(19) DANMARK

(10) DK/EP 3732293 T3

(12) Oversættelse af europæisk patentskrift

Patent- og Varemærkestyrelsen

(51) Int.Cl.: *A 61 K 39/00 (2006.01)* *A 61 K 39/12 (2006.01)* *A 61 P 31/14 (2006.01)* *A 61 P 31/16 (2006.01)* *C 12 N 15/81 (2006.01)*

(45) Oversættelsen bekendtgjort den: **2024-09-23**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2024-07-03**

(86) Europæisk ansøgning nr.: **18857443.8**

(86) Europæisk indleveringsdag: **2018-12-19**

(87) Den europæiske ansøgnings publiceringsdag: **2020-11-04**

(86) International ansøgning nr.: **DE2018000379**

(87) Internationalt publikationsnr.: **WO2019129321**

(30) Prioritet: **2017-12-27 DE 102017012109**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **OPTIMERET VÆRT/VEKTOR-SYSTEM TIL FREMSTILLING AF BESKYTTENDE MONO- OG MULTIVALENTE SUBUNIT-VACCINER BASERET PÅ GÆREN KLUYVEROMYCES LACTIS**

(56) Fremdragne publikationer:
WO-A1-2013/107436
WO-A2-2010/054649
JORRIT-JAN KRIJGER ET AL: "A novel, lactase-based selection and strain improvement strategy for recombinant protein expression in Kluyveromyces lactis, art 112", MICROBIAL CELL FACTORIES,, Bd. 11, Nr. 1, 20. August 2012 (2012-08-20), Seiten 1-12, XP021128994, ISSN: 1475-2859, DOI: 10.1186/1475-2859-11-112
ARNOLD MARINA ET AL: "Protective Vaccination against Infectious Bursal Disease Virus with Whole Recombinant Kluyveromyces lactis Yeast Expressing the Viral VP2 Subunit", PLOS ONE, PUBLIC LIBRARY OF SCIENCE , Bd. 7, Nr. 9 1. September 2012 (2012-09-01), Seiten e42870.1-e42870.11, XP002695514, ISSN: 1932-6203, DOI: 10.1371/JOURNAL.PONE.0042870 Gefunden im Internet: URL:http://www.plosone.org/article/info%3A doi%2F10.1371%2Fjournal.pone.0042870 [gefunden am 2012-09-14]
TAKAKO IWATA ET AL: "Efficient secretion of human lysozyme from the yeast, Kluyveromyces lactis", BIOTECHNOLOGY LETTERS, SPRINGER NETHERLANDS, DORDRECHT, Bd. 26, Nr. 23, 1. Dezember 2004

Fortsættes ...

(2004-12-01), Seiten 1803-1808, XP019230808, ISSN: 1573-6776, DOI: 10.1007/S10529-004-4614-9
MUSTILLI A C ET AL: "Comparison of secretion of a hepatitis C virus glycoprotein in Saccharomyces cerevisiae and Kluyveromyces lactis", RESEARCH IN MICROBIOLOGY, ELSEVIER, AMSTERDAM, NL, Bd. 150, Nr. 3, 1. April 1999 (1999-04-01) , Seiten 179-187, XP027033495, ISSN: 0923-2508 [gefunden am 1999-04-01]
CONSTANCE MEHLGARTEN ET AL: "Divergent Evolution of the Transcriptional Network Controlled by Snf1-Interacting Protein Sip4 in Budding Yeasts", PLOS ONE, Bd. 10, Nr. 10, 1. Juni 2015 (2015-06-01), Seite e0139464, XP055587956, DOI: 10.1371/journal.pone.0139464
ALBERT J.J. VAN OOYEN ET AL: "Heterologous protein production in the yeast Kluyveromyces lactis", FEMS YEAST RESEARCH, Bd. 6, Nr. 3, 1. Mai 2006 (2006-05-01), Seiten 381-392, XP055529474, GB, NL ISSN: 1567-1356, DOI: 10.1111/j.1567-1364.2006.00049.x

Optimized host/vector system for producing protective mono- and multivalent *subunit* vaccines on the basis of the yeast *Kluyveromyces lactis*

Field of the invention

The invention relates to recombinant *Kluyveromyces lactis* (*K. lactis)* yeasts which are fit for highly efficient expression of one or more foreign proteins and are suitable for use as vaccine for the generation of a protective immune response against pathogens. The invention provides in particular *K. lactis* strains for targeted cloning of foreign antigen-encoding nucleic acids into the yeast genome of the *K. lactis* strain, which is characterized in that the *K. lactis* strain has integrated expression cassettes for foreign antigens at the *KlURA3-20* locus (*KLLA0E22771g*) and/or at the *KlMET5-1* locus (*KLLA0B03938g*) in addition to the *KlLAC4* locus. The invention furthermore relates to integrative expression vectors and methods for generating the *K. lactis* strains of the invention and to the use thereof as vaccines.

Background of the invention

Vaccines are used for preventing diseases (preventive vaccines) or for treating established diseases (immunotherapeutic vaccines). In the last 100 years or so, preventive vaccination programs have substantially contributed to reducing infectious diseases. Immunotherapeutic vaccines, for instance against persistent infections with viruses, bacteria or parasites or against carcinogenic diseases, have only been developed and used for about 20 years. The goal of vaccination is the induction of a cellular (i.e., essentially T cell and NK cell-mediated) and/or humoral (i.e., essentially B cell/antibody-mediated) immune response and of an immunological memory against antigenic components of pathogens or malignant (tumorigenic) cells.

Classic vaccines contain the entire pathogen in attenuated (inactivated) or killed form, including the genetic material thereof, i.e., nucleic acids in the form of DNA or RNA. To be produced, said classic vaccines usually require special safety precautions and/or the use of infectable organisms and/or of cell cultures; moreover, said vaccines often require storage and transport that is complex and involves the use of cold chains. In addition, the use of classic vaccines involves the danger of substances from the production process (e.g., from the test animal or from the cell culture) causing adverse effects in the vaccinated individual or of the pathogen being undesirably reactivated.

Problems exist in diagnostics too: for example, in the case of the vaccination of useful animals with complete pathogens, vaccinated animals cannot be differentiated from naturally infected animals, meaning that early warning systems based on the detection of new infections are unusable. So-called "subunit vaccines", which only vaccinate with defined components of the pathogen, were therefore developed. A prerequisite for the use thereof is that "major antigens" of the pathogen in question are known. Major antigens are usually surface constituents of the pathogen that can be recognized by the immune system, for example proteins of a viral shell or of a viral capsid. In the absence of a complete virus particle, said major antigens can also induce a humoral and/or cellular immune response and an immunological memory in the host against the virus. Since further constituents of the pathogen are missing in "subunit vaccination", vaccinated individuals can be differentiated from naturally infected individuals by a differential diagnosis (Differentiating Infected from Vaccinated Animals (DIVA)); accordingly, reference is also made to a "subunit marker vaccine". Disadvantages of many subunit vaccines are an often complex production process and an often inadequate immunogenicity: whereas the pathogens themselves can be cultured efficiently (with the above-stated limitations), the major antigens thereof must be produced by gene technology by means of cost-intensive and usually inefficient methods and purified in a complex manner. Subunit vaccines thus obtained are accordingly biological material which has a short shelf life and must often be stored and transported in a cool state. For these reasons, most mass vaccines for useful animals are still based on the classic principle, which uses complete pathogens.

