expression cassette that encodes influenza antigen using an *Agrobacterium* transformation system, wherein expression of an influenza antigen is driven by an inducible promoter. Transgenic seeds can be obtained from a transformed plant, grown in a contained, regulatable environment, and induced to express an influenza antigen.

[00113] In some embodiments methods are provided that involves infecting sprouted seedlings with a viral expression cassette encoding an influenza antigen, expression of which may be driven by any of a viral promoter or an inducible promoter. Sprouted seedlings are grown for two to fourteen days in a contained, regulatable environment or at least until sufficient levels of influenza antigen have been obtained for consumption or harvesting.

[00114] The present invention further provides systems for producing influenza antigen(s) in sprouted seedlings that include a housing unit with climate control and a sprouted seedling containing an expression cassette that encodes one or more influenza antigens, wherein expression is driven by a constitutive or inducible promoter. Systems can provide unique advantages over the outdoor environment or greenhouse, which cannot be controlled. Thus, the present invention enables a grower to precisely time the induction of expression of influenza antigen. It can greatly reduce time and cost of producing influenza antigen(s).

[00115] In certain aspects, transiently transfected sprouts contain viral vector sequences encoding an inventive influenza antigen. Seedlings are grown for a time period so as to allow for production of viral nucleic acid in sprouts, followed by a period of growth wherein multiple copies of virus are produced, thereby resulting in production of influenza antigen(s).

[00116] In certain aspects, genetically engineered seeds or embryos that contain a nucleic acid encoding influenza antigen(s) are grown to sprouted seedling stage in a contained, regulatable environment. The contained, regulatable environment may be a housing unit or room in which seeds can be grown indoors. All environmental factors of a contained, regulatable environment may be

controlled. Since sprouts do not require light to grow, and lighting can be expensive, genetically engineered seeds or embryos may be grown to sprouted seedling stage indoors in the absence of light.

[00117] Other environmental factors that can be regulated in a contained, regulatable environment of the present invention include temperature, humidity, water, nutrients, gas (*e.g.*, O_2 or CO_2 content or air circulation), chemicals (small molecules such as sugars and sugar derivatives or hormones such as such as phytohormones gibberellic or absisic acid, *etc.*) and the like.

[00118] According to certain methods of the present invention, expression of a nucleic acid encoding an influenza antigen may be controlled by an exogenously inducible promoter. Exogenously inducible promoters are caused to increase or decrease expression of a nucleic acid in response to an external, rather than an internal stimulus. A number of environmental factors can act as inducers for expression of nucleic acids carried by expression cassettes of genetically engineered sprouts. A promoter may be a heat-inducible promoter, such as a heat-shock promoter. For example, using as heat-shock promoter, temperature of a contained environment may simply be raised to induce expression of a nucleic acid. Other promoters include light inducible promoters. Light-inducible promoters can be maintained as constitutive promoters if light in a contained regulatable environment is always on. Alternatively or additionally, expression of a nucleic acid can be turned on at a particular time during development by simply turning on the light. A promoter may be a chemically inducible promoter is used to induce expression of a nucleic acid. According to these embodiments, a chemical could simply be misted or sprayed onto seed, embryo, or seedling to induce expression of nucleic acid. Spraying and misting can be precisely controlled and directed onto target seed, embryo, or seedling to which it is intended. The contained environment is devoid of wind or air currents, which could disperse chemical away from intended target, so that the chemical stays on the target for which it was intended.

[00119] According to the present invention, time of expression is induced can be selected to maximize expression of an influenza antigen in sprouted seedling by the time of harvest. Inducing expression in an embryo at a particular stage of growth, for example, inducing expression in an embryo at a particular number of days after germination, may result in maximum synthesis of an influenza antigen at the time of harvest. For example, inducing expression from the promoter 4 days after germination may result in more protein synthesis than inducing expression from the promoter after 3 days or after 5 days. Those skilled in the art will appreciate that maximizing expression can

be achieved by routine experimentation. In certain methods, sprouted seedlings are harvested at about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 days after germination.

[00120] In cases where the expression vector has a constitutive promoter instead of an inducible promoter, sprouted seedling may be harvested at a certain time after transformation of sprouted seedling. For example, if a sprouted seedling were virally transformed at an early stage of development, for example, at embryo stage, sprouted seedlings may be harvested at a time when expression is at its maximum post-transformation, *e.g.*, at about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, or 14 days post-transformation. It could be that sprouts develop one, two, three or more months post-transformation, depending on germination of seed.

[00121] Generally, once expression of influenza antigen(s) begins, seeds, embryos, or sprouted seedlings are allowed to grow until sufficient levels of influenza antigen(s) are expressed. In certain aspects, sufficient levels are levels that would provide a therapeutic benefit to a patient if harvested biomass were eaten raw. Alternatively or additionally, sufficient levels are levels from which influenza antigen can be concentrated or purified from biomass and formulated into a pharmaceutical composition that provides a therapeutic benefit to a patient upon administration. Typically, influenza antigen is not a protein expressed in sprouted seedling in nature. At any rate, influenza antigen is typically expressed at concentrations above that which would be present in the sprouted seedling in nature.

[00122] Once expression of influenza antigen is induced, growth is allowed to continue until sprouted seedling stage, at which time sprouted seedlings are harvested. Sprouted seedlings can be harvested live. Harvesting live sprouted seedlings has several advantages including minimal effort and breakage. Sprouted seedlings of the present invention may be grown hydroponically, making harvesting a simple matter of lifting a sprouted seedling from its hydroponic solution. No soil is required for growth of sprouted seedlings of the invention, but may be provided if deemed necessary or desirable by the skilled artisan. Because sprouts can be grown without soil, no cleansing of sprouted seedling material is required at the time of harvest. Being able to harvest the sprouted seedling directly from its hydroponic environment without washing or scrubbing minimizes breakage of harvested material. Breakage and wilting of plants induces apoptosis. During apoptosis, certain proteolytic enzymes become active, which can degrade pharmaceutical protein expressed in the sprouted seedling, resulting in decreased therapeutic activity of the protein. Apoptosis-induced proteolysis can significantly decrease yield of protein from mature plants. Using

methods of the present invention, apoptosis may be avoided when no harvesting takes place until the moment proteins are extracted from the plant.

[00123] For example, live sprouts may be ground, crushed, or blended to produce a slurry of sprouted seedling biomass, in a buffer containing protease inhibitors. Buffer may be maintained at about 4°C. In some aspects, sprouted seedling biomass is air-dried, spray dried, frozen, or freeze-dried. As in mature plants, some of these methods, such as air-drying, may result in a loss of activity of pharmaceutical protein. However, because sprouted seedlings are very small and have a large surface area to volume ratio, this is much less likely to occur. Those skilled in the art will appreciate that many techniques for harvesting biomass that minimize proteolysis of expressed protein are available and could be applied to the present invention.

[00124] In some embodiments, sprouted seedlings are edible. In certain embodiments, sprouted seedlings expressing sufficient levels of influenza antigens are consumed upon harvesting (*e.g.*, immediately after harvest, within minimal period following harvest) so that absolutely no processing occurs before sprouted seedlings are consumed. In this way, any harvest-induced proteolytic breakdown of influenza antigen before administration of influenza antigen to a patient in need of treatment is minimized. For example, sprouted seedlings that are ready to be consumed can be delivered directly to a patient. Alternatively or additionally, genetically engineered seeds or embryos are delivered to a patient in need of treatment and grown to sprouted seedling stage by a patient. In one aspect, a supply of genetically engineered sprouted seedlings are provided to a patient, or to a doctor who will be treating patients, so that a continual stock of sprouted seedlings expressing certain desirable influenza antigens may be cultivated. This may be particularly valuable for populations in developing countries, where expensive pharmaceuticals are not affordable or deliverable. The ease with which sprouted seedlings of the invention can be grown makes sprouted seedlings of the present invention particularly desirable for such developing populations.

[00125] The regulatable nature of the contained environment imparts advantages to the present invention over growing plants in the outdoor environment. In general, growing genetically engineered sprouted seedlings that express pharmaceutical proteins in plants provides a pharmaceutical product faster (because plants are harvested younger) and with less effort, risk, and regulatory considerations than growing genetically engineered plants. The contained, regulatable environment used in the present invention reduces or eliminates risk of cross-pollinating plants in nature.

[00126] For example, a heat inducible promoter likely would not be used outdoors because outdoor temperature cannot be controlled. The promoter would be turned on any time the outdoor temperature rose above a certain level. Similarly, the promoter would be turned off every time the outdoor temperature dropped. Such temperature shifts could occur in a single day, for example, turning expression on in the daytime and off at night. A heat inducible promoter, such as those described herein, would not even be practical for use in a greenhouse, which is susceptible to climatic shifts to almost the same degree as outdoors. Growth of genetically engineered plants in a greenhouse is quite costly. In contrast, in the present system, every variable can be controlled so that the maximum amount of expression can be achieved with every harvest.

[00127] In certain embodiments, sprouted seedlings of the present invention are grown in trays that can be watered, sprayed, or misted at any time during development of sprouted seedling. For example, a tray may be fitted with one or more watering, spraying, misting, and draining apparatus that can deliver and/or remove water, nutrients, chemicals *etc.* at specific time and at precise quantities during development of the sprouted seedling. For example, seeds require sufficient moisture to keep them damp. Excess moisture drains through holes in trays into drains in the floor of the room. Typically, drainage water is treated as appropriate for removal of harmful chemicals before discharge back into the environment.

[00128] Another advantage of trays is that they can be contained within a very small space. Since no light is required for sprouted seedlings to grow, trays containing seeds, embryos, or sprouted seedlings may be tightly stacked vertically on top of one another, providing a large quantity of biomass per unit floor space in a housing facility constructed specifically for these purposes. In addition, stacks of trays can be arranged in horizontal rows within the housing unit. Once seedlings have grown to a stage appropriate for harvest (about two to fourteen days) individual seedling trays are moved into a processing facility, either manually or by automatic means, such as a conveyor belt.

[00129] The system of the present invention is unique in that it provides a sprouted seedling biomass, which is a source of a influenza antigen(s). Whether consumed directly or processed into the form of a pharmaceutical composition, because sprouted seedlings are grown in a contained, regulatable environment, sprouted seedling biomass and/or pharmaceutical composition derived from biomass can be provided to a consumer at low cost. In addition, the fact that the conditions for growth of sprouted seedlings can be controlled makes the quality and purity of product consistent. The contained, regulatable environment of the invention obviates many safety regulations of the

EPA that can prevent scientists from growing genetically engineered agricultural products out of doors.

[00130] Transformed Sprouts

[00131] A variety of methods can be used to transform plant cells and produce genetically engineered sprouted seedlings. Two available methods for transformation of plants that require that transgenic plant cell lines be generated *in vitro*, followed by regeneration of cell lines into whole plants include *Agrobacterium tumefaciens* mediated gene transfer and microprojectile bombardment or electroporation. Viral transformation is a more rapid and less costly method of transforming embryos and sprouted seedlings that can be harvested without an experimental or generational lag prior to obtaining desired product. For any of these techniques, the skilled artisan would appreciate how to adjust and optimize transformation protocols that have traditionally been used for plants, seeds, embryos, or spouted seedlings.

[00132] *Agrobacterium* Transformation Expression Cassettes

[00133] *Agrobacterium* is a representative genus of the gram-negative family Rhizobiaceae. This species is responsible for plant tumors such as crown gall and hairy root disease. In dedifferentiated plant tissue, which is characteristic of tumors, amino acid derivatives known as opines are produced by the *Agrobacterium* and catabolized by the plant. The bacterial genes responsible for expression of opines are a convenient source of control elements for chimeric expression cassettes. According to the present invention, *Agrobacterium* transformation system may be used to generate edible sprouted seedlings, which are merely harvested earlier than mature plants. *Agrobacterium* transformation methods can easily be applied to regenerate sprouted seedlings expressing influenza antigens.

[00134] In general, transforming plants involves transformation of plant cells grown in tissue culture by co-cultivation with an *Agrobacterium tumefaciens* carrying a plant/bacterial vector. The vector contains a gene encoding an influenza antigen. The *Agrobacterium* transfers vector to plant host cell and is then eliminated using antibiotic treatment. Transformed plant cells expressing influenza antigen are selected, differentiated, and finally regenerated into complete plantlets (Hellens *et al.*, 2000, *Plant Mol. Biol.*, 42:819; Pilon-Smits *et al.*, 1999, *Plant Physiolog.*, 119:123; Barfield *et al.*, 1991, *Plant Cell Reports*, 10:308; and Riva *et al.*, 1998, *J. Biotech.*, 1(3); each of which is incorporated by reference herein).

[00135] Expression vectors for use in the present invention include a gene (or expression cassette) encoding an influenza antigen designed for operation in plants, with companion sequences upstream

and downstream of the expression cassette. Companion sequences are generally of plasmid or viral origin and provide necessary characteristics to the vector to transfer DNA from bacteria to the desired plant host.

[00136] The basic bacterial/plant vector construct may desirably provide a broad host range prokaryote replication origin, a prokaryote selectable marker. Suitable prokaryotic selectable markers include resistance toward antibiotics such as ampicillin or tetracycline. Other DNA sequences encoding additional functions that are well known in the art may be present in the vector.

[00137] *Agrobacterium* T-DNA sequences are required for *Agrobacterium* mediated transfer of DNA to the plant chromosome. The tumor-inducing genes of T-DNA are typically removed and replaced with sequences encoding an influenza antigen. T-DNA border sequences are retained because they initiate integration of the T-DNA region into the plant genome. If expression of influenza antigen is not readily amenable to detection, the bacterial/plant vector construct may include a selectable marker gene suitable for determining if a plant cell has been transformed, *e.g.*, nptII kanamycin resistance gene. On the same or different bacterial/plant vector (Ti plasmid) are Ti sequences. Ti sequences include virulence genes, which encode a set of proteins responsible for excision, transfer and integration of T-DNA into the plant genome (Schell, 1987, *Science*, 237:1176). Other sequences suitable for permitting integration of heterologous sequence into the plant genome may include transposon sequences, and the like, for homologous recombination.

[00138] Certain constructs will include an expression cassette encoding an antigen protein. One, two, or more expression cassettes may be used in a given transformation. The recombinant expression cassette contains, in addition to an influenza antigen encoding sequence, at least the following elements: a promoter region, plant 5' untranslated sequences, initiation codon (depending upon whether or not an expressed gene has its own), and transcription and translation termination sequences. In addition, transcription and translation terminators may be included in expression cassettes or chimeric genes of the present invention. Signal secretion sequences that allow processing and translocation of a protein, as appropriate, may be included in the expression cassette. A variety of promoters, signal sequences, and transcription and translation terminators are described, for example, in Lawton *et al.* (1987, *Plant Mol. Biol.*, 9:315) and in U.S. Patent 5,888,789 (both of which are incorporated herein by reference). In addition, structural genes for antibiotic resistance are commonly utilized as a selection factor (Fraley *et al.* 1983, *Proc. Natl. Acad. Sci., USA*, 80:4803, incorporated herein by reference). Unique restriction enzyme sites at the 5' and 3' ends of a cassette allow for easy insertion into a pre-existing vector. Other binary vector systems for *Agrobacterium*-

mediated transformation, carrying at least one T-DNA border sequence are described (PCT/EP99/07414, incorporated herein by reference).

[00139] Regeneration

[00140] Seeds of transformed plants may be harvested, dried, cleaned, and tested for viability and for the presence and expression of a desired gene product. Once this has been determined, seed stock is typically stored under appropriate conditions of temperature, humidity, sanitation, and security to be used when necessary. Whole plants may then be regenerated from cultured protoplasts, *e.g.*, as described in Evans *et al.* (*Handbook of Plant Cell Cultures*, Vol. 1, MacMillan Publishing Co., New York, NY, 1983, incorporated herein by reference); and in Vasil (ed., *Cell Culture and Somatic Cell Genetics of Plants*, Acad. Press, Orlando, FL, Vol. I, 1984, and Vol. III, 1986, incorporated herein by reference). In certain aspects, plants are regenerated only to sprouted seedling stage. In some aspects, whole plants are regenerated to produce seed stocks and sprouted seedlings are generated from seeds of the seed stock.

[00141] All plants from which protoplasts can be isolated and cultured to give whole, regenerated plants can be transformed by the present invention so that whole plants are recovered that contain a transferred gene. It is known that practically all plants can be regenerated from cultured cells or tissues, including, but not limited to, all major species of plants that produce edible sprouts. Some suitable plants include alfalfa, mung bean, radish, wheat, mustard, spinach, carrot, beet, onion, garlic, celery, rhubarb, a leafy plant such as cabbage or lettuce, watercress or cress, herbs such as parsley, mint, or clovers, cauliflower, broccoli, soybean, lentils, edible flowers such as sunflower *etc.*

[00142] Means for regeneration vary from one species of plants to the next. However, those skilled in the art will appreciate that generally a suspension of transformed protoplants containing copies of a heterologous gene is first provided. Callus tissue is formed and shoots may be induced from callus and subsequently rooted. Alternatively or additionally, embryo formation can be induced from a protoplast suspension. These embryos germinate as natural embryos to form plants. Steeping seed in water or spraying seed with water to increase the moisture content of the seed to between 35-45% initiates germination. For germination to proceed, seeds are typically maintained in air saturated with water under controlled temperature and airflow conditions. The culture media will generally contain various amino acids and hormones, such as auxin and cytokinins. It is advantageous to add glutamic acid and proline to the medium, especially for such species as alfalfa. Shoots and roots normally develop simultaneously. Efficient regeneration will depend on the

medium, the genotype, and the history of the culture. If these three variables are controlled, then regeneration is fully reproducible and repeatable.

