

GENOMIC DELETION IN AFRICAN SWINE FEVER VACCINE ALLOWING EFFICIENT GROWTH IN STABLE CELL LINES

BACKGROUND OF THE INVENTION

[0001] Field of Invention

[0002] The present disclosure provides details on the construction of a recombinant African Swine Fever Virus (ASFV) live attenuated vaccine for prevention of ASF caused by various strains of ASFV, such as the highly virulent Georgia 2007 isolate (“ASFV-G”). An exemplary vaccine comprises a deletion resulting in efficient growth in a stable cell line, allowing for industrial-level production of ASFV vaccines.

[0003] Background

[0004] African swine fever virus (ASFV) strain Georgia (ASFV-G), the only member of the virus family *Asfarviridae*, is the causative agent of a pandemic disease currently affecting a large contiguous geographical area extended from central Europe to China and South Asia (Costard et al, Philos. Trans. R. Soc. London B Biol. Sci., (2009) 364:2683-96; O'Donnell et al, J. Virol., (2015a) 89:6048-56). This pandemic is causing important economic losses devastating swine industry and provoking worldwide protein availability shortages (O'Donnell et al, (2015a) *supra*). ASFV is a very large with a complex structure, and a 180-190 kilobases double-stranded DNA genome which encodes for over 150 open reading frames (ORFs).

[0005] There is no commercial vaccine available therefore the disease control is exclusively based in managing geographical movements of susceptible animals and culling infected animals (Costard et al, *supra*). Effective experimental vaccines have been obtained based on the development of attenuated virus strains via genetic manipulation of parental virulent virus deleting specific virus genes associated with virus virulence (O'Donnell et al, (2015a) *supra*;

O'Donnell et al, J. Virol., (2015b) 89:8556-66; O'Donnell et al, J. Virol., (2017) 91:e01760-16; Borca et al, J. Virol., (2020) 94:e02017-19). Understanding the function of viral genes in the process of virus virulence in the natural host is a critical step in the rational development of experimental vaccine using genetic manipulation. These experimental live attenuated vaccines constitute by far the more advanced approach towards the development of an effective countermeasure to control ASF.

[0006] A main technical problem in developing commercially viable ASF vaccines is that these virus strains only efficiently replicate in primary cultures of swine macrophage hampering large-scale production at industrial level. To address this problem, we herein disclose a mutation that allows for growth of ASFV vaccines in a stable cell line, while maintaining the ability to replicate in swine macrophages, and a complete attenuation when inoculated in domestic swine.

SUMMARY OF THE INVENTION

[0007] The present disclosure provides, in one embodiment, a genetically modified virus, in which the virus genome has a viral genome at least 95% identical to SEQ ID NO: 1. In a particular embodiment, the viral genome is identical to SEQ ID NO:1.

[0008] Further provided herein is a vaccine composition against African Swine Fever Virus (ASFV), comprising a genetically modified virus with a viral genome at least 95% identical to SEQ ID NO: 1. In particular embodiments, the ASFV is an ASFV-Georgia 2007 isolate (ASFV-G).

[0009] The present disclosure further provides, in an additional embodiment, a method for the protection of swine against ASFV, comprising administering to a swine a live attenuated vaccine comprising a genetically modified virus with a viral genome at least 95% identical to SEQ ID NO: 1 in an amount effective to protect said swine from clinical ASFV disease. In particular

embodiments, the ASFV is ASFV-G. In a specific embodiment, the amount effective to protect a vaccinated swine from clinical ASFV disease is a vaccine comprising 10^2 - 10^6 HAD₅₀ of a genetically modified virus with a viral genome at least 95% identical to SEQ ID NO: 1.

[0010] An additional embodiment provided by the present disclosure is a recombinant ASFV mutant virus having a deletion, or partial deletion of each of ORFs MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, MGF360-11L. In a particular embodiment, the virus comprises a deletion of a genomic fragment at least 95% identical to SEQ ID NO:2. In some embodiments, the mutant ASFV is an ASFV-Georgia isolate. In some embodiments, the mutant ASFV has a genome at least 99% identical to SEQ ID NO: 1. Such viruses can also be part of a vaccine composition against ASFV-G.

[0011] An additional embodiment provided by this disclosure is a method for the protection of swine against ASFV, comprising administering to a swine a live attenuated vaccine comprising the recombinant having a deletion, or partial deletion of each of ORFs MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, MGF360-11L in an amount effective to protect said swine from clinical ASFV disease. In a particular embodiment, the ASFV is ASFV-G. In some embodiments, the amount effective to protect inoculated swine from clinical ASFV disease is a vaccine comprising 10^2 - 10^6 HAD₅₀ of the genetically modified virus.

[0012] Further provided herein is an embodiment for a method of producing ASFV at titers of 10^4 - 10^7 HAD₅₀/mL in a cultured stable cell line, comprising inoculating a genetically modified virus, in which the virus genome has a viral genome at least 95% identical to SEQ ID NO: 1 into the cultured stable cell line; incubating the inoculated cell line under conditions allowing for viral replication, and; growing said viruses to a titer of 10^4 - 10^7 HAD₅₀/mL. In some

embodiments, the stable cell line is a porcine fetal kidney cell line engineered to express bovine $\alpha_v\beta_6$ integrin. In a particular embodiment, the ASFV virus genome comprises a viral genome at least 99% identical to SEQ ID NO: 1.