For example, the widespread poultry disease infectious bursal disease (IBD) is triggered by the infectious bursal disease virus (IBDV), a nonenveloped virus having a double-stranded, segmented RNA genome from the *Birnaviridae* family. Most vaccines against IBD are based on attenuated (weakened) or inactivated viruses. However, the problem that arises here is that, although highly attenuated non-inactivated "live viruses" and also inactivated viruses offer protection against IBD viruses of average pathogenicity, this is not the case for very virulent IBD virus strains (vvIBDV). Until recently, very virulent, attenuated viruses (intermediate hot strains) were protective against vvIBDV – these vaccine strains have, however, adverse effects in the form of the possible occurrence of immunosuppression due to transient damage to the B cells in the *Bursa fabricii*, a lymphatic organ (Rautenschlein *et al.* (2005)). However, even said intermediate hot vaccines do not offer complete protection against recently

discovered vvIBDV strains (Negash *et al.* (2012); Kasanga *et al.* (2007)). Moreover, a problem of vaccination with highly attenuated live viruses is that maternal antibodies prevent virus replication and hence the induction of an immune response. Therefore, an effective vaccination with these vaccines is only possible three weeks after hatching (Kumar *et al.* (2000); Rautenschlein *et al.* (2005)).

For example, influenza A viruses are among the most important virus pathogens worldwide (Short *et al.* (2015); Silva *et al.* (2012)). Influenza viruses belong to the *Orthomyxoviridae* family; they are enveloped viruses having single-stranded, segmented RNA as the genome. Like most RNA viruses, influenza viruses are also subject to a high mutation rate. Especially the reassortment of viral RNA segments gives rise to viral descendants having new genetic and biological properties (Short *et al.* (2015)). Owing to the rapid evolution, the problem that arises in particular in the case of vaccinations against influenza viruses is that existing vaccines do not "catch hold" in the case of newly emerged virus variants. Accordingly, attempts have already been made for a long time to develop vaccines which exhibit cross-protection and hence also long-term protection against different influenza variants (Steel *et al.* (2010); Krammer and Palese (2013); Kirchenbaum and Ross (2014); Berthoud *et al.* (2011)).

The bovine viral diarrhea virus (BVDV) is a widespread pathogen of even-toed ungulates. BVDV is a member of the Pestivirus genus of the *Flaviviridae* family. The single-stranded RNA genome of these viruses is likewise subject to a high mutation rate. Moreover, in the case of pregnant animals, the fetus can become infected, and persistently infected (PI) animals are then born owing to the immunotolerance. Said PI animals spread the virus further and can, in the case of 100% virus mutation, die from so-called mucosal disease. Here too, attempts have already been made for a long time to develop vaccines which exhibit cross-protection and long-term protection against different BVD virus variants (Ridpath (2015)).

Effective subunit vaccines can address or solve these problems. In most cases, subunits are protein components of pathogens; they can be produced by gene technology in various host cells. Besides the gut bacterium *Escherichia coli*, mammalian cells or insect cells that can be propagated in cell cultures, plant cells and various fungi have been established as host systems for heterologous protein

expression. Microbial systems such as bacteria and fungi can be cultivated particularly cost-effectively on a large scale.

Yeast cells of the yeast genera *Saccharomyces, Pichia* and *Kluyveromyces* have already been used routinely for decades for expressing foreign proteins. In contrast to bacteria, yeast cells have the advantage that they are eukaryotes, i.e., they resemble animal cells in many aspects, and eukaryotic proteins, i.e., proteins which are formed in animal cells and/or must be functional, can be produced cost-effectively in yeasts in native or virtually native form (Bathurst (1994); Gellissen & Hollenberg (1997)). Yeasts were initially only used for producing the foreign proteins; after expression, the proteins were purified from the yeast cells and used as subunit vaccines. Attempts have only recently been made to administer yeasts themselves or cell fractions of the yeasts as vaccines. “Yeast-based vaccines” are accordingly yeast particles which contain immunologically effective components of pathogens (antigens) and which, after administration (e.g., subcutaneous, intramuscular or oral/mucosal), can trigger in the host organism a specific immune response against said antigens and hence also against the pathogen from which said antigens originate. What is desired is induction in the vaccinated organisms of an immunological “memory” which, in the event of a subsequent infection (“challenge”), prevents multiplication and/or spreading of the corresponding pathogens and/or reduces the pathological effects of the infection. As already addressed above, the antigens are usually structural proteins of the pathogen, the encoding nucleic acid sequences (antigen-encoding genes) of which are introduced into yeast cells using gene-technology methods and allow the expression of one or more of such structural proteins. The thus generated recombinant yeasts in live form (yeast cells), in powder form after killing and drying (yeast particles) or after cell disruption and homogenization (yeast lysate) are yeast-based vaccines. After administration of the vaccines, the antigens are recognized by the immune system and cause a humoral and/or cellular immune defense.

Yeast-based vaccination is known to a person skilled in the art from the prior art. A range of US patent applications and patents, for example US 20090304741 A1, US 5830463 A, US 7465454 B2 and US 20070166323 A1, describe the use of *Saccharomyces cerevisiae* (*S. cerevisiae)* strains containing at least one recombinant antigen in immunotherapy. It was shown that these yeasts are effective for stimulating an immune reaction, especially a cell-mediated immune reaction.

WO 2006044923 discloses yeasts (*S. cerevisiae)* which recombinantly express various proteins of the hepatitis C virus (HCV) and which can trigger an immune reaction, especially a T cell response, against said HCV proteins and are intended to be used as vaccine against chronic hepatitis C.

WO 2007092792 describes the possible use of recombinant *S. cerevisiae* yeasts against influenza virus infections, involving use of a combination of various yeast strains, the administration of which leads to an induction of T cells, i.e., to a cellular immune response.

WO 20101054649 and WO 2013107436 describe the use of strains of the species *Kluyveromyces lactis* containing defined antigens for generating a protective humoral immune response following oral/mucosal or subcutaneous administration of entire killed yeast cells. The last-mentioned patents contain application examples in which recombinant *K. lactis* strains derived from the starting strain VAK367-D4 were successfully used for vaccination.

The possibility of using recombinant *Kluyveromyces lactis* yeasts for vaccination is known to a person skilled in the art from the prior art: (Arnold *et al.* (2012)); WO 20101054649 and WO 2013107436). Application examples were able to show that the subcutaneous administration of the yeast *K. lactis* expressing the VP2 capsid protein of the infectious bursal disease virus (IBDV) intracellularly via an expression cassette controlled by the *LAC4* promoter triggers a humoral immune response which gives effective protection against virus infection. It was possible to show this for an IBD virus of average pathogenicity, but it has so far not been possible to show this against very virulent IBDV (vvIBDV). Earlier data showed that the effectiveness of a yeast vaccine can be increased by increasing the intracellular concentration of the viral antigen

(Arnold *et al.* (2012)). A technical variant for achieving an increase in antigen concentration consists in introducing an additional copy of the transcription activator gene *KlGAL4-1* (alias *LAC9-1*) into the IBDV-VP2-expressing strain (deposited strains DSM 25406 and DSM 25407) by means of integration of the pLI-1 plasmid (Krijger *et al.* (2012) and WO 2013107436). The generation of such *K. lactis* vaccine strains was thus hitherto based on two genetic interventions: firstly, on the integration of the antigen-encoding foreign gene and, secondly, on the integration of the *KlGAL4-1* gene. However, in the hitherto practiced form, the latter regularly also led to integration of tandem repeats of the plasmid, resulting not only in cytotoxic effects owing to the strong overexpression of the activator (Breunig 1989), but also in differing copy numbers for the *KlGAL4-1* and *ScURA3* genes in vaccine strains generated in this manner.