[00143] The mature plants, grown from the transformed plant cells, are selfed and non-segregating, homozygous transgenic plants are identified. The inbred plant produces seeds containing inventive antigen-encoding sequences. Such seeds can be germinated and grown to sprouted seedling stage to produce influenza antigen(s) according to the present invention.

[00144] In related embodiments, seeds of the present invention may be formed into seed products and sold with instructions on how to grow seedlings to the appropriate sprouted seedling stage for administration or harvesting into a pharmaceutical composition. In some related embodiments, hybrids or novel varieties embodying desired traits may be developed from inbred plants of the invention.

[00145] Direct Integration

[00146] Direct integration of DNA fragments into the genome of plant cells by microprojectile bombardment or electroporation may be used in the present invention (see, *e.g.*, Kikkert, *et al.*, 1999, *Plant: J. Tiss. Cult. Assoc.*, 35:43; Bates, 1994, *Mol. Biotech.*, 2:135). More particularly, vectors that express influenza antigen(s) of the present invention can be introduced into plant cells by a variety of techniques. As described above, vectors may include selectable markers for use in plant cells. Vectors may include sequences that allow their selection and propagation in a secondary host, such as sequences containing an origin of replication and selectable marker. Typically, secondary hosts include bacteria and yeast. In one embodiment, a secondary host is bacteria (*e.g.*, *Escherichia coli*, the origin of replication is a colE1-type origin of replication) and a selectable marker is a gene encoding ampicillin resistance. Such sequences are well known in the art and are commercially available (*e.g.*, Clontech, Palo Alto, CA or Stratagene, La Jolla, CA).

[00147] Vectors of the present invention may be modified to intermediate plant transformation plasmids that contain a region of homology to an *Agrobacterium tumefaciens* vector, a T-DNA border region from *Agrobacterium tumefaciens*, and antigen encoding nucleic acids or expression cassettes described above. Further vectors may include a disarmed plant tumor inducing plasmid of *Agrobacterium tumefaciens*.

[00148] According to this embodiment, direct transformation of vectors invention may involve microinjecting vectors directly into plant cells by use of micropipettes to mechanically transfer recombinant DNA (see, *e.g.*, Crossway, 1985, *Mol. Gen. Genet.*, 202:179, incorporated herein by reference). Genetic material may be transferred into a plant cell using polyethylene glycols (see,

e.g., Krens *et al.*, 1982, *Nature* 296:72). Another method of introducing nucleic acids into plants via high velocity ballistic penetration by small particles with a nucleic acid either within the matrix of small beads or particles, or on the surface (see, *e.g.*, Klein *et al.*, 1987, *Nature* 327:70; Knudsen *et al.*, *Planta*, 185:330). Yet another method of introduction is fusion of protoplasts with other entities, either minicells, cells, lysosomes, or other fusible lipid-surfaced bodies (see, *e.g.*, Fraley *et al.*, 1982, *Proc. Natl. Acad. Sci., USA*, 79:1859). Vectors of the invention may be introduced into plant cells by electroporation (see, *e.g.*, Fromm *et al.* 1985, *Proc. Natl. Acad. Sci., USA*, 82:5824). According to this technique, plant protoplasts are electroporated in the presence of plasmids containing a gene construct. Electrical impulses of high field strength reversibly permeabilize biomembranes allowing introduction of pasmids. Electroporated plant protoplasts reform the cell wall divide and form plant callus, which can be regenerated to form sprouted seedlings of the invention. Those skilled in the art will appreciate how to utilize these methods to transform plants cells that can be used to generate edible sprouted seedlings.

[00149] Viral Transformation

[00150] Similar to conventional expression systems, plant viral vectors can be used to produce full-length proteins, including full length antigen. According to the present invention, plant virus vectors may be used to infect and produce antigen(s) in seeds, embryos, sprouted seedlings, *etc.* Viral system that can be used to express everything from short peptides to large complex proteins. Specifically, using tobamoviral vectors is described, for example, by McCormick *et al.* (1999, *Proc. Natl. Acad. Sci., USA*, 96:703; Kumagai *et al.* 2000, *Gene*, 245:169; and Verch *et al.*, 1998, *J. Immunol. Methods*, 220:69; all of which are incorporated herein by reference). Thus, plant viral vectors have a demonstrated ability to express short peptides as well as large complex proteins.

[00151] In certain embodiments, transgenic sprouts, which express influenza antigen, are generated utilizing a host/virus system. Transgenic sprouts produced by viral infection provide a source of transgenic protein that has already been demonstrated to be safe. For example, sprouts are free of contamination with animal pathogens. Unlike, for example, tobacco, proteins from an edible sprout could at least in theory be used in oral applications without purification, thus significantly reducing costs. In addition, a virus/sprout system offers a much simpler, less expensive route for scale-up and manufacturing, since trangenes are introduced into virus, which can be grown up to a commercial scale within a few days. In contrast, transgenic plants can require up to 5-7 years before sufficient seeds or plant material are available for large-scale trials or commercialization.

[00152] According to the present invention, plant RNA viruses have certain advantages, which make them attractive as vectors for foreign protein expression. The molecular biology and pathology of a number of plant RNA viruses are well characterized and there is considerable knowledge of virus biology, genetics, and regulatory sequences. Most plant RNA viruses have small genomes and infectious cDNA clones are available to facilitate genetic manipulation. Once infectious virus material enters a susceptible host cell, it replicates to high levels and spreads rapidly throughout the entire sprouted seedling (one to ten days post inoculation). Virus particles are easily and economically recovered from infected sprouted seedling tissue. Viruses have a wide host range, enabling use of a single construct for infection of several susceptible species. These characteristics are readily transferable to sprouts.

[00153] Foreign sequences can be expressed from plant RNA viruses, typically by replacing one of the viral genes with desired sequence, by inserting foreign sequences into the virus genome at an appropriate position, or by fusing foreign peptides to structural proteins of a virus. Moreover, any of these approaches can be combined to express foreign sequences by trans-complementation of vital functions of a virus. A number of different strategies exist as tools to express foreign sequences in virus-infected plants using tobacco mosaic virus (TMV), alfalfa mosaic virus (AlMV), and chimeras thereof.

[00154] The genome of AlMV is a representative of the *Bromoviridae* family of viruses and consists of three genomic RNAs (RNAs1-3) and subgenomic RNA (RNA4). Genomic RNAs1 and 2 encode virus replicase proteins P1 and 2, respectively. Genomic RNA3 encodes cell-to-cell movement protein P3 and coat protein (CP). CP is translated from subgenomic RNA4, which is synthesized from genomic RNA3, and is required to start infection. Studies have demonstrated the involvement of CP in multiple functions, including genome activation, replication, RNA stability, symptom formation, and RNA encapsidation (see *e.g.*, Bol *et al.*, 1971, *Virology*, 46:73; Van Der Vossen *et al.*, 1994, *Virology* 202:891; Yusibov *et al.*, *Virology*, 208:405; Yusibov *et al.*, 1998, *Virology*, 242:1; Bol *et al.*, (Review, 100 refs.), 1999, *J. Gen. Virol.*, 80:1089; De Graaff, 1995, *Virology*, 208:583; Jaspars *et al.*, 1974, *Adv. Virus Res.*, 19:37; Loesch-Fries, 1985, *Virology*, 146:177; Neeleman *et al.*, 1991, *Virology*, 181:687; Neeleman *et al.*, 1993, *Virology*, 196: 883; Van Der Kuyl *et al.*, 1991, *Virology*, 183:731; and Van Der Kuyl *et al.*, 1991, *Virology*, 185:496).

[00155] Encapsidation of viral particles is typically required for long distance movement of virus from inoculated to un-inoculated parts of seed, embryo, or sprouted seedling and for systemic infection. According to the present invention, inoculation can occur at any stage of plant

development. In embryos and sprouts, spread of inoculated virus should be very rapid. Virions of AlMV are encapsidated by a unique CP (24 kD), forming more than one type of particle. The size (30- to 60-nm in length and 18 nm in diameter) and shape (spherical, ellipsoidal, or bacilliform) of the particle depends on the size of the encapsidated RNA. Upon assembly, the N-terminus of AlMV CP is thought to be located on the surface of the virus particles and does not appear to interfere with virus assembly (Bol *et al.*, 1971, *Virology*, 6:73). Additionally, ALMV CP with an additional 38-amino acid peptide at its N-terminus forms particles *in vitro* and retains biological activity (Yusibov *et al.*, 1995, *J. Gen. Virol.*, 77:567).

[00156] AlMV has a wide host range, which includes a number of agriculturally valuable crop plants, including plant seeds, embryos, and sprouts. Together, these characteristics make ALMV CP an excellent candidate as a carrier molecule and AlMV an attractive candidate vector for expression of foreign sequences in a plant at the sprout stage of development. Moreover, upon expression from a heterologous vector such as TMV, AlMV CP encapsidates TMV genome without interfering with virus infectivity (Yusibov *et al.*, 1997, *Proc. Natl. Acad. Sci., USA*, 94:5784, incorporated herein by reference). This allows use of TMV as a carrier virus for AlMV CP fused to foreign sequences.

[00157] TMV, the prototype of tobamoviruses, has a genome consisting of a single plus-sense RNA encapsidated with a 17.0 kD CP, which results in rod-shaped particles (300 nm in length). CP is the only structural protein of TMV and is required for encapsidation and long distance movement of virus in an infected host (Saito *et al.*, 1990, *Virology* 176:329). 183 and 126 kD proteins are translated from genomic RNA and are required for virus replication (Ishikawa *et al.*, 1986, *Nucleic Acids Res.*, 14:8291). 30 kD protein is the cell-to-cell movement protein of virus (Meshi *et al.*, 1987, *EMBO J.*, 6:2557). Movement and coat proteins are translated from subgenomic mRNAs (Hunter *et al.*, 1976, *Nature*, 260:759; Bruening *et al.*, 1976, *Virology*, 71:498; and Beachy *et al.*, 1976, *Virology*, 73:498, each of which is incorporated herein by reference).

[00158] Other methods of transforming plant tissues include transforming the flower of a plant. Transformation of *Arabidopsis thaliana* can be achieved by dipping plant flowers into a solution of *Agrobacterium tumefaciens* (Curtis *et al.*, 2001, *Transgenic Res.*, 10:363; and Qing *et al.*, 2000, *Molecular Breeding: New Strategies in Plant Improvement* 1:67). Transformed plants are formed in the population of seeds generated by "dipped" plants. At a specific point during flower development, a pore exists in the ovary wall through which *Agrobacterium tumefaciens* gains access to the interior of the ovary. Once inside the ovary, the *Agrobacterium tumefaciens* proliferates and

transforms individual ovules (Desfeux *et al.*, 2000, *Plant Physiology*, 123:895). Transformed ovules follow the typical pathway of seed formation within the ovary.

Production and Isolation of Antigen

[00159] In general, standard methods known in the art may be used for culturing or growing plants, plant cells, and/or plant tissues of the invention (*e.g.*, clonal plants, clonal plant cells, clonal roots, clonal root lines, sprouts, sprouted seedlings, plants, *etc.*) for production of antigen(s). A wide variety of culture media and bioreactors have been employed to culture hairy root cells, root cell lines, and plant cells (see, for example, Giri *et al.*, 2000, *Biotechnol. Adv.*, 18:1; Rao *et al.*, 2002, *Biotechnol. Adv.*, 20:101; and references in both of the foregoing, all of which are incorporated herein by reference). Clonal plants may be grown in any suitable manner.

[00160] In a certain embodiments, influenza antigens of the invention may be produced by any known method. In some embodiments, an influenza antigen is expressed in a plant or portion thereof. Proteins are isolated and purified in accordance with conventional conditions and techniques known in the art. These include methods such as extraction, precipitation, chromatography, affinity chromatography, electrophoresis, and the like. The present invention involves purification and affordable scaling up of production of influenza antigen(s) using any of a variety of plant expression systems known in the art and provided herein, including viral plant expression systems described herein.

[00161] In many embodiments of the present invention, it will be desirable to isolate influenza antigen(s) for vaccine products. Where a protein of the invention is produced from plant tissue(s) or a portion thereof, *e.g.*, roots, root cells, plants, plant cells, that express them, methods described in further detail herein, or any applicable methods known in the art may be used for any of partial or complete isolation from plant material. Where it is desirable to isolate the expression product from some or all of plant cells or tissues that express it, any available purification techniques may be employed. Those of ordinary skill in the art are familiar with a wide range of fractionation and separation procedures (see, for example, Scopes *et al.*, *Protein Purification: Principles and Practice*, 3rd Ed., Janson *et al.*, 1993; *Protein Purification: Principles, High Resolution Methods, and Applications*, Wiley-VCH, 1998; Springer-Verlag, NY, 1993; and Roe, *Protein Purification Techniques*, Oxford University Press, 2001; each of which is incorporated herein by reference). Often, it will be desirable to render the product more than about 50%, 60%, 70%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% pure. See, *e.g.*, U.S. Pat. Nos. 6,740,740 and

6,841,659 for discussion of certain methods useful for purifying substances from plant tissues or fluids.

[00162] Those skilled in the art will appreciate that a method of obtaining desired influenza antigen(s) product(s) is by extraction. Plant material (*e.g.*, roots, leaves, *etc.*) may be extracted to remove desired products from residual biomass, thereby increasing the concentration and purity of product. Plants may be extracted in a buffered solution. For example, plant material may be transferred into an amount of ice-cold water at a ratio of one to one by weight that has been buffered with, *e.g.*, phosphate buffer. Protease inhibitors can be added as required. The plant material can be disrupted by vigorous blending or grinding while suspended in buffer solution and extracted biomass removed by filtration or centrifugation. The product carried in solution can be further purified by additional steps or converted to a dry powder by freeze-drying or precipitation. Extraction can be carried out by pressing. Plants or roots can be extracted by pressing in a press or by being crushed as they are passed through closely spaced rollers. Fluids expressed from crushed plants or roots are collected and processed according to methods well known in the art. Extraction by pressing allows release of products in a more concentrated form. However, overall yield of product may be lower than if product were extracted in solution.

Vaccines

[00163] The present invention provides pharmaceutical antigen proteins for therapeutic use, such as influenza antigen(s) (*e.g.*, influenza protein(s) or an immunogenic portion(s) thereof, or fusion proteins comprising influenza protein(s) or an immunogenic portion(s) thereof) active as a vaccine for therapeutic and/or prophylactic treatment of influenza infection. Further, the invention provides veterinary use, as such influenza antigen is active in veterinary applications. In certain embodiments, influenza antigen(s) may be produced by plant(s) or portion thereof (*e.g.*, root, cell, sprout, cell line, plant, *etc.*) of the invention. In certain embodiments, provided influenza antigens are expressed in plants, plant cells, and/or plant tissues (*e.g.*, sprouts, sprouted seedlings, roots, root culture, clonal cells, clonal cell lines, clonal plants, *etc.*), and can be used directly from plant or partially purified or purified in preparation for pharmaceutical administration to a subject.

[00164] The present invention provides plants, plant cells, and plant tissues expressing influenza antigen(s) that maintains pharmaceutical activity when administered to a subject in need thereof. Exemplary subjects include vertebrates (*e.g.*, mammals such as humans). According to the present invention, subjects include veterinary subjects such as bovines, ovines, canines, felines, *etc.* In

certain aspects, an edible plant or portion thereof (*e.g.*, sprout, root) is administered orally to a subject in a therapeutically effective amount. In some aspects one or more influenza antigen(s) is provided in a pharmaceutical preparation, as described herein.

[00165] Vaccine compositions of the invention comprise one or more influenza antigens. In certain embodiments, at least two influenza antigens of the invention are included in an administered vaccine composition.

[00166] According to the present invention, treatment of a subject with an influenza antigen vaccine is intended to elicit a physiological effect. A vaccine protein may have healing curative or palliative properties against a disorder or disease and can be administered to ameliorate relieve, alleviate, delay onset of, reverse or lessen symptoms or severity of a disease or disorder. A vaccine comprising an influenza antigen may have prophylactic properties and can be used to prevent or delay the onset of a disease or to lessen the severity of such disease, disorder, or pathological condition when it does emerge. A physiological effect elicited by treatment of a subject with antigen according to the present invention can include an effective immune response such that infection by an organism is thwarted.

[00167] In some embodiments, inventive vaccines are delivered by oral and/or mucosal routes. Oral and/or mucosal delivery has the potential to prevent infection of mucosal tissues, the primary gateway of infection for many pathogens. Oral and/or mucosal delivery can prime systemic immune response. There has been considerable progress in the development of heterologous expression systems for oral administration of antigens that stimulate the mucosal-immune system and can prime systemic immunity. Previous efforts at delivery of oral vaccine however, have demonstrated a requirement for considerable quantities of antigen in achieving efficacy. Thus, economical production of large quantities of target antigens is a prerequisite for creation of effective oral vaccines. The development of plants expressing antigens, including thermostable antigens, represents a more realistic approach to such difficulties.