INCORPORATION BY REFERENCE

[0013] All publications, patents and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The patent application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0015] The novel features of the invention are set forth with particularity in the claims. Features and advantages of the present invention are referred to in the following detailed description, and the accompanying drawings of which:

[0016] **FIG. 1** provides graphically represented data showing *in vitro* growth characteristics of ASFV-G- Δ I177L/ Δ LVR (**top**), ASFV-G- Δ I177L/ Δ LVR p7 (**middle**) and ASFV-G- Δ I177L/ Δ LVR p11 (**bottom**) in a stable porcine cell line and primary swine macrophage cultures. Cell cultures were infected (MOI= 0.01) with each of the viruses and the virus yield titrated at the indicated times postinfection. Data represent the means of the results from three independent experiments. The sensitivity of virus detection is $\geq 1.8 \log_{10}$ HAD₅₀/ml. Significant differences (*) in viral yields between the two viruses at specific times points were determined using the Holm-Sidak method ($\alpha = 0.05$), without assuming a consistent standard deviation. All

calculations were conducted on the software GraphPad Prism version 8. TCID₅₀, 50% tissue culture infective dose.

[0017] FIG. 2 provides a graphically represented comparison of the genomes of two viruses - ASFV-G-ΔI177LΔLVR and parental ASFV-G-ΔI177L.

[0018] FIG. 3 provides a schematic of gene deletion approaches to construct cell line adaptation mutants of ASFV. ΔLVR or a partial deletion in ΔLVR deleting just MGF300 1L, 2R, 4L. The indicated donor plasmid serves as a template for homologous recombination, a standard method for producing recombinant viruses.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Highly virulent African swine fever virus (ASFV) strain Georgia (ASFV-G) is the causative agent of the current pandemic covering a contiguous geographical area from central Europe to Asia and South Asia causing enormous economic losses. There is no commercial vaccine available and live attenuated strains, developed from virulent parental virus by genetic manipulation, are the most advanced experimental vaccines. Recently we developed a vaccine candidate by deleting the I177L gene from the genome of ASFV-G (see, U.S. Pat. App. No. 16/580,058). This mutant strain was shown to be very safe and highly efficacious in inducing protection against challenge with ASFV-G. An important technical limitation of transferring this mutant (and other recombinant ASFV vaccines) to industrial production is that replicates exclusively in primary cultures of swine macrophages. Here we present the development of a derivative strain (ASFV-G-ΔI177LΔLVR) that contains a deletion of 10.8kb in the Left variable region (LVR) which allows for efficient grows in a stable porcine cell line (see, U.S. Pat. No. 9,121,010). The deletion in the LVR affects 10 viral genes in the left end of the genome. This deletion remained stable after more than 30 additional passages in a continuous stable porcine

cell line. Importantly, ASFV-G- Δ I177L Δ LVR maintained the same level of attenuation, immunogenic characteristics and protective efficacy against challenge with virulent ASFV-G as the parental vaccine. This is the first time a rationally designed highly efficacious ASF vaccine candidate has been shown to grow in a stable cell line, while maintaining genomic stability, allowing for ASFV vaccine production at industrial levels.

[0020] Preferred embodiments of the present invention are shown and described herein. It will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will occur to those skilled in the art without departing from the invention. Various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the included claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents are covered thereby.

[0021] Technical and scientific terms used herein have the meanings commonly understood by one of ordinary skill in the art to which the instant invention pertains, unless otherwise defined. Reference is made herein to various materials and methodologies known to those of skill in the art. Standard reference works setting forth the general principles of recombinant DNA technology include Sambrook et al., "Molecular Cloning: A Laboratory Manual", 2d ed., Cold Spring Harbor Laboratory Press, Plainview, N.Y., 1989; Kaufman et al., eds., "Handbook of Molecular and Cellular Methods in Biology and Medicine", CRC Press, Boca Raton, 1995; and McPherson, ed., "Directed Mutagenesis: A Practical Approach", IRL Press, Oxford, 1991.

[0022] Any suitable materials and/or methods known to those of skill can be utilized in carrying out the instant invention. Materials and/or methods for practicing the instant invention are described. Materials, reagents and the like to which reference is made in the following

description and examples are obtainable from commercial sources, unless otherwise noted. This invention teaches methods and describes tools for producing genetically altered strains of ASFV.

[0023] As used in the specification and claims, use of the singular “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise.

[0024] The terms isolated, purified, or biologically pure as used herein, refer to material that is substantially or essentially free from components that normally accompany the referenced material in its native state.

[0025] The term “about” is defined as plus or minus ten percent of a recited value. For example, about 1.0g means 0.9g to 1.1g and all values within that range, whether specifically stated or not.

[0026] The term “a nucleic acid consisting essentially of”, and grammatical variations thereof, means nucleic acids that differ from a reference nucleic acid sequence by 20 or fewer nucleic acid residues and also perform the function of the reference nucleic acid sequence. Such variants include sequences which are shorter or longer than the reference nucleic acid sequence, have different residues at particular positions, or a combination thereof.