The strategy of performing the expression of the foreign gene via an unmodified *LAC4* promoter, as described in the abovementioned application examples (Arnold *et al.* (2012); WO 20101054649 and WO 2013107436), has the secondary effect that a minimal expression of the foreign gene occurs even under noninducing conditions, i.e., the promoter is open to a certain extent. When the *KlGAL4-1* gene dose is increased, this effect is much more pronounced once more. Accordingly, in the case of proteins having a cytopathic effect (CPE) on the yeast cell in the case of heterologous expression, biomass formation during cultivation, for example during a fed-batch fermentation process, can be severely limited. Specifically for these cases, alternative ways which minimize gene expression under noninducing conditions must be found.

Various subunit vaccines are only effectively effective when not just one, but multiple subunits of a pathogen are used for vaccination. Moreover, the use of multiple antigen subunits in vaccination can strongly increase cross-protectivity against different variants of a pathogen. The coexpression of the same or of different antigens can also be used to reincrease the antigen concentration in the yeast cell or to generate a vaccine which protects against different pathogens.

The above-discussed strains are generally auxotrophic strains which frequently grow more poorly in complete medium than prototrophic strains. Accordingly, a rapidly performable conversion of auxotrophic yeast strains into a prototrophic form can lead to improved growth properties.

Description of the invention:

The object of the invention was, then, to provide new *K. lactis* vaccine strains which can overcome the disadvantages of the prior art. In particular, what should be provided are recombinant *K. lactis* strains containing a limited copy number of the *KlGAL4-1* gene, integrated at a defined site in the genome. Moreover, what should be provided are strains which allow only slight expression of foreign protein or none under noninduced conditions, allow the expression of multiple copies of an antigen or the expression of multiple antigens in a yeast, which are better suited to cultivation and are usable more effectively for protective vaccination against pathogens. At the same time, heterologous genes encoding immunomodulatorily active proteins (antigens) should be integrated at defined sites of the *K. lactis* genome. In the case of selection of the searched clones having integration of foreign genes, no resistance genes should be used as selection markers. Moreover, prototrophic strains should be generated from auxotrophic strains via a simplest possible method. This should also allow the simplified fermentation of the generated yeast vaccine strains in nonsupplemented, synthetic medium.

These objects were achieved by providing a modular system which contains new vectors and new, genetically modified variants of the yeast *K. lactis* and which allows the generation of vaccine strains optimized for the specific properties of the protein antigens. Via a building block-type exchange of DNA elements between the vectors, an efficient, routine cloning of foreign antigen-encoding regions into the yeast genome was achieved, independent of the foreign gene to be expressed. As a result of the targeted genomic integration of the relevant foreign genes, the yeast strains are stable over very many generations and genetically exactly defined. Owing to these properties, fermentation processes proceed reproducibly under nonselective conditions and can be standardized. The optimization of the *K. lactis* yeasts according to the invention consisted in controlling the protein production rate such that it is as high as possible, but such that it is below a threshold at which cytopathic effects of the antigens severely interfere with the efficient fermentation process. This was achieved by a genetic intervention or by a combination of multiple genetic interventions:

i. the increase in the concentration of the lactose-inducible transcription activator,
ii. the targeted modification of the *LAC4* promoter, and/or
iii. the step-by-step increase in the gene dose for the antigen-encoding foreign gene.

Furthermore, the optimization of the *K. lactis* yeasts according to the invention consisted in:

iv. establishing multiple, new integration sites for foreign gene-encoding cassettes in the yeast genome in order to be able to express multiple antigens simultaneously.

In a preferred embodiment, the object of the invention is achieved by providing a *K. lactis* strain for targeted cloning of foreign gene-encoding nucleic acids into the yeast genome of the *K. lactis* strain, characterized in that the *K. lactis* strain has integrated expression cassettes for foreign antigens at the *KlURA3-20* locus (*KLLA0E22771g*) and/or at the *KlMET5-1* locus (*KLLA0B03938g*) in addition to the *KlLAC4* locus. It is particularly preferred when the *K. lactis* strain has integrated expression cassettes for foreign antigens at the *KlURA3-20* locus (*KLLA0E22771g*) and at the *KlMET5-1* locus (*KLLA0B03938g*) in addition to the *KlLAC4* locus. Such modified *K. lactis* strains have the advantage that genes for the expression of foreign genes are integrated at specified, defined loci in the *K. lactis* genome and the copy number of the foreign genes is controllable. Furthermore, said *K. lactis* strains allow the integration of different genes for the expression of different foreign antigens at defined loci in the *K. lactis* genome.

"Foreign antigens" or "foreign proteins" in the context of this invention mean all peptides, polypeptides and proteins which are suitable for generating an immune response, preferably a protective immune response, in humans or in an animal against a pathogen or carcinogenically degenerated cells. Foreign proteins can originate from pathogens or tumors of any kind, for which antigens which are solely capable of inducing a protective immune response, preferably a protective immune response, have been characterized.

In a preferred embodiment, the foreign proteins originate from pathogens (viruses, bacteria, parasites), for which antigens which are solely capable of inducing a protective immune response, preferably a protective humoral immune response, have been characterized.

For example, these are:

<u>Foreign proteins originating from parasites</u>

Necator americanus; Ancylostoma duodenale: ASP protein, *hemoglobin-degrading proteases*

Leishmania: gp63, 46 kD *promastigote antigen*, LACK
Plasmodium: CSP protein, CSA-1, CSA-3, EXP1, SSP2, STARP, SALSA, MSP1, MSP2, MSP3, AMA-1, GLURP, Pfs25, Pfs 28, Pvs25, Pvs 28, Pfs 48/45, Pfs 230
Schistosoma: TP1, Sm23, ShGSTs 26 and 28, paramyosin, *parasite myosin*, Sm14

Foreign proteins originating from bacteria
Mycobakterium tuberculosis: Ag85A, Hsp65, R8307, 19 kD, 45 kD, 10.4
Heliobacter pylori: VacA, LagA, NAP, hsp, urease, catalase
Group A *Strepptococcus*: M, SCPA peptidase, exotoxins SPEA and SPEC, *fibronectin binding protein*
Strepptococcus pneumonia: PspA, PsaA, BHV 3, BHV 4
Salmonella typhimurium: Vi antigen
Shigella: LPS
Vibrio cholera: CTB
Escherichia coli ETEC: LT, LT-ST, CTB
Yersinia pestis: F1, V

Foreign proteins originating from tumor cells/tumors (tumor-associated antigens, TAA)
CEA
5T4
MUC1
MART1
HER-2

Foreign proteins originating from viruses are especially preferred.
Caliciviridae (Norwalk, HEV): NV 60 kD; HEV ORF2
Reoviridae (Rota): VP7, VP4
Retroviridae (HIV): Gag, Pol, Nef, Env, gp160, gp120, gp140, gp41
Flaviviridae (genus Flavivirus: WNV, Dengue, YF, TBE, JEV): preM-Env, NS3, NS4, NS5
Flaviviridae (genus Pestivirus BVDV, CSFV, BDV; genus Hepacivirus HCV): E1, E2, E^{RNS} (Pesti), C, NS3, NS4, NS5
Hepadnaviridae (HBV): HBS antigen
Paramyxoviridae (*Paramyxovirinae:* PIV-1, PIV-2, mumps, Sendai, PIV-2, PIV-4, Morbilli): M, HN, N, F

Paramyxoviridae (*Pneumovirinae*: RSV): F, G, SH, M
Rhabdoviridae (Rabies): G
Herpesviridae (EBV, HSV2): gp350/220 (EBV), gB2, gD2 (HSV)
Coronaviridae (SARS): CoV, N, M, S
Orthomyxoviridae (Influenza A, B): HA, NA, M1, M2, NP
Papillomaviridae: L2, E6, E7

In a further embodiment of the invention, the modified *K. lactis* strains are characterized in that the expression cassettes contain the *K. lactis LAC4-12* promoter (P*LAC4-12*) or variants of said promoter, the ORF of the antigen to be expressed and the *Ag*TEF1 terminator. Said embodiment has the advantage that the expression of foreign genes under the control of the P*LAC4-12* promoter are induced approximately equally strongly by lactose after integration at the *LAC4* and/or *KlURA3* and/or *KlMET5* locus.