[00168] The pharmaceutical preparations of the present invention can be administered in a wide variety of ways to a subject, such as, for example, orally, nasally, enterally, parenterally, intramuscularly or intravenously, rectally, vaginally, topically, ocularly, pulmonarily, or by contact application. In certain embodiments, an influenza antigen expressed in a plant or portion thereof is administered to a subject orally by direct administration of a plant to a subject. In some aspects a vaccine protein expressed in a plant or portion thereof is extracted and/or purified, and used for the preparation of a pharmaceutical composition. It may be desirable to formulate such isolated

products for their intended use (*e.g.*, as a pharmaceutical agent, vaccine composition, *etc.*). In some embodiments, it will be desirable to formulate products together with some or all of plant tissues that express them.

[00169] Where it is desirable to formulate product together with the plant material, it will often be desirable to have utilized a plant that is not toxic to the relevant recipient (*e.g.*, a human or other animal). Relevant plant tissue (*e.g.*, cells, roots, leaves) may simply be harvested and processed according to techniques known in the art, with due consideration to maintaining activity of the expressed product. In certain embodiments of the invention, it is desirable to have expressed influenza antigen in an edible plant (and, specifically in edible portions of the plant) so that the material can subsequently be eaten. For instance, where vaccine antigen is active after oral delivery (when properly formulated), it may be desirable to produce antigen protein in an edible plant portion, and to formulate expressed influenza antigen for oral delivery together with some or all of the plant material with which the protein was expressed.

[00170] Vaccine antigens (*i.e.*, influenza antigens of the invention) provided may be formulated according to known techniques. For example, an effective amount of a vaccine product can be formulated together with one or more organic or inorganic, liquid or solid, pharmaceutically suitable carrier materials. A vaccine antigen produced according to the present invention may be employed in dosage forms such as tablets, capsules, troches, dispersions, suspensions, solutions, gelcaps, pills, caplets, creams, ointments, aerosols, powder packets, liquid solutions, solvents, diluents, surface active agents, isotonic agents, thickening or emulsifying agents, preservatives, and solid bindings, as long as the biological activity of the protein is not destroyed by such dosage form.

[00171] In general, compositions may comprise any of a variety of different pharmaceutically acceptable carrier(s), adjuvant(s), or vehicle(s), or a combination of one or more such carrier(s), adjuvant(s), or vehicle(s). As used herein the language "pharmaceutically acceptable carrier, adjuvant, or vehicle" includes solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like, compatible with pharmaceutical administration. Materials that can serve as pharmaceutically acceptable carriers include, but are not limited to sugars such as lactose, glucose and sucrose; starches such as corn starch and potato starch; cellulose and its derivatives such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered tragacanth; malt; gelatin; talc; excipients such as cocoa butter and suppository waxes; oils such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; glycols such a propylene glycol; esters such as ethyl oleate and ethyl laurate; agar;

buffering agents such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's solution; ethyl alcohol, and phosphate buffer solutions, as well as other non-toxic compatible lubricants such as sodium lauryl sulfate and magnesium stearate, as well as coloring agents, releasing agents, coating agents, sweetening agents, flavoring agents, and perfuming agents, preservatives, and antioxidants can be present in the composition, according to the judgment of the formulator (see also *Remington's Pharmaceutical Sciences*, Fifteenth Edition, E.W. Martin, Mack Publishing Co., Easton, PA, 1975). For example, vaccine antigen product may be provided as a pharmaceutical composition by means of conventional mixing granulating dragee-making, dissolving, lyophilizing, or similar processes.

Additional vaccine components

[00172] Inventive vaccines may include additionally any suitable adjuvant to enhance the immunogenicity of the vaccine when administered to a subject. For example, such adjuvant(s) may include, without limitation, extracts of Quillaja saponaria (QS), including purified subfractions of food grade QS such as Quil A and QS-21, alum, aluminum hydroxide, aluminum phosphate, MF59, Malp2, incomplete Freund's adjuvant; Complete freund's adjuvant; 3 De-O-acylated monophosphoryl lipid A (3D-MPL). Further adjuvants include immunomodulatory oligonucleotides, for example unmethylated CpG sequences as disclosed in WO 96/02555. Combinations of different adjuvants, such as those mentioned hereinabove, are contemplated as providing an adjuvant which is a preferential stimulator of TH1 cell response. For example, QS21 can be formulated together with 3D-MPL. The ratio of QS21:3D-MPL will typically be in the order of 1:10 to 10:1; 1:5 to 5:1; and often substantially 1:1. The desired range for optimal synergy may be 2.5:1 to 1:1 3D-MPL: QS21. Doses of purified QS extracts suitable for use in a human vaccine formulation are from 0.01 mg to 10 mg per kilogram of bodyweight.

[00173] It should be noted that certain thermostable proteins (*e.g.*, lichenase) may themselves demonstrate immunoresponse potentiating activity, such that use of such protein whether in a fusion with an influenza antigen or separately may be considered use of an adjuvant. Thus, inventive vaccine compositions may further comprise one or more adjuvants. Certain vaccine compositions may comprise two or more adjuvants. Furthermore, depending on formulation and routes of administration, certain adjuvants may be desired in particular formulations and/or combinations.

[00174] In certain situations, it may be desirable to prolong the effect of an inventive vaccine by slowing the absorption of one or more components of the vaccine product (*e.g.*, protein) that is subcutaneously or intramuscularly injected. This may be accomplished by use of a liquid suspension

of crystalline or amorphous material with poor water solubility. The rate of absorption of product then depends upon its rate of dissolution, which in turn, may depend upon size and form. Alternatively or additionally, delayed absorption of a parenterally administered product is accomplished by dissolving or suspending the product in an oil vehicle. Injectable depot forms are made by forming microcapsule matrices of protein in biodegradable polymers such as polylactide-polyglycolide. Depending upon the ratio of product to polymer and the nature of the particular polymer employed, rate of release can be controlled. Examples of biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations may be prepared by entrapping product in liposomes or microemulsions, which are compatible with body tissues. Alternative polymeric delivery vehicles can be used for oral formulations. For example, biodegradable, biocompatible polymers such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid, *etc.*, can be used. Antigen(s) or an immunogenic portions thereof may be formulated as microparticles, *e.g.*, in combination with a polymeric delivery vehicle.

[00175] Enterally administered preparations of vaccine antigens may be introduced in solid, semi-solid, suspension or emulsion form and may be compounded with any pharmaceutically acceptable carriers, such as water, suspending agents, and emulsifying agents. Antigens may be administered by means of pumps or sustained-release forms, especially when administered as a preventive measure, so as to prevent the development of disease in a subject or to ameliorate or delay an already established disease. Supplementary active compounds, *e.g.*, compounds independently active against the disease or clinical condition to be treated, or compounds that enhance activity of an inventive compound, can be incorporated into or administered with compositions. Flavorants and coloring agents can be used.

[00176] Inventive vaccine products, optionally together with plant tissue, are particularly well suited for oral administration as pharmaceutical compositions. Oral liquid formulations can be used and may be of particular utility for pediatric populations. Harvested plant material may be processed in any of a variety of ways (*e.g.*, air drying, freeze drying, extraction *etc.*), depending on the properties of the desired therapeutic product and its desired form. Such compositions as described above may be ingested orally alone or ingested together with food or feed or a beverage. Compositions for oral administration include plants; extractions of plants, and proteins purified from infected plants provided as dry powders, foodstuffs, aqueous or non-aqueous solvents, suspensions, or emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol,

vegetable oil, fish oil, and injectable organic esters. Aqueous carriers include water, water-alcohol solutions, emulsions or suspensions, including saline and buffered medial parenteral vehicles including sodium chloride solution, Ringer's dextrose solution, dextrose plus sodium chloride solution, Ringer's solution containing lactose or fixed oils. Examples of dry powders include any plant biomass that has been dried, for example, freeze dried, air dried, or spray dried. For example, plants may be air dried by placing them in a commercial air dryer at about 120 degrees Fahrenheit until biomass contains less than 5% moisture by weight. The dried plants may be stored for further processing as bulk solids or further processed by grinding to a desired mesh sized powder. Alternatively or additionally, freeze-drying may be used for products that are sensitive to air-drying. Products may be freeze dried by placing them into a vacuum drier and dried frozen under a vacuum until the biomass contains less than about 5% moisture by weight. Dried material can be further processed as described herein.

[00177] Plant-derived material may be administered as or together with one or more herbal preparations. Useful herbal preparations include liquid and solid herbal preparations. Some examples of herbal preparations include tinctures, extracts (*e.g.*, aqueous extracts, alcohol extracts), decoctions, dried preparations (*e.g.*, air-dried, spray dried, frozen, or freeze-dried), powders (*e.g.*, lyophilized powder), and liquid. Herbal preparations can be provided in any standard delivery vehicle, such as a capsule, tablet, suppository, liquid dosage, *etc.* Those skilled in the art will appreciate the various formulations and modalities of delivery of herbal preparations that may be applied to the present invention.

[00178] Inventive root lines, cell lines, plants, extractions, powders, dried preparations and purified protein or nucleic acid products, *etc.*, can be in encapsulated form with or without one or more excipients as noted above. Solid dosage forms such as tablets, dragees, capsules, pills, and granules can be prepared with coatings and shells such as enteric coatings, release controlling coatings and other coatings well known in the pharmaceutical formulating art. In such solid dosage forms active agent may be mixed with at least one inert diluent such as sucrose, lactose or starch. Such dosage forms may comprise, as is normal practice, additional substances other than inert diluents, *e.g.*, tableting lubricants and other tableting aids such as magnesium stearate and microcrystalline cellulose. In the case of capsules, tablets and pills, the dosage forms may comprise buffering agents. They may optionally contain opacifying agents and can be of a composition that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract,

and/or in a delayed manner. Examples of embedding compositions that can be used include polymeric substances and waxes.

[00179] In some methods, a plant or portion thereof expressing a influenza antigen according to the present invention, or biomass thereof, is administered orally as medicinal food. Such edible compositions are typically consumed by eating raw, if in a solid form, or by drinking, if in liquid form. The plant material can be directly ingested without a prior processing step or after minimal culinary preparation. For example, the vaccine protein may be expressed in a sprout which can be eaten directly. For instance, vaccine antigens expressed in an alfalfa sprout, mung bean sprout, or spinach or lettuce leaf sprout, *etc.* In one embodiment, plant biomass may be processed and the material recovered after the processing step is ingested.

[00180] Processing methods useful in accordance with the present invention are methods commonly used in the food or feed industry. The final products of such methods typically include a substantial amount of an expressed antigen and can be conveniently eaten or drunk. The final product may be mixed with other food or feed forms, such as salts, carriers, favor enhancers, antibiotics, and the like, and consumed in solid, semi-solid, suspension, emulsion, or liquid form. Such methods can include a conservation step, such as, *e.g.*, pasteurization, cooking, or addition of conservation and preservation agents. Any plant may be used and processed in the present invention to produce edible or drinkable plant matter. The amount of influenza antigen in a plant-derived preparation may be tested by methods standard in the art, *e.g.*, gel electrophoresis, ELISA, or Western blot analysis, using a probe or antibody specific for product. This determination may be used to standardize the amount of vaccine antigen protein ingested. For example, the amount of vaccine antigen may be determined and regulated, for example, by mixing batches of product having different levels of product so that the quantity of material to be drunk or eaten to ingest a single dose can be standardized. The contained, regulatable environment of the present invention, however, should minimize the need to carry out such standardization procedures.

[00181] A vaccine protein produced in a plant cell or tissue and eaten by a subject may be preferably absorbed by the digestive system. One advantage of the ingestion of plant tissue that has been only minimally processed is to provide encapsulation or sequestration of the protein in cells of the plant. Thus, product may receive at least some protection from digestion in the upper digestive tract before reaching the gut or intestine and a higher proportion of active product would be available for uptake.

[00182] Pharmaceutical compositions of the present invention can be administered therapeutically or prophylactically. The compositions may be used to treat or prevent a disease. For example, any individual who suffers from a disease or who is at risk of developing a disease may be treated. It will be appreciated that an individual can be considered at risk for developing a disease without having been diagnosed with any symptoms of the disease. For example, if the individual is known to have been, or to be intended to be, in situations with relatively high risk of exposure to influenza infection, that individual will be considered at risk for developing the disease. Similarly, if members of an individual's family or friends have been diagnosed with influenza infection, the individual may be considered to be at risk for developing the disease.

[00183] Liquid dosage forms for oral administration include, but are not limited to, pharmaceutically acceptable emulsions, microemulsions, solutions, suspensions, syrups, and elixirs. In addition to active agents, the liquid dosage forms may contain inert diluents commonly used in the art such as, for example, water or other solvents, solubilizing agents and emulsifiers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethylformamide, oils (in particular, cottonseed, groundnut, corn, germ, olive, castor, and sesame oils), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitan, and mixtures thereof. Besides inert diluents, the oral compositions can include adjuvants such as wetting agents, emulsifying and suspending agents, sweetening, flavoring, and perfuming agents.

[00184] Compositions for rectal or vaginal administration may be suppositories or retention enemas, which can be prepared by mixing the compositions of this invention with suitable non-irritating excipients or carriers such as cocoa butter, polyethylene glycol or a suppository wax which are solid at ambient temperature but liquid at body temperature and therefore melt in the rectum or vaginal cavity and release the active protein.

[00185] Dosage forms for topical, transmucosal or transdermal administration of a vaccine composition of this invention include ointments, pastes, creams, lotions, gels, powders, solutions, sprays, inhalants or patches. The active agent, or preparation thereof, is admixed under sterile conditions with a pharmaceutically acceptable carrier and any needed preservatives or buffers as may be required. For transmucosal or transdermal administration, penetrants appropriate to the barrier to be permeated may be used in the formulation. Such penetrants are generally known in the art, and include, for example, for transmucosal administration, detergents, bile salts, and fusidic acid derivatives. Transmucosal administration can be accomplished through the use of nasal sprays or

suppositories. For transdermal administration, antigen or a immunogenic portion thereof may be formulated into ointments, salves, gels, or creams as generally known in the art. Ophthalmic formulation, eardrops, and eye drops are contemplated as being within the scope of this invention. Additionally, the present invention contemplates the use of transdermal patches, which have the added advantage of providing controlled delivery of a vaccine protein to the body. Such dosage forms can be made by suspending or dispensing the vaccine product in the proper medium. Absorption enhancers can be used to increase the flux of the vaccine protein across the skin. The rate can be controlled by either providing a rate controlling membrane or by dispersing the vaccine protein in a polymer matrix or gel.

[00186] Inventive compositions are administered in such amounts and for such time as is necessary to achieve the desired result. In certain embodiments of the present invention a "therapeutically effective amount" of a pharmaceutical composition is that amount effective for treating, attenuating, or preventing a disease in a subject. Thus, the "amount effective to treat, attenuate, or prevent disease," as used herein, refers to a nontoxic but sufficient amount of the pharmaceutical composition to treat, attenuate, or prevent disease in any subject. For example, the "therapeutically effective amount" can be an amount to treat, attenuate, or prevent infection (*e.g.*, viral infection, influenza infection), *etc.*

[00187] The exact amount required may vary from subject to subject, depending on the species, age, and general condition of the subject, the stage of the disease, the particular pharmaceutical mixture, its mode of administration, and the like. Influenza antigens of the invention, including plants expressing antigen(s) and/or preparations thereof may be formulated in dosage unit form for ease of administration and uniformity of dosage. The expression "dosage unit form," as used herein, refers to a physically discrete unit of vaccine composition appropriate for the patient to be treated. It will be understood, however, that the total daily usage of the compositions of the present invention is typically decided by an attending physician within the scope of sound medical judgment. The specific therapeutically effective dose level for any particular patient or organism may depend upon a variety of factors including the severity or risk of infection; the activity of the specific compound employed; the specific composition employed; the age, body weight, general health, sex of the patient, diet of the patient, pharmacokinetic condition of the patient, the time of administration, route of administration, and rate of excretion of the specific antigen(s) employed; the duration of the treatment; drugs used in combination or coincidental with the vaccine composition employed; and like factors well known in the medical arts.

[00188] It will be appreciated that vaccine compositions of the present invention can be employed in combination therapies (*e.g.*, combination vaccine therapies), that is, pharmaceutical compositions can be administered concurrently with, prior to, or subsequent to, one or more other desired pharmaceutical and/or vaccination procedures. The particular combination of therapies (*e.g.*, vaccines, therapeutic treatment of influenza infection) to employ in a combination regimen will generally take into account compatibility of the desired therapeutics and/or procedures and the desired therapeutic effect to be achieved. It will be appreciated that the therapies and/or vaccines employed may achieve a desired effect for the same disorder (for example, an inventive antigen may be administered concurrently with another influenza vaccine), or they may achieve different effects.

[00189] In certain embodiments, vaccine compositions comprise at least two influenza antigens. For example, certain vaccine compositions can comprise at least two influenza antigens of the invention (*e.g.*, a HA domain and an NA domain containing antigen of the invention). In some aspects such combination vaccines may include one thermostable fusion protein comprising influenza antigen; in some aspects, two or more thermostable fusion proteins comprising influenza antigen are provided.