[0027] The term “adjuvant” means a substance or vehicle that non-specifically enhances the immune response to an antigen. Adjuvants can include a suspension of minerals (alum, aluminum hydroxide, or phosphate) on which antigen is adsorbed; or water-in-oil emulsion in which antigen solution is emulsified in mineral oil (for example, Freund’s incomplete adjuvant), sometimes with the inclusion of killed mycobacteria (Freund’s complete adjuvant) to further enhance antigenicity. Immunostimulatory oligonucleotides can also be used as adjuvants (for example, see U.S. Patent Nos. 6,194,388; 6,207,646; 6,214,806; 6,218,371; 6,239,116; 6,339,068; 6,406,705; and 6,429,199). Adjuvants also include biological molecules, such as costimulatory molecules.

[0028] The term "administer" / "administration" means any method of providing a subject with a substance, such as a therapeutic agent by any effective route. Exemplary routes of administration include, but are not limited to, injection (such as subcutaneous, intramuscular, intradermal, intraperitoneal, and intravenous), oral, intraductal, sublingual, rectal, transdermal, intranasal, vaginal and inhalation routes.

[0029] The terms "coding sequence" and "coding region" as used herein refer to nucleotide sequences and nucleic acid sequences, including both RNA and DNA, that encode genetic information for the synthesis of an RNA, a protein, or any portion of an RNA or protein.

[0030] The term "effective amount" of a composition provided herein refers to the amount of the composition capable of performing the specified function for which an effective amount is expressed. The exact amount required can vary from composition to composition and from function to function, depending on recognized variables such as the compositions and processes involved. An effective amount can be delivered in one or more applications. Thus, it is not possible to specify an exact amount, however, an appropriate "effective amount" can be determined by the skilled artisan via routine experimentation.

[0031] The terms "I177L", "ASFV I177L", and "genomic I177L" are synonyms and refer to the ASFV-G open reading frame I177L that encodes a 177 amino acid protein and is positioned on the reverse strand between nucleotide positions 175473 and 176006 of SEQ ID NO:3.

[0032] In the context of the present invention, the term "cell line adaptation mutation" refers to a modification of the ASFV genome resulting in the full or partial deletion of ORFs MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, MGF360-11L (**FIG. 2**). In a specific embodiment, this term refers to deletion of the ASFV-G genomic sequence disclosed as SEQ ID NO:2.

[0033] In the context of the present invention, the term “non-functional genomic” MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, or MGF360-11L refers to a modified gene or ORF, located in the genome of an ASFV, wherein such modification of the ASFV gene results in no gene product at all or a biologically non-functional gene product as compared to an unmodified functional ASFV gene. Such modifications can include, but are not limited to, full or partial deletion of the coding sequence, disruption of the open reading frame (e.g., by insertion of a shift mutation or insertion of a nonsense codon), modification of upstream or downstream regulatory elements, and/or any other currently known or conceivable method of inactivating or knocking-out functional expression of such ASFV gene(s).

[0034] The term “ASFV-G-ΔI177LΔLVR” is used to describe a specific embodiment of the present disclosure, namely the vaccine/virus having the genomic sequence of SEQ ID NO: 1. The term “ASFV-G ΔI177L” is used to refer to the parental strain of “ASFV-G-ΔI177LΔLVR”, but which lacks the “cell line adaptation mutation”.

[0035] The term “immunize” means to render a subject protected from an infectious disease, such as by vaccination.

[0036] For the purpose of this invention, the “sequence identity” of two related nucleotide or amino acid sequences, expressed as a percentage, refers to the number of positions in the two optimally aligned sequences which have identical residues (x100) divided by the number of positions compared. A gap, i.e., a position in an alignment where a residue is present in one sequence but not in the other is regarded as a position with non-identical residues. The alignment of the two sequences is performed by the Needleman and Wunsch algorithm (Needleman and Wunsch, J Mol Biol, (1970) 48:3, 443-53). A computer-assisted sequence alignment can be

conveniently performed using a standard software program such as GAP which is part of the Wisconsin Package Version 10.1 (Genetics Computer Group, Madison, Wisconsin, USA) using the default scoring matrix with a gap creation penalty of 50 and a gap extension penalty of 3.

[0037] The phrase “high percent identical” or “high percent identity”, and grammatical variations thereof in the context of two polynucleotides or polypeptides, refers to two or more sequences or sub-sequences that have at least about 80%, identity, at least about 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% nucleotide or amino acid identity, when compared and aligned for maximum correspondence, as measured using a sequence comparison algorithm or by visual inspection. In one exemplary embodiment, the sequences are high percent identical over the entire length of the polynucleotide or polypeptide sequences.

[0038] The term “swine” can generally refer to any member of the Suidae family and includes domesticated and wild pigs, hogs and boars.