As described above, there is a positive correlation between the antigen concentration in vaccine strains and the immunogenic effect of the yeast vaccine in the target organism. To prevent a CPE in the case of excessively strong overexpression, for example due to integration of an additional *KlGAL4* gene, the above-described vector system can alternatively be modified in order to rapidly and efficiently connect multiple gene copies in series and to introduce this expression cassette in one step at one of the three gene loci (see Example 5 and Figure 7A).

In an advantageous further development of the invention, the modified *K. lactis* strains therefore contain in addition to the *KlLAC4* locus at the *KlURA3-20* locus and/or at the *KlMET5-1* locus multiple copies of a foreign antigen-encoding nucleic acid sequence that are inserted via tandem expression cassettes or multi-expression cassettes. Said expression cassettes comprise multiple copies of the antigen-encoding regions (genes) flanked in each case by the *LAC4-12* promoter (P*LAC4-12*) or variants of said promoter and the *AgTEF1* terminator. Duplication of the gene copies of the antigen that is performed in this way can significantly increase the expression thereof via one of the respective gene loci.

In a preferred embodiment which is not part of the invention, the gene of the foreign antigen IBDV-VP2 is present in the form of a tandem expression cassette at the locus *KlLAC4* of the *K. lactis* strain. Said *K. lactis* strain has, compared with strains having a

single copy of the gene encoding the foreign antigen IBDV-VP2, the advantage that the foreign antigen IBDV-VP2 is expressed with increased quantity. Particular preference according to this embodiment of the invention is given to the strain VAK1118 (DSM 32701), which has the gene of the foreign antigen IBDV-VP2 in the form of a tandem expression cassette at the locus *KlLAC4*.

It is furthermore preferred when one or more copies of different foreign antigen-encoding nucleic acids are inserted via single expression cassettes, tandem expression cassettes or multi-expression cassettes at the *KlLAC4* locus and/or at the *KlURA3-20* locus and/or at the *KlMET5-1* locus of the *K. lactis* strains according to the invention. As a result, it is possible to express, firstly, different foreign antigens and, secondly, said different foreign antigens in different concentrations in the yeast cell. Particular preference according to this embodiment is given to a *K. lactis* strain in which the encoding nucleic acid sequences of the foreign antigens influenza A HA (A/Puerto Rico/8/1934(H1N1)) and influenza A M1 (A/Puerto Rico/8/1934(H1N1)) are inserted at the *KlLAC4* and *KlURA3-20* loci of the *K. lactis* strain and are expressed. Special preference according to this embodiment of the invention is given the strain VAK1283 (DSM 32697), in which the encoding nucleic acid sequences of the foreign antigens influenza A HA (A/Puerto Rico/8/1934(H1N1)) and influenza A M1 (A/Puerto Rico/8/1934(H1N1)) are inserted at the *KlLAC4* and *KlURA3-20* loci of the *K. lactis* strain.

As mentioned, it is known that the increase in the *KlGAL4* gene dose can lead to raising of antigen production (Krijger *et al.* 2012 and WO 2013107436). The disadvantages of achieving this via the integration of the KlGAL4-expressing pLI-1 plasmid in a two-step process are stated above. Said disadvantages were overcome according to the invention by providing a stable starting strain for the integration of foreign genes that contains a second copy of the *KlGAL4* gene. This ensures that all derived strains have the same genetic background and that exactly one additional *KlGAL4* gene copy is present in said strains. This decreases the cytotoxicity which has been observed in the case of expression of multiple copies and reduces the steps in vaccine strain production to just one step. In addition, genetic stability is increased, since the reversible integration/excision of the plasmid is omitted. Such a strain can, for example, be produced as described in Example 1.

In a further advantageous embodiment of the invention, what is thus provided is a *K. lactis* strain which contains, in addition to the genomic *KlGAL4* gene, additionally a second ectopic copy of the *KlGAL4* gene. In said strain, the expression of the KlGAL4 transcription activator can be maximally increased two-fold and the expression of the foreign genes inserted into the *KlLAC4* locus and/or the *KlURA3-20* locus and/or the *KlMET5-1* locus can be increased in a defined manner via the *LAC4-12* promoter or via below-described variants of said promoter. In conventional practice, plasmids encoding KlGAL4 were introduced into the cell transiently and in a multiple, uncontrolled copy number. As a result, the foreign antigen was often expressed in such a high concentration that this led to cytotoxic effects. In the case of the *K. lactis* strains of this embodiment of the invention, cytotoxic effects can be reduced or avoided with a high degree of effectiveness. Further gene loci which will be developed in the future for the same purpose (insertion of a *LAC4*-controlled expression cassette) can also be controlled in this way. It has been found to be advantageous when the ectopic copy of the *KlGAL4* gene, which is flanked by the *KlGAL4* promoter and *KlGAL4* terminator, is integrated in the *K. lactis* strain at the gene locus *KLLA0E13795g* (*Klavt3::KlGAL4-1*, SEQ ID No.: 1). Special preference according to this embodiment but not part of the invention is given to the strain VAK1111 (DSM 32696), which has these properties.

In a further preferred embodiment which is not part of the invention, it is provided a *K. lactis* strain in which the encoding nucleic acid sequence of the foreign antigen IBDV-VP2 is present at the locus *KlLAC4*. Special preference according to this embodiment of the invention is given to the strain VAK1171 (DSM 32699). Said strain additionally contains a second, ectopic copy of the *KlGAL4* gene, at which the encoding nucleic acid sequence of the foreign antigen IBDV-VP2 is likewise present. Said strain exhibits an increased expression of the foreign antigen IBDV-VP2 compared to strains without additional ectopic copy of the *KlGAL4* gene.

Heterologous protein production in microorganisms is problematic when this leads to a cytopathic effect (CPE). The invention therefore provides a way to decouple the antigen production phase from the biomass accumulation phase. Owing to the inducible *LAC4* promoter, this is partially possible by a fed-batch fermentation process for example, but is hampered because the promoter $P_{LAC4-12}$ is not completely closed down under noninducing conditions (i.e., open to a certain extent). In the case of antigens having a very strong CPE, what occurs as a result is a reduction in the growth

rate and an induction of the cellular stress response, with disadvantageous effects for antigen production. This problem is aggravated by the doubling of the *KlGAL4* gene dose and/or the increase in the number of antigen-encoding sequences (see below).

An advantageous further development of the *K. lactis* strains according to the invention therefore consists in the *K. lactis* strains having a modified promoter structure of the *LAC4-12* promoter that allows only slight foreign protein expression or none under noninducing conditions. The modified structure of the *LAC4-12* promoter is especially characterized in that the basal control region (BCR) of the promoter P*LAC4-12* between positions 1065 and 1540 (LR2 deletion; P*LAC4-12-LR2*; SEQ ID No.: 2) is deleted (see also Example 2). As already described above, this embodiment of the invention has the advantage, compared to conventional practice, that cytotoxic effects conventionally caused by excessively strong expression of the foreign genes are reduced or avoided with a high degree of effectiveness. Preference according to this embodiment is given to *K. lactis* strains in which the encoding nucleic acid sequence of the foreign antigen influenza A HA (A/Puerto Rico/8/1934(H1N1)) is present at the locus *KlLAC4*. Special preference according to this embodiment which is not part of the invention is given to the strain VAK1243 (DSM 32702). Said strain contains an LR2 deletion in the LAC4-12 promoter.