[00190] Where combination vaccines are utilized, it will be understood that any combination of influenza antigens may be used for such combinations. Compositions may include multiple influenza antigens, including multiple antigens provided herein. Furthermore, compositions may include one or more antigens provided herein with one or more additional antigens. Combinations of influenza antigens include influenza antigens derived from one or more various subtypes or strains such that immunization confers immune response against more than one infection type. Combinations of influenza antigen may include at least one, at least two, at least three, at least four or more antigens derived from different subtypes or strains. In some combinations, at least two or at least three antigens from different subtypes are combined in one vaccine composition. Furthermore, combination vaccines may utilize influenza antigen and antigen from one or more unique infectious agents.

Kits

[00191] In one aspect, the present invention provides a pharmaceutical pack or kit including influenza antigens according to the present invention. In certain embodiments, pharmaceutical packs or kits include live sprouted seedlings, clonal entity or plant producing an influenza antigen according to the present invention, or preparations, extracts, or pharmaceutical compositions

containing vaccine in one or more containers filled with optionally one or more additional ingredients of pharmaceutical compositions of the invention. In some embodiments, pharmaceutical packs or kits include pharmaceutical compositions comprising purified influenza antigen according to the present invention, in one or more containers optionally filled with one or more additional ingredients of pharmaceutical compositions of the invention. In certain embodiments, the pharmaceutical pack or kit includes an additional approved therapeutic agent (*e.g.*, influenza antigen, influenza vaccine) for use as a combination therapy. Optionally associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceutical products, which notice reflects approval by the agency of manufacture, use, or sale for human administration.

[00192] Kits are provided that include therapeutic reagents. As but one non-limiting example, influenza vaccine can be provided as oral formulations and administered as therapy. Alternatively or additionally, influenza vaccine can be provided in an injectable formulation for administration. In some embodiments, influenza vaccine can be provided in an inhalable formulation for administration. Pharmaceutical doses or instructions therefor may be provided in the kit for administration to an individual suffering from or at risk for influenza infection.

[00193] The representative examples that follow are intended to help illustrate the invention, and are not intended to, nor should they be construed to, limit the scope of the invention. Indeed, various modifications of the invention and many further embodiments thereof, in addition to those shown and described herein, will become apparent to those skilled in the art from the full contents of this document, including the examples which follow and the references to the scientific and patent literature cited herein. The following examples contain information, exemplification and guidance, which can be adapted to the practice of this invention in its various embodiments and the equivalents thereof.

Exemplification

Example 1. Generation of Vaccine Candidate Constructs

Generation of antigen sequences from influenza virus hemagglutinin

[00194] Nucleotide sequence encoding HA stem domain (SD) 1-2 and HA globular domain (GD) 3 of each of influenza virus type Vietnam H5N1 and Wyoming H3N2 was synthesized and

confirmed as being correct. Produced nucleic acid was digested with restriction endonucleases BglII/HindIII, sites for which had been engineered onto either end of sequence encoding domains. The resulting DNA fragments were fused in frame to sequence encoding an engineered thermostable carrier molecule.

[00195] HA Vietnam [H5N1]

[00196] (SD domain 1-2): HA1_2V: (SEQ ID NO.: 19):

AGATCTGATCAAATCTGCATTGGATACCACGCTAACAACTCTACTGAGCAAGTGGATAC
AATTATGGAGAAGAACGTGACTGTTACTCACGCTCAGGATATTCTTGAAAAGACTCACA
ACGGAAAGTTGGGAGGAGGAAACACTAAGTGCCAGACTCCAATGGGAGCTATTAACTC
TTCTATGCCATTCCACAACATTCACCCACTTACTATTGGAGAGTGCCCAAAGTACGTGA
AGTCTAACAGGCTTGTGCTTGCTACTGGACTTAGGAATTCTCCACAAAGAGAGAGGAGA
AGGAAGAAGAGGGGACTTTTCGGAGCTATTGCTGGATTCATTGAGGGAGGATGGCAAG
GAATGGTTGATGGATGGTACGGATACCATCACTCTAATGAGCAGGGATCTGGATATGCT
GCTGATAAGGAGTCTACTCAGAAGGCTATTGATGGAGTGACTAACAAGGTGAACTCTAT
TATTGATAAGATGAACACTCAGTTCGAAGCTGTTGGAAGGGAGTTCAACAATCTTGAGA
GGAGGATTGAGAACCTTAACAAGAAAATGGAGGATGGATTCCTTGATGTGTGGACTTA
CAACGCTGAGCTTCTTGTGCTTATGGAGAACGAGAGGACTCTTGATTTCCACGATTCTA
ACGTGAAGAACCTTTACGACAAAGTGAGGCTTCAGCTTAGGGATAACGCTAAGGAGCT
TGGAAACGGTTGCTTCGAGTTCTACCACAAGTGCGATAATGAGTGCATGGAGTCTGTTA
GGAACGGAACTTACGATTACCCACAGTACTCTGAGGAAGCTAGACTTAAGAGGGAGGA
GATTTCTGGAGTGAAGTTGGAGTCTATTGGTATCTACCAGATTAAGCTT

[00197] (SD domain 1-2): HA1_2V: (SEQ ID NO.: 20):

DQICIGYHANNSTEQVDTIMEKNVTVTHAQDILEKTHNGKLNTKCQTPMGAINSSMPFHNIH
PLTIGECPKYVKSNRLVLATGLRNSPQRERRRKKRGLFGAIAGFIEGGWQGMVDGWYGYH
HSNEQGSGYAADKESTQKAIDGVTNKVNSIIDKMNTQFEAVGREFNNLERRIENLNKKMED
GFLDVWTYNAELLVLMENERTLDFHDSNVKNLYDKVRLQLRDNAKELGNGCFEFYHKCD
NECMESVRNGTYDYPQYSEEARLKREEISGVKLESIGIYQI

[00198] (GD domain 3): HA3V: (SEQ ID NO.: 21):

AGATCTTGCGATCTTGATGGAGTGAAGCCACTTATTCTTAGGGATTGCTCTGTTGCTGGA
TGGCTTCTTGGAAACCCAATGTGCGATGAGTTCATTAACGTGCCAGAGTGGTCTTATATT
GTGGAGAAGGCTAACCCAGTGAACGATCTTTGTTACCCAGGAGATTTCAACGATTACGA
GGAGCTTAAGCACCTTCTTTCTAGGATTAACCACTTCGAGAAGATTCAGATTATTCCAA

AGTCATCTTGGTCATCTCACGAGGCTTCTCTTGGAGTTTCTTCTGCTTGCCCATACCAGG
GAAAGTCATCTTTCTTCAGGAACGTTGTGTGGCTTATTAAGAAGAACTCTACTTACCCA
ACTATTAAGAGGTCTTACAACAACACTAACCAGGAGGATCTTCTTGTGCTTTGGGGAAT
TCACCATCCAAATGATGCTGCTGAGCAGACTAAGTTGTACCAGAACCCAACTACTTACA
TTTCTGTGGGAACTTCTACTCTTAACCAGAGGCTTGTGCCAAGAATTGCTACTAGGTCTA
AGGTGAACGGACAATCTGGAAGGATGGAGTTCTTCTGGACTATTCTTAAGCCAAACGAT
GCTATTAACTTCGAGTCTAACGGAAACTTCATTGCTCCAGAGTACGCTTACAAGATTGT
GAAGAAGGGAGATTCTACTATTATGAAGTCTGAGCTTGAGTACGGAAACTGCAAGCTT

[00199] (GD domain 3): HAV3: (SEQ ID NO.: 8):

CDLDGVKPLILRDCSVAGWLLGNPMCDEFINVPEWSYIVEKANPVNDLCYPGDFNDYEELK
HLLSRINHFEKIQIIPKSSWSSHEASLGVSSACPYQGKSSFFRNVVWLIKKNSTYPTIKRSYNN
TNQEDLLVLWGIHHPNDAAEQTKLYQNPTTYISVGTSTLNQRLVPRIATRSKVNGQSGRME
FFWTILKPNDAINFESNGNFIAPEYAYKIVKKGDSTIMKSELEYGNC

[00200] (full length): HAS_V: (SEQ ID NO.: 22):

GGATCCATTAATTAAAATGGGATTCGTGCTTTTCTCTCAGCTTCCTTCTTTCCTTCTTGTG
TCTACTCTTCTTCTTTTCCTTGTGATTTCTCACTCTTGCCGTGCTGATCAAATCTGCATTG
GATACCACGCTAACAACTCTACTGAGCAAGTGGATACAATTATGGAGAAGAACGTGAC
TGTTACTCACGCTCAGGATATTCTTGAAAAGACTCACAACGGAAAGTTGTGCGATCTTG
ATGGAGTGAAGCCACTTATTCTTAGGGATTGCTCTGTTGCTGGATGGCTTCTTGGAAACC
CAATGTGCGATGAGTTCATTAACGTGCCAGAGTGGTCTTATATTGTGGAGAAGGCTAAC
CCAGTTAATGATCTTTGCTACCCAGGAGATTTCAACGATTACGAGGAGCTTAAGCACCT
TCTTTCTAGGATTAACCACTTCGAGAAGATTCAGATTATTCCAAAGTCATCTTGGTCATC
TCACGAGGCTTCTCTTGGAGTTTCTTCTGCTTGCCCATACCAGGGAAAGTCATCTTTCTT
CAGGAACGTTGTGTGGCTTATTAAGAAGAACTCTACTTACCCAACTATTAAGAGGTCTT
ACAACAACACTAACCAGGAGGATCTTCTTGTGCTTTGGGGAATTCACCATCCAAATGAT
GCTGCTGAGCAGACTAAGTTGTACCAGAACCCAACTACTTACATTTCTGTGGGAACTTC
TACTCTTAACCAGAGGCTTGTGCCAAGAATTGCTACTAGGTCTAAGGTGAACGGACAAT
CTGGAAGGATGGAGTTCTTCTGGACTATTCTTAAGCCAAACGATGCTATTAACTTCGAG
TCTAACGGAAACTTCATTGCTCCAGAGTACGCTTACAAGATTGTGAAGAAGGGAGATTC
TACTATTATGAAGTCTGAGCTTGAGTACGGAAACTGCAACACTAAGTGCCAAACTCCAA
TGGGAGCTATTAACTCTTCTATGCCATTCCACAACATTCACCCACTTACTATTGGAGAGT
GCCCAAAGTACGTGAAGTCTAACAGGCTTGTGCTTGCTACTGGACTTAGGAATTCTCCA

CAAAGAGAGAGGAGAAGGAAGAAGAGGGGACTTTTCGGAGCTATTGCTGGATTCATTG
AGGGAGGATGGCAAGGAATGGTTGATGGATGGTACGGATACCATCACTCTAATGAGCA
GGGATCTGGATATGCTGCTGATAAGGAGTCTACTCAGAAGGCTATTGATGGAGTGACTA
ACAAGGTGAACTCTATTATTGATAAGATGAACACTCAGTTCGAAGCTGTTGGAAGGGAG
TTCAACAATCTTGAGAGGAGGATTGAGAACCTTAACAAGAAAATGGAGGATGGATTCC
TTGATGTGTGGACTTACAACGCTGAGCTTCTTGTGTTGATGGAGAACGAGAGGACTCTT
GATTTCCACGATTCTAACGTGAAGAACCTTTACGACAAAGTGAGGCTTCAGCTTAGGGA
TAACGCTAAGGAGCTTGGAAACGGTTGCTTCGAGTTCTACCACAAGTGCGATAATGAGT
GCATGGAGTCTGTTAGGAACGGAACTTACGATTACCCACAGTACTCTGAGGAAGCTAGA
CTTAAGAGGGAGGAGATTTCTGGAGTGAAGTTGGAGTCTATTGGTATCTACCAGATTCA
CCATCACCATCACCACAAGGATGAGCTTTGATGACTCGAGCTC

[00201] HA A/Wyoming (H3N2)

[00202] (SD domain 1-2): HA1_2W: (SEQ ID NO.: 23):

AGATCTCAAAAGTTGCCAGGAAACGATAACTCTACTGCTACTCTTTGCCTTGGACATCA
CGCTGTTCCAAACGGAACTATTGTGAAAACTATTACTAACGATCAGATTGAGGTGACAA
ACGCTACTGAGCTTGTTCAGTCATCTTCTACTGGAGGAATTGGAGGAGGAAACTCTGAG
TGCATTACACCTAATGGATCTATTCCAAACGATAAGCCATTCCAGAACGTGAACAGGAT
TACTTATGGAGCTTGCCCAAGATACGTGAAGCAGAACACTCTTAAGTTGGCTACTGGAA
TGAGGAATGTGCCAGAGAAGCAGACTAGGGGAATTTTCGGAGCTATTGCTGGATTCATT
GAGAATGGATGGGAGGGAATGGTTGATGGATGGTACGGATTCAGGCATCAGAATTCTG
AGGGAACTGGACAAGCTGCTGATCTTAAGTCTACTCAGGCTGCTATTAACCAGATTAAC
GGAAAGTTGAACAGGCTTATTGGAAAGACTAACGAGAAGTTCCACCAGATTGAGAAGG
AGTTCTCTGAGGTTGAGGGAAGGATTCAGGATCTTGAGAAGTACGTGGAGGATACAAA
GATTGATCTTTGGTCTTACAACGCTGAGCTTCTTGTTGCTCTTGAGAACCAGCACACTAT
TGATCTTACTGATTCTGAGATGAACAAGTTGTTCGAGAGGACTAAGAAGCAGCTTAGGG
AGAACGCTGAGGATATGGGAAATGGATGCTTCAAAATCTACCACAAGTGCGATAACGC
TTGCATTGAGTCTATTAGGAACGGAACTTACGATCACGATGTGTACCGTGATGAGGCTC
TTAACAACAGGTTCCAGATTAAGGGAGTGGAGCTTAAGTCTGGATACAAGGATTGGATT
CTTAAGCTT

[00203] (SD domain 1-2): HA1_2: (SEQ ID NO.: 24):

QKLPGNDNSTATLCLGHHAVPNGTIVKTITNDQIEVTNATELVQSSSTGGINSECITPNGSIPN
DKPFQNVNRITYGAC*PRYVKQNTLKLAT*GMRNVPEKQTRGIFGAIAGFIENGWEGMVDGWY

GFRHQNSEGTGQAADLKSTQAAINQINGKLNRLIGKTNEKFHQIEKEFSEVEGRIQDLEKYV
EDTKIDLWSYNAELLVALENQHTIDLTDSEMNKLFERTKKQLRENAEDMGNGCFKIYHKC
DNACIESIRNGTYDHDVYRDEALNNRFQIKGVELKSGYKDWIL

[00204] (GD domain 3): HA3W: (SEQ ID NO.: 25):

AGATCTTGCGATTCTCCACACCAGATTCTTGATGGAGAGAACTGCACTCTTATTGATGCT
CTTCTTGGAGATCCACAGTGCGATGGATTCCAGAACAAGAAGTGGGATCTTTTCGTGGA
AAGGTCTAAGGCTTACTCTAACTGCTACCCATACGATGTTCCAGATTACGCTTCTCTTAG
GAGTCTTGTGGCTTCTTCTGGAACTCTTGAGTTCAACAACGAGTCTTTCAACTGGGCTGG
AGTTACTCAGAACGGAACTTCTTCTGCTTGTAAGAGGAGGTCTAACAAGTCTTTCTTCTC
TAGGCTTAACTGGCTTACTCACCTTAAGTACAAGTACCCAGCTCTTAACGTGACTATGCC
AAACAACGAGAAGTTCGATAAGTTGTACATTTGGGGAGTTCACCACCCAGTTACTGATT
CTGATCAGATTTCTCTTTACGCTCAGGCTTCTGGAAGGATTACTGTGTCTACTAAGAGGT
CTCAGCAGACTGTGATTCCAAACATTGGATACCGTCCAAGAGTGAGGGATATTTCTTCT
AGGATTTCTATCTACTGGACTATTGTGAAGCCAGGAGATATTCTTCTTATTAACTCTACT
GGAAACCTTATTGCTCCAAGGGGATACTTCAAGATTAGGAGTGGAAAGTCATCTATTAT
GAGGAGTGATGCTCCAATTGGAAAGTGCAAGCTT

[00205] (GDdomain 3): HA3W: (SEQ ID NO.: 12):

CDSPHQILDGENCTLIDALLGDPQCDGFQNKKWDLFVERSKAYSNC*YPYDVPDYA*SLRSLVA
SSGTLEFNNESFNWAGVTQNGTSSACKRRSNKSFFSRLNWLTHLKYKYPALNVTMPNNEK
FDKLYIWGVHHPVTDSDQISLYAQASGRITVSTKRSQQTVIPNIGYRPRVRDISSRISIYWTIV
KPGDILLINSTGNLIAPRGYFKIRSGKSSIMRSDAPIGKC

[00206] (full length): HASW: (SEQ ID NO.: 26):