[0039] A “vaccine” is herein defined as a biological agent capable of providing a protective response in an animal to which it has been delivered but not capable of causing a serious disease. Administration of the vaccine results in immunity from the disease. Thus, the vaccine stimulates antibody production or cellular immunity against the disease-causing pathogen (e.g., ASFV). Immunity is herein defined as the induction of significantly higher levels of protection against lethality and clinical symptoms following vaccination in a swine population, as compared to the non-vaccinated group. In particular, the vaccine according to the invention protects most of the vaccinated animals against the development of clinical symptoms and lethality of the disease. The vaccine of the present disclosure is typically a genetically engineered (recombinant) mutant virus vaccine.

[0040] In the context of the present disclosure, the term "non-deficient in its replication" refers to a non-naturally occurring recombinant ASFV which is able to replicate *in vitro* and/or *in vivo* and/or is capable of producing viral progeny although such replication and/or viral progeny production may also occur at reduced levels compared to the unmodified parent strain.

Therefore, it can be the case that such ASFV is non deficient in its replication *in vitro*, e.g. in a cell culture, although *in vivo* in a mammal such ASFV is at least partially impaired in its replication, e.g. resulting in a replication and/or viral progeny production below detection limits.

[0041] As used herein, the term "minimal dose" or "minimal effective dose" refers to a dose that demonstrates the absence of, or minimal presence of, toxicity to the recipient, but still results in producing a desired result (e.g., protective immunity).

[0042] Viruses / Vaccines

[0043] Provided herein is a novel mutant ASFV-G virus (SEQ ID NO: 1), resulting from the recombinant deletion of a portion of the I177L gene of the parental ASFV-G genome (described in U.S. Pat. App. No. 16/580,058) and deletion of an approximately 9kb genomic region. The genomic nucleotide sequence of a specific recombinant mutant ASFV-G Δ I177L (SEQ ID NO: 1) is described herein and differs from the genomic nucleotide sequence encoding the parental ASFV-G.

[0044] The exemplary mutant strain of ASFV-G (SEQ ID NO: 1) is representative of the genus of recombinant vaccines in which the cell line adaptation mutation is present, which includes, without limitation, deletion mutants, nonsense mutants, insertional mutants, frameshift mutants and other mutants resulting in deletion, non-functionality, and non-expression of the various ORFs within the mutation (SEQ ID NO: 2). An exemplary virus disclosed herein also has a non-functional I177L ORF, but other recombinant viruses

envisioned include mutants in other ORFs, including regulatory elements for those ORFs resulting in non-expression or non-translation of their respective proteins. Such variants can be in the ASFV-G wild type genomic background (SEQ ID NO: 3).

[0045] Modifications intended to preclude functional expression of a target protein or reduced expression or reduced activity of a target protein can involve mutations of the DNA or gene encoding the target protein, including deletion of all or a portion of a target gene, including but not limited to the open reading frame of a target locus, transcriptional regulators such as promoters of a target locus, and any other regulatory nucleic acid sequences positioned 5' or 3' from the open reading frame, insertion of premature stop codons in the open reading frame, and insertions or deletions that shift the reading frame leading to premature termination of translation. Such deletional mutations can be achieved using any technique known to those of skill in the art. Reduced levels of the target protein or reduced activity of the target protein may also be achieved with point mutations or insertions in the DNA or gene encoding the target protein. Mutational, insertional, and deletional variants of the disclosed nucleotide sequences and genes can be readily prepared by methods which are well known to those skilled in the art. Techniques used to achieve reduced levels and/or reduced activity of the target protein may include CRISPR/Cas, TALEN, and Zn-finger nuclease. It is well within the skill of a person trained in this art to make mutational, insertional, and deletional mutations which are equivalent in function to the specific ones disclosed herein.

[0046] The approaches described herein that were used to create a deletion mutant in ASFV-G can be used in different isolates of ASFV (such as isolates circulating in Asia, Europe or Africa), including naturally occurring and recombinant strains. Such approaches can be varied by methodologies known in the art, such as using different selection markers that can select

recombinant virus by purification such as, but not limited to, fluorescent proteins, enzymes such as beta-glucuronidase or beta-galactosidase that can be used with chromogenic substrates, and drug selection makers. Such approaches can also be used to create any mutation to any of the individual ORFs within the larger mutation described herein. For example, any single ORF selected from MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, or MGF360-11L, as well as to regulatory elements controlling the expression and translation of these ORFs that results in a non-functional protein produced by that ORF. For all usages herein, the nomenclature utilized for these ORFs will be recognized by the skilled artisan as utilizing the standard names for these ASFV ORFs.

[0047] Mutants in other ASFV strains and genotypes is also encompassed by the present disclosure. ASFV strains comprising synthetic mutations in nucleic acid sequences that exhibit at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity to SEQ ID NO: 2 are encompassed in the instant invention. ASFV strains comprising entire genomes with 95%, 96%, 97%, 98%, 99% or higher identity to SEQ ID NO: 1 are also encompassed in the instant invention.

[0048] The present disclosure further contemplates the combination of a cell-line adaptation mutation with other recombinant mutations. As such, it is not only wild-type viruses that can be modified as disclosed herein, but also strains containing non-naturally occurring mutations in other genes or genomic regions (see, e.g., U.S. Pat. No. 9,814,771).