The *K. lactis* strain can also have a modified structure of the *LAC4-12* promoter that allows modulation of foreign protein expression, wherein the number of binding sites for the activator KlGal4 of the promoter ("upstream activating sequences" 1, 2 and 4, 5) varies and 1, 2, 3 or 4 KlGal4-binding sites are present. In this way, it is possible to express different foreign proteins in differing concentration (quality by design) in a yeast cell. The shortened promoter variants are, *inter alia*, important for the modularity of the system in order, for example, to express proteins in the same strain in optimal stoichiometric ratios, for example for the formation of highly immunogenic virus-like particles (VLPs). It is preferred according to this embodiment of the invention when the encoding nucleic acid sequence of the foreign antigen IBDV-VP2 is inserted at the locus *KlLAC4* of the *K. lactis* strain. Special preference according to this embodiment which is not part of the invention is given to the strain VAK1131 (DSM 32700). Said strain contains an LR2 deletion and a deletion of the upstream activating sequences 4 and 5 in the LAC4-12 promoter.

Part of the object of the invention was to provide *K. lactis* strains which are better suited to cultivation. This problem is solved by restoring the gene function of the alleles *Kllac4, Klura3-20* and *Klmet5-1* in the *K. lactis* strains according to the invention. The resultant *K. lactis* strains are prototrophic (Example 6, Fig. 8). The fermentation of the vaccine strains is thus simplified, and the establishment of the production processes is facilitated and made more cost-efficient. Preference according to this embodiment of the invention is given to *K. lactis* strains in which the encoding nucleic acid sequences of the foreign antigens BVDV E2 ectodomain (type 1, CP7), BVDV E2 ectodomain (type 2, New York 93) and BVDV Npro-NS3 (type 1, CP7) are inserted into the at the loci *KlLAC4*, *KlURA3-20* and *KlMet5-1* of the *K. lactis* strain. Special preference according to this embodiment of the invention is given to the strain VAK1400 (DSM 32698). Said strain is prototrophic.

In a particularly preferred embodiment, the invention provides a *K. lactis* strain selected from the strains

VAK1283	DSM 32697;
VAK1395	DSM 32706;
VAK1400	DSM 32698

Said strains were deposited on November 24, 2017 or December 1, 2017 (DSM 32705, DSM 32706) at the *Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH* [German Collection of Microorganisms and Cell Cultures GmbH], DSMZ, Inhoffenstrasse 7B, 38124 Braunschweig, Germany, in accordance with the Budapest Treaty under the above-specified numbers.

In a further aspect, the invention provides integrative expression vectors, with the aid of which the *K. lactis* strains of the invention are producible.

In a preferred embodiment which is not part of the invention there are provided the integrative expression vectors *Kl*pURA3 (SEQ ID No.: 3) and *Kl*pMET5 (SEQ ID No.: 4). Said vectors contain the *LAC4-12* promoter (P*LAC4-12*) or variants of said promoter (as described above for the *K. lactis* strains) including the ORF of the antigen to be expressed, additionally the *AgTEF1* terminator sequence and also targeting sequences which allow a targeted restoration of the functionality of the *Klura3-20* and

Klmet5-1 alleles after integration. The antigen-encoding sequence is cloned between the promoter sequence and terminator sequence of the expression cassette via defined restriction sites. By means of said vectors, foreign gene-expressing cassettes are integrated into the *K. lactis* genome in a stable manner, without markers and without use of antibiotic resistances. Accordingly, the strengths of this vector system are that foreign genes are easily exchangeable between the different vectors and that promoters and terminators of the expression cassettes are replaceable with others. The expression cassette consists of the P*LAC4-12* promoter and the *AgTEF1* terminator, and also the foreign gene in between. The foreign gene can be exchanged via the restriction sites *Asc*I and *Not*I. The P*LAC4-12* promoter can be replaced via the restriction sites *Sma*I and *Asc*I in both vectors, and the terminator can be replaced via *Not*I and *Box*I (or *Mlu*I) in *Kl*pURA3 and via *Not*I and *Ecl*136II (or *Sac*I) in *Kl*pMET5. Alternative expression cassettes are cloned between the restriction sites *Sma*I and *Box*I (or *Mlu*I) in *Kl*pURA3, and between *Sma*I and *Ecl*136II (or *Sac*I) in KlpMET5. Using the stated restriction enzymes, the expression cassettes are also exchanged between *Kl*pMET5 and *Kl*pURA3 vectors or additional expression cassettes are introduced. An improvement over the *Kl*p3 and *Kl*p3-MCS vectors (WO 20101054649) is that selection is carried out under noninducing conditions (without lactose), and this leads to higher transformation rates in the case of proteins with CPE and prevents a possible enrichment of transformants with reduced foreign gene expression. See also Examples 3.1 and 3.2.

In a particularly preferred embodiment, an integrative expression vector selected from *Kl*pMET5-P*LAC4-12*-Et, *Kl*pMET5-P*LAC4-12-LR2*-Et, *Kl*pMET5-P*LAC4*-Et, *Kl*pMET5-*PLAC4-LR2* and from *Kl*pURA3-P*LAC4-12*-Et, *Kl*pURA3-P*LAC4-12-LR2*-Et, *Kl*pURA3-P*LAC4*-Et and *Kl*pURA3-P*LAC4-LR2* (SEQ ID No.: 3 or SEQ ID No. 4 in combination with SEQ ID No.: 5, 6, 7 or 8) is provided.

The vectors *Kl*pURA3-P*LAC4-12*-Et, *Kl*pURA3-P*LAC4-12-LR2*-Et, *Kl*pURA3-P*LAC4*-Et and *Kl*pURA3-P*LAC4-LR2* are variants of the vector *Kl*pURA3-Et, into which the encoding nucleic acid sequence for the Etx.B-HA protein is inserted in each case. The vectors *Kl*pURA3-P*LAC4-12*-Et, *Kl*pURA3-P*LAC4-12-LR2*-Et, *Kl*pURA3-P*LAC4*-Et and *Kl*pURA3-P*LAC4-LR2* have differences in the promoter compared to the vector *Kl*pURA3-Et.

The vectors *Kl*pMET5-P*LAC4-12*-Et, *Kl*pMET5-P*LAC4-12-LR2*-Et, *Kl*pMET5-P*LAC4*-Et, *Kl*pMET5-P*LAC4-LR2* are variants of the vector *Kl*pMET5, into which the encoding nucleic acid sequence for the Etx.B-HA protein is inserted in each case. The vectors *Kl*pMET5-P*LAC4-12*-Et, *Kl*pMET5-P*LAC4-12-LR2*-Et, *Kl*pMET5-P*LAC4*-Et, *Kl*pMET5-P*LAC4-LR2* have differences in the promoter compared to the vector *Kl*pMET5.

A further aspect provides a method for producing a *K. lactis* strain according to the invention, comprising the steps of:

(i) inserting the encoding nucleic acid sequence of the desired antigen into the *Kl*pURA3 or *Kl*pMET5 vector,

(ii) transforming a *K. lactis* culture with the modified and previously enzymatically digested vector construct,

(iii) selecting transformed *K. lactis* cells with the aid of a solid medium which does not contain uracil or/and methionine, and

(iv) optionally: restoring prototrophy.