GGATCCATTAATTAAAATGGGATTCGTGCTTTTCTCTCAGCTTCCTTCTTTCCTTCTTGTG
TCTACTCTTCTTCTTTTCCTTGTGATTTCTCACTCTTGCCGTGCTCAAAAGTTGCCAGGAA
ACGATAACTCTACTGCTACTCTTTGCCTTGGACATCACGCTGTTCCAAACGGAACTATTG
TGAAAACTATTACTAACGATCAGATTGAGGTGACAAACGCTACTGAGCTTGTTCAGTCA
TCTTCTACTGGAGGAATTTGCGATTCTCCACACCAGATTCTTGATGGAGAGAACTGCAC
TCTTATTGATGCTCTTCTTGGAGATCCACAGTGCGATGGATTCCAGAACAAGAAGTGGG
ATCTTTTCGTGGAAAGGTCTAAGGCTTACTCTAACTGCTACCCATACGATGTTCCAGATT
ACGCTTCTCTTAGGAGTCTTGTGGCTTCTTCTGGAACTCTTGAGTTCAACAACGAGTCTT
TCAACTGGGCTGGAGTTACTCAGAACGGAACTTCTTCTGCTTGTAAGAGGAGGTCTAAC
AAGTCTTTCTTCTCTAGGCTTAACTGGCTTACTCACCTTAAGTACAAGTACCCAGCTCTT

AACGTGACTATGCCAAACAACGAGAAGTTCGATAAGTTGTACATTTGGGGAGTTCACCA
CCCAGTTACTGATTCTGATCAGATTTCTCTTTACGCTCAGGCTTCTGGAAGGATTACTGT
GTCTACTAAGAGGTCTCAGCAGACTGTGATTCCAAACATTGGATACCGTCCAAGAGTGA
GGGATATTTCTTCTAGGATTTCTATCTACTGGACTATTGTGAAGCCAGGAGATATTCTTC
TTATTAACTCTACTGGAAACCTTATTGCTCCAAGGGGATACTTCAAGATTAGGAGTGGA
AAGTCATCTATTATGAGGAGTGATGCTCCAATTGGAAAGTGCAACTCTGAGTGCATTAC
TCCAAACGGATCTATTCCAAACGATAAGCCATTCCAGAACGTGAACAGGATTACTTATG
GAGCTTGCCCAAGATACGTGAAGCAGAACACTCTTAAGTTGGCTACTGGAATGAGGAA
TGTGCCAGAGAAGCAGACTAGGGGAATTTTCGGAGCTATTGCTGGATTCATTGAGAATG
GATGGGAGGGAATGGTTGATGGATGGTACGGATTCAGGCACCAGAATTCAGAGGGAAC
TGGACAAGCTGCTGATCTTAAGTCTACTCAGGCTGCTATTAACCAGATTAACGGAAAGT
TGAACAGGCTTATTGGAAAGACTAACGAGAAGTTCCACCAGATTGAGAAGGAGTTCTCT
GAGGTTGAGGGAAGGATTCAGGATCTTGAGAAGTACGTGGAGGATACAAAGATTGATC
TTTGGTCTTACAACGCTGAGCTTCTTGTTGCTCTTGAGAACCAGCACACTATTGATTTGA
CTGATTCTGAGATGAACAAGTTGTTCGAGAGGACTAAGAAGCAGCTTAGGGAGAACGC
TGAGGATATGGGAAATGGATGCTTCAAAATCTACCACAAGTGCGATAACGCTTGCATTG
AGTCTATTAGGAACGGAACTTACGATCACGATGTGTACCGTGATGAGGCTCTTAACAAC
AGGTTCCAGATTAAGGGAGTGGAGCTTAAGTCTGGATACAAGGATTGGATTCTTCATCA
TCACCACCACCACAAGGATGAGCTTTGATGACTCGAGCTC

Generation of antigen sequences from influenza virus neuraminidase

[00207] Nucleotide sequence encoding neuraminidase of each of influenza virus type Vietnam H5N1(NAV) and Wyoming H3N2(NAW) was synthesized and confirmed as being correct. Produced nucleic acid was digested with restriction endonuclease SalI, sites for which had been engineered onto either end of sequence encoding domains. The resulting DNA fragments were fused in frame into the C-terminus to sequence encoding an engineered thermostable carrier molecule.

[00208] NAV(N1): (SEQ ID NO.: 27):

GGATCCTTAATTAAAATGGGATTCGTGCTTTTCTCTCAGCTTCCTTCTTTCCTTCTTGTGT
CTACTCTTCTTCTTTTCCTTGTGATTTCTCACTCTTGCCGTGCTCAAAATGTCGACCTTAT
GCTTCAGATTGGAAACATGATTTCTATTTGGGTGTCACACTCTATTCACACTGGAAACCA
GCATCAGTCTGAGCCAATTTCTAACACTAACCTTTTGACTGAGAAGGCTGTGGCTTCTGT

TAAGTTGGCTGGAAACTCTTCTCTTTGCCCTATTAACGGATGGGCTGTGTACTCTAAGGA
TAACTCTATTAGGATTGGATCTAAGGGAGATGTGTTCGTGATTAGGGAGCCATTCATTT
CTTGCTCTCACCTTGAGTGCCGTACTTTCTTCCTTACTCAGGGTGCTCTTCTTAACGATAA
GCACTCTAACGGAACTGTGAAGGATAGGTCTCCACACAGGACTCTTATGTCTTGTCCAG
TTGGAGAAGCTCCATCTCCATACAACTCTAGATTCGAGTCTGTTGCTTGGAGTGCTTCTG
CTTGCCATGATGGAACTTCATGGCTTACTATTGGAATTTCTGGACCAGATAACGGAGCT
GTTGCTGTGCTTAAGTACAACGGAATTATTACTGATACCATCAAGTCTTGGAGGAACAA
CATTCTTAGGACTCAGGAGTCTGAGTGTGCTTGCGTTAACGGATCTTGCTTCACTGTGAT
GACTGATGGACCATCTAATGGACAGGCTTCTCACAAGATTTTCAAGATGGAGAAGGGA
AAGGTTGTGAAGTCTGTGGAACTTGATGCTCCAAACTACCATTACGAGGAGTGTTCTTG
CTATCCAGATGCTGGAGAGATTACTTGTGTGTGCCGTGATAATTGGCATGGATCTAACA
GGCCATGGGTGTCATTCAATCAGAACCTTGAGTACCAGATTGGTTACATTTGCTCTGGA
GTGTTCGGAGATAATCCAAGGCCAAACGATGGAACTGGATCTTGTGGACCAGTGTCATC
TAATGGAGCTGGAGGAGTGAAGGGATTCTCTTTCAAGTACGGAAACGGAGTTTGGATTG
GAAGGACTAAGTCTACTAACTCTAGGAGTGGATTCGAGATGATTTGGGACCCAAACGG
ATGGACTGAGACTGATTCTTCTTTCTCTGTGAAGCAGGATATTGTGGCTATTACTGATTG
GAGTGGATACTCTGGATCTTTCGTTCAGCACCCAGAGCTTACTGGACTTGATTGCATTAG
GCCATGCTTCTGGGTTGAACTTATTAGGGGAAGGCCAAAGGAGTCTACTATTTGGACTT
CTGGATCTTCTATTTCTTTCTGCGGAGTGAATTCTGATACTGTGGGATGGTCTTGGCCAG
ATGGAGCTGAGCTTCCATTCACTATTGATAAGGTCGACCATCATCATCATCACCACAAG
GATGAGCTTTGACTCGAG

[00209] NAV: (SEQ ID NO.: 16):

LMLQIGNMISIWVSHSIHTGNQHQSEPISNTNLLTEKAVASVKLAGNSSLCPINGWAVYSKD
NSIRIGSKGDVFVIREPFISCSHLECRTFFLTQGALLNDKHSNGTVKDRSPHRTLMSCPVGEA
PSPYNSRFESVAWSASACHDGTSWLTIGISGPDNGAVAVLKYNGIITDTIKSWRNNILRTQES
ECACVNGSCFTVMTDGPSNGQASHKIFKMEKGKVVKSVELDAPNYHYEECSCYPDAGEIT
CVCRDNWHGSNRPWVSFNQNLEYQIGYICSGVFGDNPRPNDGTGSCGPVSSNGAGGVKGF
SFKYGNGVWIGRTKSTNSRSGFEMIWDPNGWTETDSSFSVKQDIVAITDWSGYSGSFVQHP
ELTGLDCIRPCFWVELIRGRPKESTIWTSGSSISFCGVNSDTVGWSWPDGAELPFTIDK

[00210] NAW(N2): (SEQ ID NO.: 28):

GGATCCTTAATTAAAATGGGATTCGTGCTTTTCTCTCAGCTTCCTTCTTTCCTTCTTGTGT
CTACTCTTCTTCTTTTCCTTGTGATTTCTCACTCTTGCCGTGCTCAAAATGTCGACAAGCA

GTACGAGTTCAACTCTCCACCAAACAACCAGGTTATGCTTTGCGAGCCAACTATTATTG
AGAGGAACATTACTGAGATTGTGTACCTTACTAACACTACTATTGAGAAGGAGATTTGC
CCAAAGTTGGCTGAGTACCGTAATTGGTCTAAGCCACAGTGCAACATTACTGGATTCGC
TCCATTCTCTAAGGATAACTCAATTAGGCTTTCTGCTGGAGGAGATATTTGGGTTACAA
GGGAGCCATACGTTTCTTGCGATCCAGATAAGTGCTACCAGTTCGCTCTTGGACAAGGA
ACTACTCTTAACAACGTGCACTCTAACGATACTGTGCACGATAGGACTCCATACCGTAC
TCTTTTGATGAACGAGCTTGGAGTTCCATTCCACCTTGGAACTAAGCAAGTGTGCATTGC
TTGGTCATCTTCATCTTGCCACGATGGAAAGGCTTGGCTTCATGTTTGCGTGACTGGAGA
TGATGAGAACGCTACTGCTTCTTTCATCTACAACGGAAGGCTTGTGGATTCTATTGTTTC
TTGGTCTAAGAAGATTCTTAGGACTCAGGAGTCTGAGTGTGTGTGCATTAACGGAACTT
GCACTGTGGTTATGACTGATGGATCTGCTTCTGGAAAGGCTGATACAAAGATTCTTTTC
ATTGAGGAGGGAAAGATTGTGCACACTTCTACTCTTTCTGGATCTGCTCAGCATGTTGA
GGAGTGTTCTTGCTACCCAAGGTATCCAGGAGTTAGATGTGTGTGCCGTGATAACTGGA
AGGGATCTAACAGGCCAATTGTGGATATTAACATTAAGGATTACTCTATTGTGTCATCTT
ATGTGTGCTCTGGACTTGTTGGAGATACTCCAAGGAAGAACGATTCTTCTTCATCTTCAC
ACTGCCTTGATCCAAATAACGAGGAGGGAGGACATGGAGTTAAGGGATGGGCTTTCGA
TGATGGAAACGATGTTTGGATGGGAAGGACTATTTCTGAGAAGTTGAGGAGCGGATAC
GAGACTTTCAAAGTGATTGAGGGATGGTCTAACCCAAATTCTAAGCTGCAGATTAACAG
GCAAGTGATTGTGGATAGGGGAAACAGGAGTGGATACTCTGGAATTTTCTCTGTGGAGG
GAAAGTCTTGCATTAACAGATGCTTCTACGTGGAGCTTATTAGGGGAAGGAAGCAGGA
GACTGAGGTTTTGTGGACTTCTAACTCTATTGTGGTGTTCTGCGGAACTTCTGGAACTTA
CGGAACTGGATCTTGGCCAGATGGAGCTGATATTAACCTTATGCCAATTGTCGACCATC
ATCACCATCACCACAAGGATGAGCTTTGACTCGAG

[00211] NAW: (SEQ ID NO.: 18):

KQYEFNSPPNNQVMLCEPTIIERNITEIVYLTNTTIEKEICPKLAEYRNWSKPQCNITGFAPFS
KDNSIRLSAGGDIWVTREPYVSCDPDKCYQFALGQGTTLNNVHSNDTVHDRTPYRTLLMN
ELGVPFHLGTKQVCIAWSSSSCHDGKAWLHVCVTGDDENATASFIYNGRLVDSIVSWSKKI
LRTQESECVCINGTCTVVMTDGSASGKADTKILFIEEGKIVHTSTLSGSAQHVEECSCYPRYP
GVRCVCRDNWKGSNRPIVDINIKDYSIVSSYVCSGLVGDTPRKNDSSSSSHCLDPNNEEGGH
GVKGWAFDDGNDVWMGRTISEKLRSGYETFKVIEGWSNPNSKLQINRQVIVDRGNRSGYS
GIFSVEGKSCINRCFYVELIRGRKQETEVLWTSNSIVVFCGTSGTYGTGSWPDGADINLMPI

Generation of thermostable carrier construct

[00212] Full length native *C. thermocellum* lichenase, LicB, consists sequentially of a leader peptide (Lp), an N-terminal portion (A), a surface loop (l), a C-terminal portion (C), a Pro-Thr box, and a cellulosome-binding domain (C-BD). We removed the Lp, Pro-Thr box and C-BD encoding sequences from the LicB encoding gene, circularly permutated the molecule to invert the N- and C-termini (Musiychuk *et al.*, 2007, *Influenza and Other Respiratory Viruses*, 1:1), and incorporated unique restriction endonuclease sites for cloning target sequences at the N- and C-termini as well as into the surface loop (l). The resulting engineered carrier molecule sequence was verified, and is designated LicKM.

[00213] SEQ ID NO.: 29:

GGATCCTTAATTAAAATGGGAGGTTCTTATCCATATAAGTCTGGTGAGTATAGAACTA
AGTCTTTCTTTGGATATGGTTATTATGAAGTTAGGATGAAGGCTGCAAAGAACGTTGGA
ATTGTTTCTTCTTTCTTTACTTATACTGGACCATCTGATAACAACCCATGGGATGAGATT
GATATTGAGTTTCTTGGAAAGGATACTACTAAGGTTCAATTCAACTGGTATAAGAATGG
TGTTGGTGGAAACGAGTATCTTCATAACCTTGGATTTGATGCTTCTCAAGATTTTCATAC
TTATGGTTTTGAGTGGAGACCAGATTATATTGATTTTTATGTTGATGGAAAGAAGGTTTA
TAGAGGTACTAGAAACATTCCAGTTACTCCTGGAAAGATTATGATGAATCTTTGGCCAG
GAATTGGTGTTGATGAATGGCTTGGTAGATATGATGGAAGAACTCCACTTCAAGCTGAG
TATGAGTATGTTAAGTATTATCCAAACGGT**AGATCTGAATTCAAGCTT**GTTGTTAATAC
TCCATTTGTTGCTGTTTTCTCTAACTTTGATTCTTCTCAATGGGAAAAGGCTGATTGGGC
TAACGGTTCTGTTTTTAACTGTGTTTGGAAGCCATCTCAAGTTACTTTTTCTAACGGAAA
GATGATTCTTACTTTGGATAGAGAGTATGTCGACCATCATCATCATCATCAT*TGA***CTCGA**
GCTC

[00214] SEQ ID NO.:30:

MGGSYPYKSGEYRTKSFFGYGYYEVRMKAAKNVGIVSSFFTYTGPSDNNPWDEIDIEFLGK
DTTKVQFNWYKNGVGGNEYLHNLGFDASQDFHTYGFEWRPDYIDFYVDGKKVYRGTRNI
PVTPGKIMMNLWPGIGVDEWLGRYDGRTPLQAEYEYVKYYPNGRSEFKLVVNTPFVAVFS
NFDSSQWEKADWANGSVFNCVWKPSQVTFSNGKMILTLDREYVD**HHHHHH**

[00215] For certain constructs, we engineered a PR1a signal peptide and KDEL sequence at the N- and C-termini of LicKM. The nucleic acid and amino acid sequences of these constructs are shown in SEQ ID NO.: 31 and SEQ ID NO.: 32.

[00216] SEQ ID NO.: 31:

GGATCCTTAATTAAAATGGGATTTGTTCTCTTTTCACAATTGCCTTCATTTCTTCTTGTCT
CTACACTTCTCTTATTCCTAGTAATATCCCACTCTTGCCGTGCCCAAAATGGAGGTTCTT
ATCCATATAAGTCTGGTGAGTATAGAACTAAGTCTTTCTTTGGATATGGTTATTATGAAG
TTAGGATGAAGGCTGCAAAGAACGTTGGAATTGTTTCTTCTTTCTTTACTTATACTGGAC
CATCTGATAACAACCCATGGGATGAGATTGATATTGAGTTTCTTGGAAAGGATACTACT
AAGGTTCAATTCAACTGGTATAAGAATGGTGTTGGTGGAAACGAGTATCTTCATAACCT
TGGATTTGATGCTTCTCAAGATTTTCATACTTATGGTTTTGAGTGGAGACCAGATTATAT
TGATTTTTATGTTGATGGAAAGAAGGTTTATAGAGGTACTAGAAACATTCCAGTTACTC
CTGGAAAGATTATGATGAATCTTTGGCCAGGAATTGGTGTTGATGAATGGCTTGGTAGA
TATGATGGAAGAACTCCACTTCAAGCTGAGTATGAGTATGTTAAGTATTATCCAAACGG
TAGATCTGAATTCAAGCTTGTTGTTAATACTCCATTTGTTGCTGTTTTCTCTAACTTTGAT
TCTTCTCAATGGGAAAAGGCTGATTGGGCTAACGGTTCTGTTTTTAACTGTGTTTGGAAG
CCATCTCAAGTTACTTTTTCTAACGGAAAGATGATTCTTACTTTGGATAGAGAGTATGTC
GACCATCATCATCATCATCATAAGGATGAACTTTGACTCGAGCTC

[00217] SEQ ID NO.: 32:

MGFVLFSQLPSFLLVSTLLLFLVISHSCRAQNGGSYPYKSGEYRTKSFFGYGYYEVRMKAA
KNVGIVSSFFTYTGPSDNNPWDEIDIEFLGKDTTKVQFNWYKNGVGGNEYLHNLGFDASQD
FHTYGFEWRPDYIDFYVDGKKVYRGTRNIPVTPGKIMMNLWPGIGVDEWLGRYDGRTPLQ
AEYEYVKYYPNGRSEFKLVVNTPFVAVFSNFDSSQWEKADWANGSVFNCVWKPSQVTFSN
GKMILTLDREYVDHHHHHHHKDEL

Generation of recombinant antigen constructs

[00218] We used pET expression vectors, derived from pBR322 plasmid, engineered to take advantage of the features of the T7 bacteriophage gene *10* that promote high-level transcription and translation. The bacteriophage encoded RNA polymerase is highly specific for the T7 promoter sequences, which are rarely encountered in genomes other than T7 phage genome (Figure 2). pET-32 has been used for fusing the HA and NA constructs into the loop region of a modified lichenase sequence that had been cloned in this vector. The catalytic domain of the lichenase gene with the upstream sequence PR-1A ("Pathogen-Related protein 1 A"), with a endoplasmic reticulum (KDEL) or a vacuolar retaining sequence (VAC) and a downstream His_6 tag were cloned between the *Pac I* and *XhoI* sites in a modified pET-32 vector (in wich the region between the T7 promoter and the T7

terminator had been excised). In this way the pET–PR-LicKM-KDEL and pET–PR-LicKM-VAC were obtained (Figure 3).