[0049] The present disclosure provides that such rationally-designed, live, attenuated ASFV-G mutants can be incorporated into immunogenic compositions to produce a vaccine effective to protect an animal, such as a pig, from clinical ASF disease when challenged with ASFV-G. Thus, one object of the invention is to provide a method for protecting an animal against

ASFV-G by administering an effective amount of rationally designed live attenuated vaccine. In another embodiment, the present disclosure provides a method for eliciting a protective immune response in an animal, preferably of the family Suidae (e.g., domestic pigs (*Sus scrofa domesticus*), wild pigs (*Sus scrofa scrofa*), warthogs (*Potamochoerus porcus*), bushpigs (*Potamochoerus larvatus*), giant forest hogs (*Hylochoerus meinertzhageni*) as well as feral pigs), Such methods will typically comprise administering to such animal the one or more ASFV immunogenic compositions and vaccines described herein.

[0050] The immunogenically effective amounts of immunogenic compositions disclosed herein can vary based upon multiple parameters. In general, however, effective amounts per dosage unit for intramuscular application can be about 10^2 50% hemadsorption dose (“HAD₅₀”) to 10^6 HAD₅₀. One, two, or more dosage units can be utilized in practicing the methodologies of the present invention. A dosage unit can readily be modified to fit a desired volume or mass by one of skill in the art. Regardless of the dosage unit parameters, immunogenic compositions disclosed herein can be administered in an amount effective to produce an immune response.

[0051] Dosage levels of active ingredients in vaccines disclosed herein, can be varied by one of skill in the art to achieve a desired result in a subject or per application. As such, a selected dosage level can depend upon a variety of factors including, but not limited to, formulation, combination with other treatments, severity of a pre-existing condition, and the presence or absence of adjuvants. In preferred embodiments, a minimal dose of an immunogenic composition is administered. Determination of a minimal dose is well within the capabilities of one skilled in the art.

[0052] Vaccines of the present invention can be prepared by conventional methods used for commercially available live attenuated ASFV vaccines. In a specific embodiment, a susceptible

substrate is inoculated with an ASFV mutant disclosed herein and propagated until the virus has replicated to a desired titer after which ASFV -containing material is harvested. Following this, the harvested material can be formulated into a vaccine preparation with immunogenic properties. Every substrate which is able to support the replication of the recombinant viruses provided herein can be used in the present invention, including primary cultures of swine peripheral blood macrophages or blood from infected swine.

[0053] Virus replication and production in stable cell lines

[0054] The vaccines provided herein containing a cell line adaptation mutation of the present disclosure replicate and grow at increased rates in stable cell lines compared to viruses lacking the mutation. ASFV-G-I177L can grow increasing titer 4-5 logs in swine macrophages (over 3-5 days), however was unable to grow in stable cell lines tested. When the adaptation mutation was added to the vaccine, the vaccine could grow to comparable rates to the parental vaccine in macrophages increasing the titer of the vaccine 4-5 logs (over 3-6 days).

[0055] Formulations and Administration

[0056] A vaccine provided herein comprises one of the recombinant viruses as defined above in a live form, and a pharmaceutically acceptable carrier or diluent customarily used for such compositions. Carriers include stabilizers, preservatives and buffers. Suitable stabilizers include, for example, SPGA (sucrose, phosphate, glutamate and albumin), carbohydrates (sorbitol, mannitol, starch, sucrose, dextran, glutamate, and glucose), proteins (dried milk, serum, albumin, casein), or degradation products thereof. Suitable buffers include, for example alkali metal phosphates. Preservatives that can be utilized, include, but

are not limited to, thimerosal, merthiolate and gentamicin. Diluents include water, aqueous buffers (e.g., buffered saline), alcohols and polyols (e.g., glycerol).

[0057] In some instances, vaccines of the present invention also contain or comprise one or more adjuvants, which includes any material included in the immunogenic composition formulation that enhances an immune response in the recipient that is induced by the immunogenic composition. In some instances, such adjuvants can include proteins other components included with the recombinant virus. Other adjuvants can be included as an extra component of the immunogenic compositions, and include such categories as aluminum salts (alum), oil emulsions, saponins, immune-stimulating complexes (ISCOMs), liposomes, microparticles, nonionic block copolymers, derivatized polysaccharides, cytokines, and a wide variety of bacterial derivatives. Any relevant adjuvant known in the art can be utilized in practicing the inventions disclosed herein. Factors influencing the selection of an adjuvant include animal species, specific pathogen, antigen, route of immunization, and type of immunity needed and can be readily determined by one of skill in the art.

[0058] Immunogenic compositions of the present disclosure can also comprise carriers in addition to the recombinant virus. Carriers utilized in practicing the immunogenic compositions provided herein can be any known in the art and can be liquid, solid, semi-solid, or gel. The type of formulation can be modified depending on the route of administration of the antigen. Preferably, carriers are non-toxic to the recipient. One of skill in the art is readily able to choose such carriers for application to recipient animals such as poultry.

[0059] Vaccines provided herein may be administered by intramuscular, subcutaneous, intranasal or injection in an amount which is effective to protect the animal against challenge by a virulent strain of ASFV. The vaccine may be administered orally, through

direct oral inoculation, dosed in drinking water, or through bait delivery systems. The effective amount of recombinant virus may vary according to parameters considered by those skilled in the art. Effective amounts can be experimentally determined as necessary by those of skill in the art by following any known method or the guidance provided in the Examples herein.