In one embodiment of the method, the gene sequences of multiple antigens can be inserted ectopically at the same time and expressed in a regulated manner. It is preferred when different gene sequences encoding antigens of different variants of a pathogen are inserted ectopically and expressed in a regulated manner. Furthermore, it is preferred when different gene sequences encoding antigens of different pathogens are inserted ectopically and expressed in a regulated manner.

In a further aspect, the invention provides pharmaceutical or veterinary-medicine compositions for parenteral, enteral, intramuscular, mucosal or oral administration, containing a *K. lactis* strain according to the invention, optionally in combination with customary vehicles and/or excipients. In particular, the invention provides pharmaceutical or veterinary-medicine compositions suitable for vaccination.

Preferably, the pharmaceutical or veterinary-medicine composition comprises at least one physiologically compatible vehicle, diluent, adjuvant and/or excipient. The *K. lactis* strains according to the present invention can be contained in a pharmaceutically compatible vehicle, for example in a conventional medium, such as an aqueous saline medium or a buffer solution as pharmaceutical composition for injection. Such a medium can also contain conventional pharmaceutical substances, such as, for example, pharmaceutically compatible salts for setting the osmotic pressure, buffers,

preservatives and the like. The preferred media include physiological saline solution and human serum. A particularly preferred medium is PBS-buffered saline solution.

Further suitable pharmaceutically compatible vehicles are known to a person skilled in the art from, for example, Remington's Practice of Pharmacy, 13th edition and J. of Pharmaceutical Science & Technology, Vol. 52, No. 5, Sept-Oct, pages 238-311.

A further aspect of the invention provides for the use of the recombinant *K. lactis* yeasts according to the invention for vaccination, such as, for example, for generating a protective immunization, especially a protective immunization directed against a pathogen.

A corresponding method for generating a protective immunization comprises, for example, the following steps:

a) cultivating and propagating the recombinant yeasts according to the invention,
b) harvesting and inactivating the yeasts,
c) administering the recombinant yeasts according to an immunization scheme to be defined,
d) determining the titer of the antibodies formed and/or
e) detecting the immunization.

The cultivation and propagation of the recombinant yeasts according to the invention can be achieved using any conventionally available method. Particular preference is given to methods which lead to high cell yields in a cost-effective manner. These include fermentation methods, especially high-cell-density fermentation methods. Carrying out the fermentation using a fed-batch fermentation protocol has been found to be particularly advantageous.

In a preferred embodiment, the protective immunization is achieved in that the recombinant yeasts are administered orally/mucosally, intramuscularly or subcutaneously.

The recombinant yeast cells should be used in an inactivated/killed state in the method according to the invention. To this end, the yeasts are dried after cultivation and expression of the foreign genes and subsequently inactivated. The inactivation can be

carried out using any conventionally available method. Particularly suitable for use in the method according to the invention are heat inactivation (e.g., heat inactivation for 2 hours at 90°C) or γ-irradiation (e.g., with 25 or 50 kGy).

The invention also provides a method for vaccination, comprising administering a *K. lactis* strain according to the invention to a subject, for example an animal or a human, preferably an animal, in an amount sufficient for triggering an immune response, preferably a protective immune response against one or more foreign antigens, in the subject.

A particular advantage is that, using the *K. lactis* strains according to the invention, a protective immune response against one pathogen is triggered solely after a single use/immunization ("one shot") or after a double use/immunization ("prime-boost"). What has been found to be a further advantage is that, using the *K. lactis* strains according to the invention, a cross-protective immune response against different variants of a pathogen can be triggered after a single use/immunization ("one shot") or after a double use/immunization ("prime-boost"). If the *K. lactis* strains according to the invention bear and express different foreign genes against antigens of different pathogens, it is even possible to trigger a protective immune response against different pathogens after a single use/immunization ("one shot") or in a double use/immunization ("prime-boost").

Summary of the advantages of the invention

The described improvements in the *K. lactis* platform result in numerous advantages:

a. A great simplification (**ready to use toolbox/kit**) and a high reproducibility in the construction of strains of "subunit vaccines" based on yeast is made possible. They can now be generated within a defined, short time span.
b. The yeast vaccines can contain one or more antigens; they can be customized in a flexible manner and produced in different quantities.
c. Moreover, an efficient fermentation of the prototrophic yeasts is made possible.
d. A stringent inducibility of recombinant protein production is made possible. The latter is particularly important for proteins which can trigger a CPE.
e. The targeted, stable, genomic integration of the foreign genes and the associated genetic stability of the strains offers the advantage that production

processes proceed reproducibly. This is particularly important for GMP production.

f. The protectivity of the yeast vaccine is improved with the increase in recombinant antigen production that is achieved as a result of an increase in foreign gene copies and/or in KlGAL4 concentration.

g. In addition, the vaccine dose to be administered can be reduced with the increase in recombinant antigen production that is achieved as a result of an increase in foreign gene copies and/or in KlGAL4 concentration. Yeast production is thereby more cost-efficient and the compatibility of the vaccine for the vaccine recipient is improved.

h. Multivalent yeast vaccines can be used in a cross-protective or multivalent protective manner for prophylaxis against different variants of the same pathogen or against different pathogens. Apart from inactivation and admixing with an adequate adjuvant and/or a suitable liquid volume, no further downstream processing of the yeast for use as vaccine is required.

The invention is more particularly elucidated below on the basis of the drawings and exemplary embodiments.

Figure 1 shows the characterization of a newly generated *K. lactis* background strain having two *KlGAL4* copies. The presence of the second ectopic *KlGAL4* copy at the identified integration site was checked and the effect of the integration on yeast growth was analyzed. **A**: Diagram of the integration site of the ectopic *KlGAL4* copy. The integration site is indicated and the gene names are given. **B**: Agarose gel of PCR-amplified fragments, using the primers VK183 (5'-GAGCCCACCACCTGCTCCTG-3') (SEQ ID No.: 9) and VK184 (5'-CTGATGTATTGCGCTCCTTACTAAC-3') (SEQ ID No.: 10), of the *KlAVT3* locus of a yeast strain with (VAK1110) and without (VAK367) an additionally integrated, ectopic *KlGAL4* gene. The respectively expected fragment sizes are given on the right in the diagram. **C**: Drop test with serial tenfold dilutions (Start-OD 1) on glucose (YPD) or lactose (YPLac). The incubation was carried out at 30°C and 37°C in each case. The growth of yeast strains having a *KlGAL4* copy at the native gene locus (VAK1139), at the ectopic gene locus and deleted *KlGAL4* at the native gene locus (VAK1110), having no *KlGAL4* copy (Δ*Klgal4*; VAK964) or having two *KlGAL4* copies (VAK1168) were compared. What is shown is that the defined

integration of a further *KlGAL4* gene only leads to marginal growth defects: said defects are only visible at 37°C and under inducing conditions. What is clearer is the growth defect in the case of complete deletion of *KlGAL4*.