[00219] The DNA fragment HA domain or NA was subcloned into the loop (l) portion of LicKM to give a fusion in the correct reading frame for translation. LicKM-NA fusions were constructed. The DNA fragment of NAW or NAV was subcloned into the C-terminus of LicKM using a SalI site to give a fusion in the correct reading frame for translation.

Example 2. Generation of Vaccine Candidate Antigen Vectors

[00220] Target antigen constructs LicKM-HA(SD), LicKM-HA(GD), or LicKM-NA were individually subcloned into the chosen viral vector (pBI-D4). pBI-D4 is a pBI121-derived binary vector in which the reporter gene coding for the *Escherichia coli* β-D-glucuronidase (GUS) has been replaced by a "polylinker" where, between the *Xba I* and *Sac I* sites, a TMV-derived vector has been cloned (Figure 4). pBI-D4 is a TMV-based construct in which a foreign gene to be expressed (*e.g.*, target antigen, such as LicKM-HA(SD), LicKM-HA(GD), LicKM-NA) replaces the coat protein (CP) gene of TMV. The virus retains the TMV 126/183kDa gene, the movement protein (MP) gene, and the CP subgenomic mRNA promoter (sgp), which extends into the CP open reading frame (ORF). The start codon for CP has been mutated. The virus lacks CP and therefore cannot move throughout the host plant via phloem. However, cell-to-cell movement of viral infection remains functional, and the virus can move slowly to the upper leaves in this manner. A multiple cloning site (PacI-PmeI-AgeI-XhoI) has been engineered at the end of sgp for expression of foreign genes, and is followed by the TMV 3' non-translated region (NTR). The 35S promoter is fused at the 5' end of the viral sequence. The vector sequence is positioned between the BamHI and SacI sites of pBI121. The hammerhead ribozyme is placed 3' of the viral sequence (Chen *et al.*, 2003, *Mol. Breed.*, 11:287). These constructs include fusions of sequences encoding LicKM-HA-SD, LicKM-HA(GD), or NA to sequences encoding the signal peptide from tobacco PR-1a protein, a 6x His tag and the ER-retention anchor sequence KDEL or vacuolar sequence (Figure 5). For constructs that contain sequence encoding, PR-LicKM-HA(SD)-KDEL, PR-LicKM-HA(GD)-KDEL, and PR-LicKM-NA-KDEL the coding DNA was introduced as PacI-XhoI fragments into pBI-D4. Furthermore, HAW (HA Wyoming), HAV (HA Vietnam), NAW (NA Wyoming), and NAV (NA Vietnam) were introduced directly as PacI-XhoI fragments into pBI-D4. Nucleotide sequence was subsequently verified spanning the subcloning junctions of the final expression constructs (Figure 6).

Example 3: Generation of Plants and Antigen Production

Agrobacterium *infiltration of plants*

[00221] *Agrobacterium*-mediated transient expression system achieved by *Agrobacterium* infiltration can be utilized (Turpen *et al.*, 1993, *J. Virol. Methods*, 42:227). Healthy leaves of *N. benthamiana* were infiltrated with *A. rhizogenes* or *A. tumefaciens* (GV3101) containing viral vectors engineered to express LicKM-HA or LicKM-NA.

[00222] The *A. rhizogenes* strain A4 (ATCC 43057) was transformed with the constructs pBI-D4-PR-LicKM-HA(SD)-KDEL, PR-LicKM-HA(GD)-KDEL, and pBI-D4-PR-LicKM-NA-KDEL. *Agrobacterium* cultures were grown and induced as described by Kapila *et al.* (1997, *Plant Sci.*, 122:101). A 2 ml starter-culture (picked from a fresh colony) was grown overnight in YEB (5 g/l beef extract, 1 g/l yeast extract, 5 g/l peptone, 5 g/l sucrose, 2 mM $MgSO_4$) with 25 μg/ml kanamycin at 28°C. The starter culture was diluted 1:500 into 500 ml of YEB with 25 μg/ml kanamycin, 10 mM 2-4(-morpholino)ethanesulfonic acid (MES) pH 5.6, 2 mM additional $MgSO_4$ and 20 μM acetosyringone. The diluted culture was then grown overnight to an $O.D._{600}$ of ~1.7 at 28°C. The cells were centrifuged at 3,000 x g for 15 minutes and re-suspended in MMA medium (MS salts, 10 mM MES pH 5.6, 20 g/l sucrose, 200 μM acetosyringone) to an $O.D._{600}$ of 2.4, kept for 1-3 hour at room temperature, and used for *Agrobacterium*-infiltration. *N. benthamiana* leaves were injected with the *Agrobacterium*-suspension using a disposable syringe without a needle. Infiltrated leaves were harvested 4-7 days (*e.g.*, 6 days) post-infiltration.

[00223] Plants were screened for the presence of target antigen expression by assessment of lichenase activity assay and immunoblot analysis (Figures 7, 8, 9, and 10). Zymogram analysis revealed the expression of both HA and NA chimeric proteins in the *Nicotiana benthamiana* infiltrated leaves tested. The expression is associated with lichenase activity (Figures 7 and 9). The activity band related to the fusion proteins show a higher molecular weight than the lichenase control and the same molecular weight of the product expressed by plants after agro-infection, confirming the presence of whole fusion product.

Clonal root and clonal root line generation

[00224] *Nicotiana benthamiana* leaf explants 1 cm x 1 cm wide are obtained from leaves after sterilization in 0.1% NH_4Cl and six washing in sterile dH_2O. The explants are slightly damaged with

a knife on the abacsial side and co-cultured with the *Agrobacterium rhizogenes*, strain A4, containing either the pBID4-Lic-HA-KDEL or the pBID4-Lic-NA-KDEL. The explants are incubated for 2' with an *Agrobacterium* overnight culture ($O.D._{.600nm}$=0.8-1) centrifuged for 10 minutes at 3000 rpm a 4°C and resuspended in MMA medium to a final $O.D._{.600nm}$=0.5 in presence of 20mM acetosyringone. At the end of the incubation, the explant is dried on sterile paper and tranferred onto 0.8% agar MS plates in presence of 1% glucose and 20mM acetosyringone. Plates are parafilmed and and kept at R.T. for two days. The explants are then transferred onto MS plates in presence of 500mg/l Cefotaxim (Cif), 100mg/l Timentin (Tim) and 25mg/l kanamycin. After approximately 5 weeks the generation of trangenic roots is obtained from *Nicotiana benthamiana* leaf explants transformed with *Agrobacterium rhizogenes* containing the pBID4-Lic-HA-KDEL and pBID4-Lic-NA-KDEL constructs.

[00225] After transformation, hairy roots can be cut off and placed in a line on solid, hormone free K_3 medium. Four to six days later the most actively growing roots are isolated and transferred to liquid K_3 medium. Selected roots are cultured on a rotary shaker at 24°C in the dark and clonal lines are isolated and subcultured weekly. Roots and/or clonal lines can be screened for the presence of target antigen expression by assessment of lichenase activity assay and immunoblot analysis.

Example 4: Production of Vaccine Candidate

[00226] 100 mg samples of *N. benthamiana* infiltrated leaf material were harvested at 4, 5, 6 and 7 days post-infection. The fresh tissue was analysed for protein expression right after being harvested or collected at -80°C for the preparation of subsequent crude plants extracts or for fusion protein purification.

[00227] Fresh samples were resuspended in cold PBS 1x plus Protease inhibitors (Roche) in a 1/3 w/v ratio (1ml / 0.3 g of tissue) and ground with a pestel. The homogenates were boiled for 5 minutes in SDS gel loading buffer and then clarified by centrifugation for 5 minutes at 12.000 rpm at 4°C. The supernatants were transferred in a fresh tube and 20 µl, 1 µl or their dilutions were separated on a 12% SDS-PAGE and analyzed by Western analysis using anti- His_6-HA mouse or rabbit anti-lichenase polyclonal antibodies and/or by zymogram analysis to assess enzymatic activity indicating functional lichenase activity. Zymography is an electrophoretic method for measuring enzymatic activity. The method is based on a sodium dodecyl sulfate gel impregnated with a substrate which is degraded by the enzymes resolved during the incubation period. The staining of

the gel reveals sites of enzymatic activity as white bands on a dark red background. Within a certain range the band intensity can be related linearly to the amount of enzyme loaded.

[00228] HA expression in *Nicotiana benthamiana* plants infiltrated either with *Agrobacterium tumefaciens* or *Agrobacterium rhizogenes* containing the plasmid pBID4-LicKM-HA(SD)-KDEL or pBID4-LicKM-HA(GD)-KDEL leads to a specific band corresponding to the molecular weight of the chimeric protein LicKM-HA(SD)-KDEL or LicKM-HA(GD)-KDEL if the HA protein electrophoretic mobility in the fusion protein corresponds to the theoretic MW (the lichenase enzyme MW is about 28 kD).

[00229] Quantification of the chimeric proteins Lic-HA-KDEL and Lic-NA-KDEL expressed in the crude extract can be made by immunoblotting both on the manually infiltrated tissues and on the vacuum-infiltrated tissues.

Purification of antigens

[00230] Leaves from plants infiltrated with recombinant *Agrobacterium tumefaciens* containing the pBID4-LicKM-HA(SD)-KDEL, pBID4-LicKM-HA(GD)-KDEL, and pBID4-full-length-NA-KDEL constructs were ground by homogenization. Extraction buffer with "EDTA-free" protease inhibitors (Roche) and Triton X-100 1% was used at a ratio of 3 volumes w/v and rocked for 30 min at 4°C. Extracts were clarified by centrifugation at 9000 x g per 10' at 4°C. The supernatant was sequentially filtered through miracloth, centrifugated at 20.000 x g for 30' at 4°C and filtered through 0.45-μm filter, before chromatographic purification.

[00231] Resulting extract was cut using ammonium sulfate precipitation. Briefly, $(NH_4)_2SO_4$ was added to extract to 20% saturation, incubated on ice for 1h and spun down at 18,000 x g for 15 min. Pellet was discarded and $(NH_4)_2SO_4$ added slowly to 60% saturation, incubated on ice for 1h, and spun down at 18,000 x g for 15 min. Supernatant was discarded and resulting pellet resuspended in buffer, then maintained on ice for 20 min, followed by centrifuge at 18,000 x g for 30 min and supernatant dialyzed overnight against 10000 volumes of washing buffer:

[00232] His-tagged LicKM-HA(SD)-KDEL, LicKM-HA(GD)-KDEL, and full-length-NA-KDEL chimeric proteins were purified by using IMAC ("Immobilized Metal Affinity Chromatography," GE Healthcare) at room temperature under gravity. The purification was performed under non-denaturing conditions. Proteins were collected as 0.5 ml fractions, which are unified, added with 20mM EDTA, dialyzed against PBS 1X overnight at 4°C and analyzed by SDS-PAGE.

[00233] Alternatively, fractions were then collected together added with 20mM EDTA, dialyzed against NaH_2PO_4 10 mM, overnight, at 4°C and purified by Anion Exchange Chromatography. For LicKM-HA(SD)-KDEL, LicKM-HA(GD)-KDEL, and full-length-NA-KDEL purification, anion exchange column Q Sepharose Fast Flow (Amersham Pharmacia Biosciences) was used. Samples of the LicKM-HA(SD)-KDEL, LicKM-HA(GD)-KDEL, and full-length-NA-KDEL affinity or ion-exchange purified chimeric proteins were separated on 12% polyacrylamide gels followed by Coomassie staining. Separated proteins were also electrophoretically transferred onto PDVF membranes for Western blot analysis using polyclonal anti-lichenase antibody and successively with anti-rabbit IgG horseradish peroxidase-conjugated antibody.

[00234] Collected fractions after dialysis were analyzed by immunoblotting using both the pAb α-lichenase and the pAb α-His_6. The His-tag was maintained by the expressed chimeric proteins and the final concentration of the purified protein was evaluated by software.

Hemagglutination assay

[00235] Three species of red blood cells (RBC's) from two different sources were used to demonstrate hemagglutinating activity in plant-produced preparations of Influenza vaccines. The vaccine material assayed was referred to as "domain 3" (globular domain) from either Influenza A/Wyoming/03/03 (an H3N2 virus) or Influenza A/Vietnam/1194/2004 (an H5N1 virus).

[00236] RBC's from chicken, turkey and horse were washed individually in phosphate buffered saline (PBS) three times and adjusted to 0.5% v/v with PBS. Round bottomed, 96 well microtiter plates were tested with PBS alone for quality assurance demonstrating that only Falcon plates consistently provided clear delineation between positive and negative results. Vaccine material was assayed in duplicate starting at 0.5 mg/ml and diluted 2 fold up the plate by pipetting 25 µl of material into 25 µl of PBS stepwise. 25 µl of a 0.5% suspension of one species of RBC/plate was then dispensed into all wells of that plate. Plates were shaken to distrubute RBC's and incubated at 4C for 4 hours before determining positive from negative results.

[00237] Domain 3 from Influenza A/Vietnam/1194/2004 (an H5N1 virus) consistently and reproducibly gave a positive result on avian RBC's but not horse RBC's. The endpoint dilution was consistently 8 in replicates and experiment repeats, indicating the H5 domain 3 could hemagglutinate avian RBC's at a concentration of 62.5 µg (Figure 11).

Example 5: Immunogenicity Studies

Initial immunogenicity study

[00238] An initial immunogenicity study was conducted to determine whether plant-produced LicKM-antigen fusions could induce specific serum IgG in mice immunized intraperitoneally, and whether the induced antibodies could neutralize influenza virus *in vitro*. The study used LicKM, LicKM-HA(SD), LicKM-HA(SD), and recombinant NA enriched from *Agrobacterium* infiltrated leaves of *N. benthamiana* to 75% purity, as described above.

[00239] Eight-week old female BALB/c mice were immunized with 100 μg per dose of recombinant LicKM-HA(SD), LicKMHA(GD), and 50μg per dose of recombinant NA. Three immunizations of immunogen were administered intraperitoneally at day 1, the first boost 14 days later, followed by a second boost 10 days later. The first dose included complete Freund's adjuvant at a 1:1 volume ratio, the second dose did not include any adjuvant. A negative control group received 250 μg per dose of recombinant LicKM. Three mice were in each group. Pre-immune sera were collected one day before the first dosing, and sera were subsequently collected at day 28, after the second boost. Influenza specific IgG antibody titers were determined using an ELISA assay (Figure 12).

Inhibition of hemagglutination activity of virus by immune sera raised against influenza vaccine

[00240] Preimmune serum and post-second boost serum from mice immunized as described above were assessed for the ability of antibody titers to inhibit hemagglutination activity of inactivated influenza virus. 4 HA units of inactivated influenza A/Vietnam/1194/2004 virus (an H5N1 virus) was combined with 25μl of dilutions of pre-immune serum or serum collected after the second boost of vaccine. Inhibition of hemagglutination activity in avian RBCs was assessed as described in Example 4. Resultant antibody titers were effective at inhibition of hemagglutination of virus. Exemplary results depicted in Figure 13, and summarized in Table 1, demonstrate that antibodies raised can protect against hemagglutination activity of virus.

Table 1: Hemagglutination inhibition by immune sera raised against experimental influenza vaccine

Vaccination Group	Hemagglutinin inhibition titers (serum dilution –1)

PBS control	<10
PreImmune Serum	160
Vaccine w/o adjuvant	2560
Vaccine w/ adjuvant	2560

Example 6: Model System of Influenza Vaccination

A. Intramuscular vaccination

[00241] The ferret, an established animal model for the study of influenza infection, has been used to determine the efficacy of influenza vaccines (*e.g.* Boyd *et al.*, 1975; Chen *et al.*, 1995; Scheiblauer *et al.*, 1995; Sweet *et al.*, 1980, *Microbiol. Rev.*, 44:303; Maassab *et al.*, 1982, *J. Infect. Dis.*,146:780; Toms *et al.*, 1977; Webster *et al.*, 1994; Fenton *et al.*, 1981; and Webster *et al.*, 1994). Transmission studies utilizing a ferret animal model have not only demonstrated donor to recipient spread of influenza virus, but also the effects of mutations on virulence of virus (Herlocher *et al.*, 2001; and Herlocher *et al.*, 2002). The heterologous prime-vaccine-challenge model used in the studies described herein has been successfully tested with inactivated non adjuvanted influenza vaccines.