[0060] Having generally described this invention, the same will be better understood by reference to certain specific examples, which are included herein to further illustrate the invention and are not intended to limit the scope of the invention as defined by the claims.

EXAMPLES

[0061] Example 1

[0062] Cell Culture and Viruses.

[0063] Primary cultures of swine macrophage were prepared from swine blood, following procedures previously described (O'Donnell et al, (2015b), *supra*) Preparation of macrophage cultures in 96-well plates for virus titration also was performed as previously described (O'Donnell et al, (2015b), *supra*).

[0064] Porcine Epithelial Cells (PEC) are a cell subclone derived after over 60 passages from the parental LFPK $\alpha_v\beta_6$ cell line, a porcine fetal kidney cell line engineered to express bovine $\alpha_v\beta_6$ integrin (U.S. Pat. No. 9,121,010). Cell cultures were passaged in culture using DMEM medium (Life Technologies, Grand Island, NY) with 10% heat-inactivated fetal bovine serum (HI-FBS; Thermo Fisher Scientific, Waltham, MA) and 1% antibiotic-antimycotic (Thermo Fisher Scientific) at 37°C under 5% CO₂.

[0065] ASFV-G-ΔI177LΔLVR (SEQ ID NO: 1) was generated after sequential passages of the live attenuated vaccine candidate strain ASFV-G-ΔI177L (U.S. Pat. App. No. 16/580,058) as described below.

[0066] Comparative growth curves between ASFV-G-ΔI177L (parental strain) and ASFV-G-ΔI177LΔLVR (SEQ ID NO: 1) were performed in primary swine macrophage and stable porcine cell cultures. Preformed monolayers were prepared in 24-well plates and infected at an MOI of 0.01 (based on the HAD₅₀ previously determined in primary swine macrophage cell cultures). After 1 h of adsorption at 37°C under 5% CO₂, the inoculum was removed, and the cells were rinsed two times with PBS. The monolayers were then rinsed with macrophage medium and incubated for 2, 24, 48, 72, and 96 h at 37°C under 5% CO₂. At appropriate times post-infection, the cells were frozen at <−70°C, and the thawed lysates were used to determine titers by HAD₅₀/ml in primary swine macrophage cell cultures. All samples were run simultaneously to avoid intraassay variability.

[0067] Virus titration was performed on primary swine macrophage cell cultures in 96-well plates. Virus dilutions and cultures were performed using macrophage medium. The presence of virus was assessed by hemadsorption (HA), and virus titers were calculated by the Reed and Muench method (Reed & Muench, Am. J. Hygiene, (1938), 27:493-497). ASFV Georgia (ASFV-G) used in the animal challenge experiments is a field isolate kindly provided by Nino Vepkhvadze from the Laboratory of the Ministry of Agriculture (LMA) in Tbilisi, Republic of Georgia. ASFV DNA was extracted from infected cells and quantified as described earlier. The full-length sequence of the virus genome was determined as described previously (Borca et al, Sci. Rep., (2018), 8:3154) using an Illumina NextSeq 500 sequencer.

[0068] Example 2

[0069] Cell line mutation and adaptation.

[0070] ASFV-G Δ I177L did not significantly replicate in more than 30 cell lines tested in our laboratory, including commercially available cell lines of swine origin. In most of the cases only the initial replication steps, evidenced by presence of intracellular expression of fluorescence due to the expression of the recombinant RFP present in the ASFV-G Δ I177L genome, were perceived with minor or no virus yield detected (data not shown).

[0071] ASFV-G Δ I177L after 6 successive passages in stable porcine cell line cells showed a clear cytopathic effect occurring. The first passage of ASFV-G- Δ I177L was performed using a MOI of 10. By passage six, ASFV-G- Δ I177L yield reached a titer of approximately 10^5 HAD₅₀/ml. Further successive passages reached virus yields of approximately 10^7 HAD₅₀/ml (**FIG. 1**).

[0072] Assessment of genomic changes accompanying the passage of ASFV-G- Δ I177L (ASFV-G- Δ I177L Δ LVR) was performed in virus obtained after the sixth passage by next-generation sequencing (NGS). Compared to parental virus, a deletion occurred between positions 16818 and 27660 of the viral genome, resulting in a deletion of 10842bp. This genomic modification fully deletes the following genes: MGF360-6L, X69R, MGF300-1L, MGF300-1L, MGF300-2R, MGF300-4L, MGF360-8L, MGF360-9L, and MGF360-10L. In addition, the genomic modification also causes the deletion of the N-terminal portion of MGF 360-4L gene, and the C-terminus of MGF360-11L gene (**FIG. 2**). This deletion results in the creation of a novel hybrid protein, MGF360-4l/11L. This resulting ORF, which resides on the reverse coding strand, has 839nt of MGF-360-11L combined with 592nt MGF-360-4L. The resulting ORF is composed by 1432nt that encodes a novel 476 amino acid protein (SEQ ID NO: 4).