Figure 2 shows the western blot analysis with proteins of an IBDV-VP2-producing *K. lactis* strain having an additional, ectopic *KlGAL4* copy. The effect of an additional *KlGAL4* copy on the *LAC4-12* promoter-dependent recombinant protein production was analyzed by Western blotting. The test strain used was a yeast strain having an IBDV-VP2 expression cassette, which yeast strain was compared with other IBDV-VP2 yeast strains. The presence (+) or absence (-) of an ectopic *KlGAL4* copy and of a tandem IBDV-VP2 expression cassette (see below) are indicated above. In strain VAK911, the ectopic copy was introduced by linearization of the plasmid pLI-1 by means of *Bst*EII (Krijger *et al*. 2012 and WO 2013107436), and in strain VAK1130, the ectopic *KlGAL4* copy was at the *KlAVT3* locus (see Fig. 1). Yeast strain VAK367 was included as wild-type control without a foreign gene. The yeast strains were cultivated in YPLac for 15 h after a preliminary culture in YPD. 20 μg in each case of the protein extract were analyzed per yeast strain by means of SDS-PAGE. The immunoblotting was carried out using anti-IBDV rabbit serum (1:8000) and HRP-conjugated anti-rabbit antibody from goat (1:10 000). Multimeric (agg.) and monomeric (mon.) IBDV-VP2 are indicated on the right by arrows, nonspecific bands by asterisks. What is shown is that the ectopic expression of an additional *KlGAL4* gene leads to a strong increase in foreign antigen concentration, as does the presence of a tandem expression cassette (see also below).

Figure 3 illustrates the effect of LR2 deletion in the *LAC4-12* promoter on noninduced, recombinant protein production and on yeast growth on glucose. The unmodified *LAC4-12* promoter also exhibits a basal expression of the GOI (gene of interest) under noninducing conditions. This is particularly problematic in the case of cytotoxically acting foreign antigens. What was tested with these experiments was whether a deletion in the BC region (LR2 deletion) of the *LAC4-12* promoter can reduce or even completely suppress recombinant protein production under noninducing conditions. A: Diagram of a *LAC4-12* promoter (P*LAC4-12*). The basal control region (BCR), the LR2 deletion and the four KlGal4-binding sites (upstream activating sequence: U1, U2, U4, U5) and also the encoding nucleic acid sequence of the foreign gene (GOI) are drawn in. B: Western blotting of IBDV-VP2 yeast strains, with (VAK1131) and without

(VAK1130) LR2 deletion, after cultivation under noninducing conditions (YP 3% EtOH). VAK1111 was used as wild-type control without a foreign gene. For each yeast strain, 50 µg of protein extract were loaded onto a 12% SDS gel. The immunoblotting was carried out using anti-IBDV rabbit serum (1:5000) and HRP-conjugated anti-rabbit antibody from goat (1:10 000). The loading control *Kl*Nop1 was detected using mouse anti-Nop1 antibody (1:5000) and HRP-conjugated anti-mouse antibody from goat (1:10 000). C: Drop test with serial tenfold dilutions (Start-OD 1) on YPD, YPD containing 0.5% glucose and YPLac. The incubation was carried out at 30°C and 37°C in each case. The growth of the yeast strains bearing an influenza A HA foreign gene at the *LAC4* locus, with (VAK1243) and without (VAK952) LR2 deletion, was compared. The yeast strain VAK367 was used as wild-type controls without a foreign gene. What is shown is that the LR2 deletion prevents the unwanted, basal foreign protein expression. Furthermore, what is shown is that the LR2 deletion improves the growth of a yeast strain expressing a cytotoxic protein (influenza hemagglutinin, HA), both under noninducing conditions and under inducing conditions. This is particularly clear at 37°C.

Figure 4 shows the *Kl*p vectors which can be used for integrating protein expression cassettes into different loci of the *K. lactis* genome. Whereas the use of the *LAC4* locus (*Kl*p3 vector system) has already been described (WO 20101054649 and WO 2013107436), the use of the *KlURA3* and *KlMET5* loci is new. A: Diagram of the different *Kl*p vectors with their respective integration site in the genome. B & C: Expression cassettes and flanking ends in the *Kl*pURA3 (B) and *Kl*pMET5 (C) vectors that are newly described here. The different DNA sequence segments and relevant restriction sites are indicated. *GOI*: foreign gene (gene of interest). D: Western blotting analysis of foreign protein expression in yeast strains constructed with the aid of the *Kl*p vectors (A, B & C). Here, the foreign gene is Etx.B-HA. The yeast 'house-keeping' KlNop1 protein (KLLA0C04389g) was detected as loading control. The yeast strains were cultivated in YPLac (+U) for 4 h after a preliminary culture in YPD (+U). For each yeast strain, 30 µg of protein extract were loaded onto a 12% SDS-PAGE. The immunoblotting was carried out using monoclonal mouse anti-HA (1:5000) and anti-KlNop1 (1:5000; Santa Cruz, TX, USA) antibodies and also HRP-conjugated anti-mouse antibody from goat (1:10 000; Jackson ImmunoResearch, PA, USA). What is shown is that, similarly to the *LAC4* locus (WO 20101054649 and WO 2013107436), both *KlURA3* and *KlMET5* loci are usable for heterologous gene expression.

Figure 5 shows the production of different, recombinant proteins in the same yeast strain. Said yeast strain (VAK1234) was constructed using the KlpURA3 and Klp3-MCS vectors. Western blotting analysis with proteins of a tandem IBDV VP2-expressing yeast strain (see below) into which an additional expression cassette, with Etx.B-HA as foreign gene, was introduced with the aid of the KlpURA3 vector (VAK1234). The controls used were yeast strains bearing only the expression cassette with Etx.B-HA at the *LAC4* (VAK899) or *KlURA3* locus (VAK1235) or only the tandem IBDV-VP2 expression cassette at the *LAC4* locus (VAK1171) in the genome. The yeast strains were cultivated in YPLac for 6 h after a preliminary culture in YPD. For each yeast strain, 30 μg of protein extract were loaded onto a 12% SDS-PAGE. The detection of the proteins in the immunoblot was carried out using mouse anti-HA antibody (1:5000; Santa Cruz, TX, USA) and HRP-conjugated anti-mouse antibody from goat (1:10 000) for Etx.B-HA and using rabbit anti-IBDV antiserum (1:5000; Granzow *et al.* (1997)) and HRP-conjugated anti-rabbit antibody from goat (1:10 000; Jackson ImmunoResearch, PA, USA) for IBDV-VP2. What is shown is that both foreign proteins are expressed in the same yeast cell. Surprisingly, the expression level of one antigen is not limited upon coexpression of another antigen. This is clear in the comparison of the expression levels in monovalent and bivalent strains (see also Fig. 12).

Figure 6 shows the differently induced *LAC4-12* promoter variants for expression cassettes in Klp vectors. The expression cassettes of the Klp vectors were provided with different variants of the *LAC4-12* promoter. The effect of the promoter variants on the strength of induction of protein synthesis was tested on the basis of the analysis of yeast strains containing the corresponding expression cassettes with Etx.B-HA as foreign gene. A: Schematic representation of the promoter variant, the associated KlpURA3 vectors with Etx.B-HA as foreign gene and the yeast strains created therefrom. BCR: binding region of the transcription activators KlCat8 and KlSip4, transcription activators under noninducing conditions; U1, U2, U4, U5: binding regions for the transcription activator KlGal4 (upstream activating sequence). B: Western blotting analysis for characterizing the *LAC4-12* promoter variants in the yeast strains created using the KlpURA3 vector (A). The yeast strains were cultivated in YPLac for 4 h after a preliminary culture in YPD. For each yeast strain, 30 μg of protein extract were loaded onto a 12% SDS-PAGE. The immunoblotting was carried out using

monoclonal mouse anti-HA (1:5000) and anti-Nop1 (1:5000) antibody and also HRP-conjugated anti-mouse antibody from goat (1:10 000). What is shown is that the expression rate of the foreign gene varies depending on the nature of the promoter used.