Production of Test Articles

[00242] We assessed the immunogenicity and protective efficacy of plant-produced antigens in ferrets. Test articles consisted of purified target antigen produced in plants. HA domains from a strain of influenza type A (A/Wyoming/3/03 [H3N2]) were engineered as fusions with thermostable carrier molecule and produced in a plant-based expression system as described above. NA from a the same strain was produced in a plant-based expression system as described above. Test articles did not contain any nucleic acids, toxic substance, or infectious agent.

[00243] Specifically, nucleotide sequences encoding amino acids 17 to 67 plus 294 to 532 of HA, which together comprise the stem domain (Wilson *et al.*, 1981, *Nature* 289:366), were inserted into LicKM (GenBank accession number DQ776900) to give LicKM-HA(SD). Nucleotide sequences encoding amino acids 68 to 293 of HA, comprising the globular domain (Wilson *et al.*, *supra*), were similarly inserted to give LicKM-HA(GD). Sequence encoding the signal peptide of the *Nicotiana tabacum* pathogenesis-related protein PR1a (Pfitzner *et al.*, 1987, *Nucleic Acids Res.*, 15:4449) was included at the N-terminus of the fusions. Sequences encoding the poly-histidine affinity

purification tag (6xHis) and the endoplasmic reticulum retention signal (KDEL) were included at the C-terminus. The LicKM fusions were introduced into the hybrid vector pBID4 (Wilson *et al.*, *supra*), which allows for viral genome transcription from the cauliflower mosaic virus 35S promotor, followed by viral replication and target sequence expression from tobacco mosaic virus (TMV) coat protein subgenomic mRNA (Shivprasad *et al.*, 1999, *Virology*, 255:312) and which is derived from the *Agrobacterial* binary plasmid pBI121 (Chen *et al.*, 2003, *Mol, Breed.*, 11:287), for the transient expression of targets in leaves. In addition, sequence encoding amino acids 38 to 469 of NA from the same influenza strain was introduced into pBID4, without prior fusion to LicKM. As above, the signal peptide of PR1a was included at the N-terminus and 6xHis plus KDEL were included at the C-terminus.

[00244] The engineered vectors containing influenza antigens were introduced into *Agrobacterium tumefaciens* strain GV3101 by electroporation. Suspensions of recombinant *A. tumefaciens* were introduced into *Nicotiana benthamiana* plants by innoculating leaves approximately six weeks after sowing in order to introduce target sequences into leaf tissues. Plants were grown in potting soil under 12 hour light / 12 hour dark conditions at 21°C. Leaves were harvested four to seven days after inoculation, depending on the expression construct. Protein extracts were prepared by grinding leaves in a buffer comprising 50 mM sodium phosphate, pH 7.0; 100 mM sodium chloride; 10 mM sodium diethyldithiocarbamate; and 10 mM β-mercaptoethanol. Recombinant antigens were enriched by ammonium sulfate precipitation followed by immobilized metal affinity chromatography (*e.g.*, by using 6xHis tag) and anion exchange chromatography, with dialysis after each step, to at least 80% purity.

[00245] The reactions of plant-produced antigens with reference antisera were assessed by ELISA analysis (Fig. 16A) and under denaturing conditions by immunoblotting (Fig. 16B). For ELISA, 96-well plates were coated with LicKM-HA(SD), LicKM-HA(GD), or NA purified from plants or coated with inactivated influenza A/Wyoming/3/03 virus. Coated plates were incubated with sheep antiserum raised against purified HA of A/Wyoming/3/03 virus, sheep antiserum raised against NIBRG-18 (H7N2) reassorted virus, or sheep antiserum raised against NIBRG-17 (H7N1) reassorted virus. For immunoblot analysis, 100 ng of LicKM-HA(SD), 100 ng of LicKM-HA(GD), and an amount of inactivated influenza A/Wyoming/3/03 corresponding to 100 ng of HA were separated by SDS-PAGE, transferred to polyvinylidene fluoride membrane and incubated with rabbit antiserum raised against LicKM or sheep antiserum raised against purified HA from A/Wyoming/3/03 virus. NA activity was assayed according to the standard WHO protocol WHO/CDS/CSR/NCS 2002.5

Rev.1. The inhibition of NA activity was assessed by pre-incubating plant-produced NA with sheep antiserum raised against homologous (NIBRG-18 [H7N2]) or heterologous (NIBRG-17 [H7N1]) reassorted virus prior to conducting the neuraminidase assay.

[00246] In both ELISA and immunoblot assays, LicKM-HA(SD) was more strongly recognized by the reference serum than LicKM-HA(GD), although polyclonal rabbit serum raised against LicKM recognized each fusion to a similar extent (Fig. 16B). In addition, plant-produced NA was recognized by reference polyclonal sheep serum raised against reassortant H7N2 virus (Fig. 16C), and showed enzymatic activity that was inhibited by reference serum in a strain specific manner (Fig. 16C).

Vaccination

[00247] Ferret studies were carried out under UK Home Office license as required by the UK Animal (Scientific Procedures) Act, 1986. Male fitch or albino ferrets (Highgate Farm, Highgate, England), 4.5 months old, weighing from 441 to 629 g at the initiation of the study, and maintained on high-density ferret LabDiet 5L15 (IPS Product Supplies, London, UK), were assigned to treatment groups as shown in Table 2.

Table 2. Treatment Groups

Group No.	Route of Administration	Number of animals in each group	Dose	Volume	Treatment
1	SC	8	-	300 µl	Negative control
2	SC	8	100 µg	300 µl	*Test article 1* VC1 plus adjuvant
3	SC	8	100 µg	300 µl	*Test article 2* VC2 NO adjuvant
4	SC	8	100 µg	300 µl	*Test article 3* VC2 plus adjuvant
5	SC	8	$TCID_{50}$ recorded	300 µl	Positive control

* $TCID_{50}$ ("Tissue Culture Infecting Dose") = the level of dilution of a virus at which half of a series of laboratory wells contain active, growing virus.

[00248] Three groups of eight ferrets were immunized subcutaneously by priming and boosting twice (on days 0, 14, and 28) with candidate vaccine formulations (VC1 plus adjuvant, VC2, and

VC2 plus adjuvant) containing combinations of plant-produced influenza antigens (Table 1). VC1 animals received 100 μg of LicKM-HA(SD) and 100 μg LicKM-GD plus 1.3 mg alum. VC2 animals received 100 μg LicKM-(SD), 100 μg LicKM-(GD), and 50 μg NA, plus 1.3 mg alum ("plus adjuvant") or plus no alum ("NO adjuvant"). 100 μg of LicKM-(SD)and 100 μg of LicKM-(GD) delivered together correspond to approximately 100 μg of HA. Negative control animals received alum adjuvant alone, and positive control animals were given a single intranasal dose of influenza A/Wyoming/3/03 virus (0.5 ml at a concentration of $10^{5.5}$ $TCID_{50}$ per ml on day 0). Following immunization, animals were monitored daily for lesions or irritation, mobility, erythema and general activity.

[00249] Animals were challenged intranasally while under anaesthetic with 0.5 ml of influenza A/Wyoming/3/03 virus at a concentration of $10^{5.5}$ $TCID_{50}$ per ml ten days after the final dose. Blood samples were collected from superficial tail veins on days of vaccination, challenge, and four days post-challenge, and nasal washes were collected for four days post-challenge. Serum HI titers were determined for homologous influenza A/Wyoming/3/03 virus and heterologous influenza A/Sydney/5/97 (H3N2), A/California/7/04 (H3N2) and A/New Caledonia/20/99 (H1N1) viruses.

[00250] Influenza vaccinations, procedures, and virus challenges were carried out according to the schedule set forth in Table 3. No adverse effects were noted in any animals receiving plant-produced vaccine candidates. Animals were implanted with transponders for individual identification and monitoring body temperature. Dosing was carried out on three separate occasions at time points detailed in the study schedule (Table 3). Test material prepared in advance was aliquoted for each dose. Test material was mixed with adjuvant immediately prior to administration.

Table 3. Study Schedule.

Day of study	-38	-24	-10	0	1	2	3	4
Transponder Implantation	X							
Vaccination	X	X	X					
Challenge				X				
Anaesthesia	X	X	X	X	X	X	X	X
Body Weight	X	X	X	X	X	X	X	X
Temperature Daily	X	X	X	X	X	X	X	X
Health Score	X	X	X	X	X	X	X	X
Nasal Wash					X	X	X	X
Serum for Antibody	X	X	X	X				X
Culling								X

Analysis

[00251] Clinical signs (health scores), body weight, and temperature changes were recorded. Once daily, post-infection, each animal examined for lesions or irritation, mobility, erythema, and general activity, and observations were recorded for determination of health scores. Each animal was scored as follows: sneezing or nasal rattling (1 point); purulent discharge from the external nares (1 point); decreased spontaneous activity or play (1 point); no spontaneous activity or decreased alertness (2 points). "Decreased spontaneous activity or play" and "no spontaneous activity or decreased alertness" were mutually exclusive scoring points. Maximum loss in weight from day of infection was calculated for each animal. Maximum increase in body temperature from day of infection was also calculated for each animal. Mean and standard deviation of maximum health score, weight loss, and temperature change for each animal on any day was calculated by treatment group and compared by ANOVA. An AUC-like measure comprising the sum health, weight loss, and temperature change scores on each day post-infection was calculated for each animal; treatment group means, medians and standard deviations were calculated and compared by ANOVA or Kruskal-Wallis test, as appropriate. Following challenge of live virus, each of the treatment groups demonstrated recovery from challenge as indicated by clinical signs, and changes in temperature and body weight. Groups of animals that received the test vaccine were protected and showed little or no symptoms of disease following challenge with homologous influenza virus. Both test vaccine candidates provided full protection to animals (Figure 14).

[00252] Nasal washes were collected after virus challenge. The volume of nasal wash recovery was measured, and the weight of the nasal wash was monitored. The inflammatory cell response was assessed in post-challenge nasal washes by staining with Trypan blue (used to determine total cell counts) and counting leukocytes. Cell counts in nasal wash were summarized by mean, median, and Standard deviation of log-transformed data on each sampling day post-infection; treatment groups were compared by ANOVA or Kruskal-Wallis test, as appropriate. Similar to clinical signs discussed above, monitoring of nasal washes indicated treatment groups receiving each of the test treatment vaccines demonstrated protection from infection equal to, or greater than positive control groups (Figure 14).

[00253] Viral shedding was determined using a Madin-Darby canine kidney (MDCK) cell titration on the nasal wash samples. The endpoint of the MDCK cell titration assay was determined by performing a hemagglutination assay with turkey red blood cells. The Karber calculation was used to determine $\log_{10}$ $TCID_{50}$/ml for each sample. Virus shedding from the nasal wash samples was determined on post-infection nasal wash samples. Maximum titer shed for each animal was log-transformed; treatment group means, medians, and standard deviations were calculated and compared by Kruskal-Wallis test. The proportion of animals in each treatment group with any virus shedding at any time was tabulated and the groups were contrasted using a χ^2 test for independence. Results from virus shed are depicted in Figure 15. Only the negative control treatment group resulted in significant shedding of virus (Figure 15).

[00254] Hemagglutinin inhibition assays (HAI) were performed as described in Example 5 using pre and post-vaccination serum samples against homologous virus (Influenza A/Wyoming/3/2003 (H3N2) virus) to confirm sero-negativity of the animals at baseline and whether or not animals sero-convert following immunization and infection. HAI titres were tabulated and animals with a $\geq$ 4-fold rise between day 0 and the terminal day were identified.

[00255] Hemagglutination-inhibition (HI) activity of sera from immunized animals is regarded as a correlate of protection (Brown *et al.*, 2004, *Dev. Biol. (Basel)*, 115:1; and Hobson *et al.*, 1972, *J. Hyg.*, 70:767). Results from one such experiment are presented in Table 4. All animals in groups immunized with test vaccines against H3N2 or positive control mounted strong target-specific immune responses with high serum hemagglutination inhibiting activity. Following a first dose of vaccine, VC2 plus adjuvant generated high HAI titers. VC2 without adjuvant generated a protective response, though titers not as high as with adjuvant after a first dose. However, following a second dose, titers reached similar levels to CMB1 with adjuvant. VC1 plus adjuvant also resulted in

generation of protective levels of antibody which were significantly higher following a second dose of vaccine (Table 4).

Table 4: Ferret HAI Data Summary

Vaccination Group	Hemagglutinin inhibition titers (serum dilution –1)		
	pre-Imm	Dose 1 (D1)	Dose2 (D2)
N/controle	5	5	5
VC2+A	5	1280	1280
VC1+A	5	50	1826
VC2 no A	5	322	1440
P/controle	5	3000	1367

[00256] Results from a second HA assay experiment are presented in Figure 17. No HI activity was observed in pre-immune sera from any animal, or in sera from NC animals (Fig. 17). However, sera from all ferrets vaccinated with VC2 plus adjuvant exhibited high HI titers in the range of 1:320 to 1:2560 (mean titer 1273) following the first dose (Fig. 17). Fewer responders and lower HI titers following the first dose were observed among animals that received VC1 plus adjuvant (Fig. 17), suggesting that NA might have modulated the immune response. Five of the eight animals that received VC2 gave HI titers in the range of 1:160 to 1:1280, whereas commercial inactivated influenza vaccines in the absence of adjuvant typically induce very low, if any, HI titers (Potter *et al.*, 1972, *Br. J. Exp. Pathol.*, 53:168; Potter *et al.*, 1973, *J. Hyg. (Lond.)*, 71:97; and Potter *et al.*, 1973, *Arch. Gesamte Virusforsch.*, 42:285). Following the second dose of VC1 plus adjuvant, VC2, or VC2 plus adjuvant, sera from all ferrets had HI titers in the range of 1:640 to 1:2560, and these remained similarly high after the third dose (Fig. 17). Sera from all of these animals had titers in excess of 1:40, regarded by some as the minimum HI titer consistent with protection in humans (Brown *et al.*, 2004, *Dev. Biol. (Basel)*, 115:1; and Hobson *et al.*, 1972, *J. Hyg.*, 70:767).

[00257] HI titers in sera from ferrets receiving two or three doses of any of the plant-produced vaccine candidates were equivalent to or greater than those in sera from intranasally infected positive control animals (Fig. 17), and were in excess of those observed in other ferret studies. For example, ferrets immunized intramuscularly with a commercial, inactivated H3N2 influenza vaccine were reported to develop HI titers of 1:20 after receiving two doses (Lambkin *et al.*, 2004, *Vaccine*, 22:4390). Sera from ferrets immunized with VC1 plus adjuvant, VC2, or VC2 plus adjuvant had HI

titers four to twenty-fold lower against the heterologous H3N2 virus strains A/Sydney/5/97 and A/California/7/04 than against A/Wyoming/3/03, but these titers were all in excess of the 1:40 threshold consistent with protection, suggesting the potential for these vaccine candidates to protect against heterologous H3N2 strains. HI titers below 1:10 were observed against influenza A/New Caledonia/20/99 (H1N1), indicating the H3 subtype specificity of the HI antibody response.

[00258] A follow-up immunogenicity and protective efficacy study was conducted to assess the protective efficacy of plant-produced HA and NA antigens in immunized ferrets by intranasal challenge with live egg-grown influenza A/Wyoming/3/03 virus.

[00259] The extent of viral infection following challenge was determined for each animal by monitoring the titer of virus shed in nasal washes for four days post-challenge. Only one animal that received any of the three candidate vaccine formulations showed detectable virus shedding, and even then at less than 10^2 $TCID_{50}$, whereas animals in the NC group showed virus shedding in the range of 10^6 to 10^7 $TCID_{50}$ (Fig. 18A). The level of virus shedding in the PC group was in the range of 10^2 to 10^3 $TCID_{50}$, greater than that for any animal in the candidate vaccine groups (Fig. 18A).

[00260] Evidence of protection was observed for animals receiving any of the candidate vaccine formulations. Weight loss post-infection was greatly reduced in ferrets that received VC1 plus adjuvant, VC2 plus adjuvant, or the homologous virus, compared to those in the NC group (Fig. 18B). The reduction in weight loss for animals that received VC2 was less striking (Fig. 18B). In addition, the rise in body temperature in ferrets immunized with any of the candidate vaccine formulations was reduced compared to that observed for animals in either the NC or PC groups (Fig. 18C). Furthermore, the mean peak of symptom scores, an index indicating the frequency of several influenza related symptoms following challenge, was reduced in animals that received the candidate vaccine formulations compared to those in the NC group (Fig. 18D). Similarly, counts of leukocytes in nasal washes of ferrets, taken as an indicator of upper respiratory tract infection, were reduced in candidate vaccine recipients compared to animals in the NC group (Fig. 18E).