[0073] The genomic stability of ASFV-G- Δ I177L Δ LVR was further assessed in the population of virus obtained after passage twenty and passage thirty. Surprisingly, NGS analysis demonstrated no major additional genomic changes when compared with the genome of the virus obtained after the sixth passage. This result indicates that the viral genome of ASFV-G- Δ I177L Δ LVR remains stable with continuous passage in the stable porcine cell line cells.

[0074] *Replication of ASFV-G- Δ I177L Δ LVR in primary swine macrophages.*

[0075] The goal of developing aptASFV-G- Δ I177L is to use it as vaccine strain. Therefore, it is important to assess its ability to replicate in swine macrophages, the primary cell targeted by ASFV during infection in swine. Then, the *in vitro* growth characteristics of ASFV-G- Δ I177L Δ LVR were evaluated in primary swine macrophage cell cultures in a multistep growth curve. Two different passages of ASFV-G- Δ I177L Δ LVR in PEC, the sixth and twelfth passages, were tested. Cell cultures were infected at a multiplicity of infection (MOI) of 0.01, and samples were collected at 2h, and every 24hours for the next 6-8 days after infection. The results demonstrated that both strains of ASFV-G- Δ I177L Δ LVR displayed a similar growth kinetic compared to that of parental ASFV-G- Δ I177L (**FIG. 1**). Therefore, the ability of ASFV-G- Δ I177L Δ LVR to grow in stable porcine cell line cells does not affect the ability of ASFV-G- Δ I177L Δ LVR to replicate *in vitro* in primary swine macrophage cell cultures.

[0076] Example 3

[0077] Animal Experiments

[0078] Animal experiments were performed under biosafety level 3-Agriculture (3-AG) conditions in the animal facilities at Plum Island Animal Disease Center (PIADC) following a protocol approved by the PIADC Institutional Animal Care and Use Committee of the U.S.

Department of Agriculture and U.S. Department of Homeland Security (protocol number 225.04-16-R, 09-07-16).

[0079] To evaluate if changes in the genome of ASFV-G-ΔI177LΔLVR produced any alteration in the attenuated phenotype of the parental virus, ASFV-G-ΔI177L, a group of 80- to 90-pound pigs were inoculated via intramuscularly (IM) with a high dose, 10^6 hemadsorbing doses (HAD₅₀), and the clinical evolution of the animals were observed for a 28 day period. The five animals inoculated did not present with any ASF-related signs, remaining clinically normal during the entire observation period indicating that ASFV-G-ΔI177LΔLVR remains completely attenuated (Table 1). Therefore, ASFV-G-ΔI177LΔLVR maintains the complete attenuation phenotype of the parental virus.

Table 1. Swine survival and fever response following infection with different doses of ASFV-G-ΔI177LΔLVR.

Virus and dose (HAD ₅₀) ⁽¹⁾	No. of survivors/total	Mean time to death (days ± SD)	Fever		
			No. of days to onset (days ± SD)	Duration No. of days (days ± SD)	Maximum daily temp (°F ± SD)
ASFV-G-ΔI177LΔLVR 10^6	5/5	-	-	-	103 (0.64)
ASFV-G-ΔI177LΔLVR 10^2	5/5	-	-	-	103.8 (1.04)
ASFV-G-ΔI177LΔLVR 10^4	5/5	-	-	-	103.2 (1.68)
ASFV-G-ΔI177LΔLVR 10^6	5/5	-	-	-	102.9 (0.46)

[0080] *Protective efficacy of ASFV-G-ΔI177L against challenge with parental ASFV-G*

[0081] To assess the ability of ASFV-G-ΔI177LΔLVR infection to induce protection against challenge with highly virulent parental virus ASFV-G, all animals infected with ASFV-G-

Δ I177L Δ LVR were challenged 28 days later with 10^2 HAD₅₀ of ASFV-G by the IM route. An additional group of five naive animals were challenged as a mock-inoculated control group. All mock animals started showing disease-related signs by 3 to 4 days post challenge (dpc), with rapidly increasing disease severity in the following hours; they were euthanized around 5 dpc (**Table 2**). On the other hand, the group of animals infected with ASFV-G- Δ I177L Δ LVR remained clinically healthy, not showing any significant signs of disease during the 21-day observational period. Therefore, ASFV-G- Δ I177L Δ LVR-treated animals are protected against clinical disease when challenged with the highly virulent parental virus.

[0082] In order to quantify the effectivity of ASFV-G- Δ I177L Δ LVR in protecting swine against the challenge with the parental virulent ASFV-G, three groups of pigs were IM inoculated with either 10^2 , 10^4 or 10^6 HAD₅₀ of ASFV-G- Δ I177L Δ LVR, respectively. All animals remained clinical normal during the 28-day period before they were challenge IM with 10^2 HAD₅₀ of parental virulent ASFV-G. Animals were observed for 21 days. All animals remained clinically normal after the challenge without showing any ASF clinical related sign (**Table 2**). Therefore, ASFV-G- Δ I177L Δ LVR efficacy is comparable to that reported for ASFV-G- Δ I177L (U.S. Pat. App. No. 16/580,058).