[00261] The challenge study indicates that the plant-produced HA and NA antigens confer a high degree of protective immunity in ferrets, showing promise for vaccine development. In future studies we will elucidate the protective role of LicKM-SD and LicKM-GD when administered individually, and the role of NA in further facilitating immune responses.

B. Intranasal Vaccination

[00262] Immunogenicity of candidate vaccines is evaluated following intranasal immunization in Balb/c mice or ferret model animals. The study design is similar to that of intramuscular immunization discussed in the Examples above. In brief, groups of mice or ferrets (approximately 8-10 animals/group) are immunized intranasally with three doses (100 μg/dose) of target antigen on about days 0, 14 and 28, in the presence or absence of adjuvant (*e.g.*, aluminum hydroxide, MALP-2, *etc.*). Serum samples and nasal washes are collected on each vaccination day before administering the antigen and ten days after the third dose. Immunized animals are challenged after the last dose by the nasal route with the homologous strain of influenza virus known to infect the animals and to produce symptoms of respiratory infection with fever. The nature of the immune response is examined by determining level of virus shedding, weight loss post-infection, rise in body temperature, mean peak of symptom scores, and counts of leukocytes in nasal washes, as measured after virus challenge. The presence of antibodies to NA and/or HA, as well as HI and virus neutralization activity, is examined.

C. Dose Escalation Studies

[00263] Optimum composition and doses of antigens and adjuvant, route of administration, as well as immunization regimens may be further assessed using dose escalation studies. We anticipate testing three of six test vaccine compositions in this study. The study is performed using both the intramuscular route (Table 3) and intranasal route. Similar to that of intramuscular and intranasal immunization discussed in the Examples above, groups of animals (approximately 8-10 animals/group) are immunized intranasally with various doses of test vaccine, in the presence or absence of adjuvant (*e.g.*, aluminum hydroxide, MALP-2, *etc.*). See Table 5 for an exemplary dosing schedule.

[00264] As in other studies, serum samples and nasal washes are collected on each vaccination day before administering the antigen and ten days after the third dose. Immunized animals are challenged after the last dose by the nasal route with the homologous strain of influenza virus known to infect animals and to produce symptoms of respiratory infection with fever. The nature of the immune response can be determined by examining level of virus shedding; weight loss post-infection; rise in body temperature; mean peak of symptom scores; counts of leukocytes in nasal washes; presence of antibodies to NA, HA, and/or M2; hemagglutination inhibition; and/or virus neutralization activity.

Table 5: Exemplary Design for Dose Escalation Study in Animals.

Group	Vaccine Candidate Composition #	Route of Vaccination	Number of Animals	Number of Doses	µg VC per Dose
1	Standard	i.m.*	8		
2	1	i.m.	8	3	10
3	1	i.m.	8	2	50
4	1	i.m.	8	1	100
5	LicKM	i.m.	8	2	100
6	2	i.m.	8	3	10
7	2	i.m.	8	2	50
8	2	i.m.	8	1	100
9	3	i.m.	8	3	10
10	3	i.m.	8	2	50
11	3	i.m.	8	1	100

* i.m. = intramuscular injection

What is claimed is:

1. An isolated antigen comprising a component of an influenza A integral membrane protein fused to a thermostable protein;

wherein the integral membrane protein component comprises at least one domain selected from the group consisting of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2.

2. The isolated antigen of claim 1, wherein the integral membrane protein component consists of at least one domain hemagglutinin (HA), wherein the domain is selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20 and SEQ ID NO.: 24.

3. The isolated antigen of claim 1, wherein the integral membrane protein component consists of at least one domain of neuraminidase (NA) selected from the group consisting of SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

4. The isolated antigen of claim 1, wherein the integral membrane protein component consists of full length hemagglutinin (HA) selected from SEQ ID NO.: 1 or SEQ ID NO.: 3.

5. The isolated antigen of claim 1, wherein the integral membrane protein component consists of full length neuraminidase (NA) selected from SEQ ID NO.: 2 or SEQ ID NO.: 4.

6. The isolated antigen of claim 1, wherein the thermostable protein comprises a modified lichenase protein sequence.

7. The isolated antigen of claim 6, wherein the coding sequence for lichenase has been optimized for protein expression in plants.

8. The isolated antigen of claim 6, wherein the lichenase protein sequence comprises the N-terminal domain, the C-terminal domain, and the surface loop domain of lichenase LicB.

9. The isolated antigen of claim 1, wherein the integral membrane protein component fused to lichenase is any one of an N-terminal fusion, a C-terminal fusion, or a surface loop insertion fusion protein.

10. The isolated antigen of claim 1, wherein the integral membrane protein component comprises at least two domains selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20, SEQ ID NO.: 24, SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

11. The isolated antigen of claim 10, wherein the integral membrane protein component comprises a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

12. A vaccine composition comprising an antigen comprising a component of an influenza A integral membrane protein fused to a thermostable protein and a pharmaceutically acceptable carrier;

wherein the integral membrane protein component comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2; and

wherein the composition is capable of eliciting an immune response upon administration to a subject.

13. The vaccine composition of claim 12, wherein the integral membrane protein component consists of at least one domain hemagglutinin (HA), wherein the domain is selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20 and SEQ ID NO.: 24.

14. The vaccine composition of claim 12, wherein the integral membrane protein component consists of at least one domain of neuraminidase (NA) selected from the group consisting of SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

15. The vaccine composition of claim 12, wherein the integral membrane protein component consists of full length hemagglutinin (HA) selected from SEQ ID NO.: 1 or SEQ ID NO.: 3.

16. The vaccine composition of claim 12, wherein the integral membrane protein component consists of full length neuraminidase (NA) selected from SEQ ID NO.: 2 or SEQ ID NO.: 4.

17. The vaccine composition of claim 12, wherein the thermostable protein comprises a modified lichenase protein sequence.

18. The vaccine composition of claim 12, wherein the thermostable protein comprises a modified lichenase protein sequence from *Clostridium thermocellum.*

19. The vaccine composition of claim 17, wherein the coding sequence for lichenase has been optimized for protein expression in plants.

20. The vaccine composition of claim 17, wherein the lichenase protein sequence comprises the N-terminal domain, the C-terminal domain, and the surface loop domain of lichenase.

21. The vaccine composition of claim 20, wherein the integral membrane protein component fused to lichenase is any one of an N-terminal fusion, a C-terminal fusion, or a surface loop insertion fusion protein.

22. The vaccine composition of claim 12, wherein the integral membrane protein component comprises at least two domains selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20, SEQ ID NO.: 24, SEQ ID NO.: 2, 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.and wherein the composition is capable of eliciting an immune response upon administration to a subject.

23. The vaccine composition of claim 22, wherein the integral membrane protein component comprises a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

24. The vaccine composition of claim 22, wherein the integral membrane protein component comprises full length hemagglutinin (HA) and full length neuraminidase (NA).

25. The vaccine composition of claim 12, further comprising a second antigen, wherein the composition is capable of eliciting an immune response upon administration to an animal.

26. The vaccine composition of claim 25, wherein the second antigen comprises a component of influenza A integral membrane protein fused to a thermostable protein and a pharmaceutically acceptable carrier;

wherein the integral membrane protein component of the first antigen comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2, and the integral membrane protein component of the second antigen comprises at least one domain distinct from the first antigen selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2; and

wherein the composition is capable of eliciting an immune response upon administration to a subject.

27. The vaccine composition of claim 26, wherein the integral membrane protein component of the first antigen comprises a domain of hemagglutinin (HA) and the integral membrane protein component of the second antigen comprises a domain of neuraminidase (NA).

28. The vaccine composition of claim 12 wherein the antigen is produced in a plant selected from a transgenic plant and a plant transiently expressing the antigen.

29. The vaccine composition of claim 12 wherein the composition comprises antigen which is purified, partially purified, or unpurified from plant cells, a plant, seeds, fruit, or an extract thereof.

30. The vaccine composition of claim 12, further comprising at least one vaccine adjuvant.

31. The vaccine composition of claim 30 wherein the adjuvant is selected from the group consisting of alum, MF59, saponin, and MALP2.

32. A vaccine composition comprising at least two antigens, each of which comprises a component of an influenza A integral membrane protein, wherein the integral membrane protein component comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2; wherein at least one antigen is fused to a thermostable protein and a pharmaceutically acceptable carrier; wherein the composition is capable of eliciting an immune response upon administration to a subject.

33. The vaccine composition of claim 32, wherein at least one integral membrane protein component comprises of at least one domain hemagglutinin (HA), wherein the domain is

selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20 and SEQ ID NO.: 24.

34. The vaccine composition of claim 32, wherein at least one integral membrane protein component comprises at least one domain of neuraminidase (NA) selected from the group consisting of SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

35. The vaccine composition of claim 32, wherein at least one integral membrane protein component consists of full length hemagglutinin (HA)selected from SEQ ID NO.: 1 or SEQ ID NO.: 3.

36. The vaccine composition of claim 32, wherein at least one integral membrane protein component consists of full length neuraminidase (NA) selected from SEQ ID NO.: 2 or SEQ ID NO.: 4.

37. The vaccine composition of claim 32, wherein the thermostable protein comprises a modified lichenase protein sequence.

38. The vaccine composition of claim 32, wherein the thermostable protein comprises a modified lichenase protein sequence from *Clostridium thermocellum.*

39. The vaccine composition of claim 37, wherein the coding sequence for lichenase has been optimized for protein expression in plants.

40. The vaccine composition of claim 37, wherein the lichenase protein sequence comprises the N-terminal domain, the C-terminal domain, and the surface loop domain of lichenase.

41. The vaccine composition of claim 40, wherein the integral membrane protein component fused to lichenase is any one of an N-terminal fusion, a C-terminal fusion, or a surface loop insertion fusion protein.

42. The vaccine composition of claim 32, wherein the integral membrane protein component comprises at least two domains selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID

NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20, SEQ ID NO.: 24, SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.and wherein the composition is capable of eliciting an immune response upon administration to a subject.

43. The vaccine composition of claim 42, wherein the integral membrane protein component comprises a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

44. The vaccine composition of claim 42, wherein the integral membrane protein component comprises full length hemagglutinin (HA) and full length neuraminidase (NA).

45. The vaccine composition of claim 32, further comprising a third antigen, wherein the composition is capable of eliciting an immune response upon administration to an animal.

46. The vaccine composition of claim 45, wherein the third antigen comprises a component of influenza A integral membrane protein fused to a thermostable protein and a pharmaceutically acceptable carrier;

wherein the integral membrane protein component of the first antigen comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2, and the integral membrane protein component of the second antigen comprises at least one domain distinct from the first antigen selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2; and

wherein the composition is capable of eliciting an immune response upon administration to a subject.

47. The vaccine composition of claim 32 wherein the antigen is produced in a plant selected from a transgenic plant and a plant transiently expressing the antigen.

48. The vaccine composition of claim 32 wherein the composition comprises antigen which is purified, partially purified, or unpurified from plant cells, a plant, seeds, fruit, or an extract thereof.

49. The vaccine composition of claim 32, further comprising at least one vaccine adjuvant.

50. The vaccine composition of claim 49 wherein the adjuvant is selected from the group consisting of alum, MF59, saponin, and MALP2.

51. A method for inducing a protective immune response against influenza A infection in a subject comprising administering to a subject an effective amount of an anti-influenza A vaccine composition, wherein the administration is sufficient to stimulate production of antigen specific antibodies or stimulate a cellular immune response by the subject; thereby inducing a protective immune response;

wherein the vaccine composition comprises an antigen comprising a component of an influenza A integral membrane protein fused to a thermostable protein; and

wherein the integral membrane protein component comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) a domain of neuraminidase (NA) and a domain of M2.

52. The method of claim 51, wherein the composition is administered orally, intranasally, subcutaneously, intravenously, intraperitoneally, or intramuscularly.

53. The method of claim 52, wherein the composition is administered orally via feeding plant cells to the subject.

54. The method of claim 51 wherein the subject is human.

55. The method of claim 51 wherein the subject is selected from the group consisting of a bird, a pig, and a horse.

56. A method for producing an antigen protein comprising a component of an influenza A integral membrane protein fused to a thermostable protein, comprising:

a. preparing a nucleic acid construct encoding an antigen comprising a component of an influenza A integral membrane protein fused to a thermostable protein;
b. introducing the nucleic acid of step a into a cell; and
c. incubating the cell under conditions favorable for expression of the antigen protein;

thereby producing the antigen protein;

wherein the integral membrane protein component comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

57. The method of claim 56, wherein the integral membrane protein component consists of at least one domain hemagglutinin (HA), wherein the domain is selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20 and SEQ ID NO.: 24.

58. The method of claim 56, wherein the integral membrane protein component consists of at least one domain of neuraminidase (NA) selected from the group consisting of SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

59. The method of claim 56, wherein the integral membrane protein component consists of full length hemagglutinin (HA) selected from SEQ ID NO.: 1 or SEQ ID NO.: 3.

60. The method of claim 56, wherein the integral membrane protein component consists of full length neuraminidase (NA) selected from SEQ ID NO.: 2 or SEQ ID NO.: 4.

61. The method of claim 56, wherein the thermostable protein comprises a modified lichenase protein sequence.

62. The method of claim 56, wherein the coding sequence for lichenase has been optimized for protein expression in plants.

63. The method of claim 56, wherein the lichenase protein sequence comprises the N-terminal domain, the C-terminal domain, and the surface loop domain of lichenase.

64. The method of claim 56, wherein the integral membrane protein component fused to lichenase is any one of an N-terminal fusion, a C-terminal fusion, or a surface loop insertion fusion protein.

65. The method of claim 56, wherein the integral membrane protein component comprises at least two domains selected from the group consisting of a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

66. The method of claim 56, wherein the integral membrane protein component comprises a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

67. The method of claim 56, wherein expression of the antigen protein is under control of a viral promoter.

68. The method of claim 56, wherein the nucleic acid construct further comprises vector nucleic acid sequence.

69. The method of claim 56, wherein the vector is a binary vector.

70. The method of claim 56, wherein the nucleic acid construct further comprise sequences encoding viral proteins.

71. The method of claim 56, wherein the cell is a plant cell.

72. The method of claim 71, wherein the plant cell is selected from the group consisting of alfalfa, radish, mustard, mung bean, broccoli, watercress, soybean, wheat sunflower, cabbage, clover, petunia, tomato, potato, nicotine, spinach, and lentil cell.

73. The method of claim 56, wherein the antigen protein is produced in a clonal root cell.

74. The method of claim 56, wherein the antigen protein is produced in sprouted seedlings.

75. The method of claim 56, further comprising recovering partially purified or purified antigen protein which is produced.

76. An isolated nucleic acid construct comprising nucleic acid sequence encoding a component of an influenza A integral membrane protein fused to a thermostable protein; and wherein the integral membrane protein component comprises at least one domain selected from the group consisting of a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

77. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin (HA) wherein the domain is selected from the group consisting of SEQ ID NO.: 1, SEQ ID NO.: 3, SEQ ID NO.: 7, SEQ ID NO.: 8, SEQ ID NO.: 33, SEQ ID NO.: 11, SEQ ID NO.: 12, SEQ ID NO.: 13, SEQ ID NO.: 20 and SEQ ID NO.: 24.

78. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the integral membrane protein component consists of at least one domain of neuraminidase (NA) selected from the group consisting of SEQ ID NO.: 2, SEQ ID NO.: 4, SEQ ID NO.: 16, and SEQ ID NO.: 18.

79. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the integral membrane protein component consists of full length hemagglutinin (HA) selected from SEQ ID NO.: 1 or SEQ ID NO.: 3.

80. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the integral membrane protein component consists of full length neuraminidase (NA) selected from SEQ ID NO.: 2 or SEQ ID NO.: 4.

81. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the thermostable protein comprises a modified lichenase protein sequence.

82. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the coding sequence for lichenase has been optimized for protein expression in plants.

83. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the lichenase protein sequence comprises the N-terminal domain, the C-terminal domain, and the surface loop domain of lichenase.

84. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the integral membrane protein component fused to lichenase is any one of an N-terminal fusion, a C-terminal fusion, or a surface loop insertion fusion protein.

85. The isolated nucleic acid construct of claim 76, wherein the integral membrane components comprises at least one domain of hemagglutinin wherein the integral membrane protein component comprises at least two domains selected from the group consisting of a domain of hemagglutinin (HA) and a domain of neuraminidase (NA).

86. The isolated acid construct of claim 85, wherein the integral membrane protein component at least one domain of hemagglutinin (HA) and at least one domain of neuraminidase (NA).

87. The isolated nucleic acid construct of claim 76 further comprising vector nucleic acid sequences.

88. The isolated nucleic acid construct of claim 76 further comprising viral promoter nucleic acid sequence.

89. The method of claim 76 wherein the vector is a binary vector.

90. The method of claim 76, further comprising nucleic acid sequences encoding viral proteins.

91. A host cell comprising the nucleic acid construct of claim 76.

92. The host cell of claim 91 which is a plant cell.

93. The plant of claim 92 which is selected from the group consisting of alfalfa, radish, mustard, mung bean, broccoli, watercress, soybean, wheat sunflower, cabbage, clover, petunia, tomato, potato, nicotine, spinach, and lentil.

94. The plant of claim 92 which is of a genus selected from the *Brassica* genus, the *Nicotana* genus, and the *Petunia* genus.