Table 2. Swine survival and fever response in ASFV-G- Δ I177L Δ LVR-infected animals challenged with parental ASFV-G virus.

Virus and dose (HAD ₅₀)	No. of survivors/total	Mean time to death (days $\pm$ SD)	Fever		
			No. of days to onset (days $\pm$ SD)	Duration No. of days (days $\pm$ SD)	Maximum daily temp (°F $\pm$ SD)
ASFV-G- Δ I177L Δ LVR 10^6	5/5	-	-	-	103 (0.59)

ASFV-G-ΔI177LΔLVR 10 ²	5/5	-	-	-	103 (0.29)
ASFV-G-ΔI177LΔLVR 10 ⁴	5/5	-	-	-	103 (0.28)
ASFV-G-ΔI177LΔLVR 10 ⁶	5/5	-	-	-	
ΔI177L (10 ²)	5/5	-	-	-	102.7 (0.44)
Mock	10/10	-	-	-	102.8 (0.52)

[0083] Example 4

[0084] Recombinant virus construction

[0085] Recombinant ASFV lacking one or more genes have been produced by us and other laboratories. A donor plasmid is made containing flanking arms of identical DNA (typically 1000bp) of both sides of the area that is targeted for deletion, between these two arms is a reporter cassette (i.e. GFP, RFP) that allows for selection of the recombinant ASFV. Introduction of this plasmid into virally infected cells allows for exchange of the donor plasmid for ASFV DNA. This occurs specifically in the homologous DNA arms. Examples of this deleting individual genes I177L, 9GL, UK (O'Donnell et al, (2015b), *supra*; O'Donnell et al, (2017), *supra*; Borca et al; (2020), *supra*) or deleting multiple MGF genes (O'Donnell et al, (2015a), *supra*). **FIG. 3** shows a schematic of how this could be done, making the exact deletion of the ΔLVR in the ASFV-G genome in 4A and a partial deletion in the ΔLVR region deleting only 3 genes MGF3001L, 2R, 4. The same methodology can be applied to delete any gene or any group of genes in the cell line adaptation mutation region (SEQ ID NO: 2) or other parts of the genome. Selection and screening of recombinant viruses can be performed as described herein, or by any means known in the art.

[0086] While the invention has been described with reference to details of the illustrated embodiments, these details are not intended to limit the scope of the invention as defined in the

appended claims. The embodiments of the disclosure in which exclusive property or privilege is claimed is defined as follows:

CLAIMS

WHAT IS CLAIMED IS:

1. A genetically modified virus, wherein the virus genome comprises a viral genome at least 95% identical to SEQ ID NO: 1.
2. The virus of claim 1, wherein the viral genome comprises SEQ ID NO:1.
3. A vaccine composition against African Swine Fever Virus (ASFV), comprising the genetically modified virus of claim 1.
4. The vaccine composition of claim 3, wherein the ASFV is ASFV-Georgia 2007 isolate (ASFV-G).
5. A method for the protection of swine against ASFV, comprising administering to a swine a live attenuated vaccine comprising the genetically modified virus of claim 1 in an amount effective to protect said swine from clinical ASFV disease.
6. The method of claim 5, wherein the ASFV is ASFV-G.
7. The method of claim 5, wherein the amount effective to protect said swine from clinical ASFV disease is a vaccine comprising 10^2 - 10^6 HAD₅₀ of the genetically modified virus of claim 1.
8. A recombinant ASFV mutant virus, a deletion, or partial deletion of each of ORFs MGF360-4L, MGF360-6L, X69R, MGF300-1L, MGF300-2R, MGF300-4L, MGF3608L, MGF360-9L, MGF360-10L, MGF360-11L.
9. The recombinant virus of claim 8, wherein the virus comprises a deletion of a genomic fragment at least 95% identical to SEQ ID NO:2.
10. The recombinant virus of claim 8, wherein the mutant ASFV is an ASFV-Georgia isolate.

11. The recombinant virus of claim 8, wherein the mutant ASFV comprises a genome at least 99% identical to SEQ ID NO: 1.
12. A vaccine composition against ASFV-G, comprising the recombinant virus of claim 8.
13. A method for the protection of swine against ASFV, comprising administering to a swine a live attenuated vaccine comprising the recombinant virus of claim 8 in an amount effective to protect said swine from clinical ASFV disease.
14. The method of claim 13, wherein the ASFV is ASFV-G.
15. The method of claim 14, wherein the amount effective to protect said swine from clinical ASFV disease is a vaccine comprising 10^2 - 10^6 HAD₅₀ of the genetically modified virus of claim 8.
16. A method of producing ASFV at titers of 10^4 - 10^7 HAD₅₀/mL in a cultured stable cell line, comprising inoculating the virus of claim 1 into said cultured stable cell line; incubating the inoculated cell line under conditions allowing for viral replication, and; growing said viruses to a titer of 10^4 - 10^7 HAD₅₀/mL.
17. The method of claim 16, wherein the stable cell line is a porcine fetal kidney cell line engineered to express bovine $\alpha v \beta_6$ integrin.
18. The method of claim 16, wherein the ASFV virus genome comprises a viral genome at least 99% identical to SEQ ID NO: 1.