Figure 7 shows the effect of doubling the number of foreign gene copies by means of a tandem expression cassette on recombinant protein production. The effect on recombinant protein production (IBDV-VP2) by increasing the number of foreign gene copies by means of a tandem expression cassette was tested. A: Schematic representation of the tandem expression cassette. DNA segments and relevant restriction sites are indicated. *GOI*: foreign gene (gene of interest). B: The tandem construct derived from (A) for random integration with the aid of an *ScURA3* selection marker is depicted. C: Western blotting analysis for comparing IBDV-VP2 protein production in a yeast strain (VAK1118) having a tandem expression cassette (A) and a yeast strain (VAK910) having an expression cassette containing only one foreign gene copy. The yeast strains were cultivated in YPLac for 3 h or 6 h after a preliminary culture in YPD. For each yeast strain, 60 μg of protein extract were loaded onto a 12% SDS-PAGE. The immunoblotting was carried out using anti-IBDV rabbit serum (1:10 000) and HRP-conjugated anti-rabbit antibody from goat (1:10 000). Aggregated (agg.) and monomeric (mon.) IBDV-VP2 are indicated on the right by arrows, nonspecific bands by asterisks. D: Western analysis of yeast strains having a randomly integrated tandem IBDV-VP2 expression cassette (B) in comparison with a KIp3-MCS-generated yeast strain having one expression cassette (VAK910) and also the yeast strain derived therefrom having additional *KlGAL4-1* copies (pLI-1). The yeast strains were cultivated in YPLac for 8 h after a preliminary culture in YPD. The immunoblotting was carried out as described under (b). What is shown is that the use of a tandem expression cassette significantly increases the foreign protein expression rate.

Figure 8 shows the gene fragments for restoring the gene function of the alleles *Klura3-20* and *Klmet5-1* (A). Schematically depicted are the gene loci and the gene fragments, amplified using the specified primers, for *KlURA3* (A) and *KlMET5* (B). The mutations of the alleles *Klura3-20* (A) and *Klmet5-1* (B) reconstituted with these gene fragments by homologous recombination are shown as stars below the genes. The restriction sites with which the subcloned fragments are cut out are drawn in. This

diagram illustrates the strategy of generating prototrophic foreign gene-expressing yeast strains at the *URA3* or *MET5* locus.

Figure 9 illustrates, in combination with Table 1 and Table 2, the protective immunization of chickens against vvIBDV in a classic prime-boost vaccination scheme. In two experiments (A and B), groups of at least 16 SPF chickens were vaccinated subcutaneously according to a prime-boost method with lyophilized and heat-inactivated yeast cells of the genetically optimized tandem IBDV-VP2 *K. lactis* yeast strain VAK1127. The first vaccination took place two weeks after hatching (prime), and the second (boost) two weeks after that. Two weeks after the boost, a virus challenge with a vvIBDV strain (very virulent 89163/7.3) was effected. One subject group serving as infection control was subjected to a mock treatment in which only PBS or adjuvant was administered. In experiment 1 (A), the wild-type yeast (VAK367) was also administered as control. At least seven chickens per group served as control without virus challenge, and at least five in experiment 2 (B). Sera were obtained just before the first administration, before and after the challenge, and otherwise at ten-day intervals. The strength of seroconversion was determined by means of ELISA (ProFLOK IBD Plus, Synbiotics). The converted titers according to the kit information are shown. A: Experiment 2 was performed in the same way as experiment 1 (A). The mean value of the ELISA titers from 12 animals is shown with standard deviation. Both experiments show a strong development of titers of anti-IBDV VP2 antibodies in the case of the VAK1127-vaccinated animals. The associated tables summarize the results of the protection of the vaccinated animals against challenge with the vvIBDV: in both vaccination experiments, it was possible to achieve complete protection against the viral infection.

Figure 10 shows the effect of the genetic modifications for restoring prototrophy on the amount of recombinant protein production and immunogenicity of a tandem IBDV-VP2 yeast strain. The auxotrophic tandem IBDV-VP2 yeast strain VAK1127 and the prototrophic yeast strain VAK1171 derived therefrom were compared with regard to efficiency of recombinant protein production and immunogenicity. A: Western blotting analysis for ascertaining the IBDV-VP2 content in freshly harvested yeast material. The yeast strains were cultivated in YPLac for 8 h after a preliminary culture in YPD. 40 μg of protein extract per yeast strain were loaded onto a 12% SDS-PAGE. The immunoblotting was carried out using anti-IBDV rabbit antiserum (1:10 000) and HRP-

conjugated anti-rabbit antibodies from goat (1:10 000). Aggregated (agg.) and monomeric (mon.) IBDV-VP2 are indicated on the right by arrows, nonspecific bands by asterisks. B: Western blotting analysis for ascertaining the IBDV-VP2 content in lyophilized, heat-inactivated yeast material which was used afterwards in an immunization study in BALB/c mice (C). The yeast strains were cultivated in YPLac for 15 h after a preliminary preculture in YPD. For each yeast strain, 10 μg of protein extract were loaded onto a 12% SDS-PAGE, otherwise the immunoblotting was carried out as (A) above and the bands are indicated correspondingly. C: Testing of the immunogenicity of the two yeast strains VAK1127 and VAK1171 in the immunization experiment in BALB/c mice. Groups of five mice each were vaccinated three times subcutaneously using 0.1 mg (dry weight) of the above-analyzed (B) yeast material. The control used was a wild-type strain (VAK367) without antigen. The first administration was carried out using CFA (complete Freund's adjuvant) as adjuvant, and the further two, at two-week intervals, using IFA (incomplete Freund's adjuvant) as adjuvant. One week after the third administration, the mice were euthanized and bled. The sera were analyzed by IBDV-VP2 ELISA (IDEXX). The absorption at 650 nm, correlating with the anti-IBDV-VP2 antibody titer, is shown with standard error. A monoclonal anti-IBDV-VP2 antibody (pos. mab64) was used as positive control for the ELISA, and either sample buffer (neg. 1) or a nonspecific antibody (neg. 2) was used as negative control. What is shown is that both strains exhibit a similar level of foreign protein expression and exhibit immunogenic potential.

Figure 11 shows, in combination with Table 3, the protective immunization of SPF chickens against vvIBDV by means of a single, subcutaneous administration with genetically optimized IBDV-VP2 vaccine yeast. Groups of at least 18 SPF chickens were vaccinated singly subcutaneously with 10 mg of heat-inactivated cells of the genetically optimized tandem IBDV-VP2 *K. lactis* yeast strain VAK1171 two weeks after hatching. The controls used were animals vaccinated with PBS or 10 mg of VAK367. They were vaccinated two times, two weeks and four weeks after hatching. All animals were challenged with vvIBDV six weeks after hatching. The sera were analyzed by ELISA (ProFLOK IBD Plus, Synbiotics) as described above. The antibody titers ascertained are shown. The individual points represent individual antibody titers of the twelve chickens analyzed per group, and the bar represents the mean value with standard deviation. In the case of the controls, only the antibody titer of the surviving chickens were ascertained after the challenge. What is shown is that just a 'one-shot'

vaccination with the yeast subunit vaccine VAK 1171 achieves complete protection against a subsequent exposure to vvIBDV.

Figure 12 shows the characterization of the strains VAK952 and VAK1283. (A) The yeast strains VAK952 (monovalent HA) and VAK1283 (bivalent HA, M1) were preincubated in a shake flask in YPD and subsequently induced in YPL for 6 h. The optical density at 600 nm was measured and 30 OD unit of the culture was harvested, the pellet was disrupted using glass beads, and the soluble protein fraction (LF) and the insoluble protein fraction (P, Pellet) were examined in an immunoblot. The primary antibody used was α-HA1 or α-M1 and the secondary antibody used was α-mouse-IR-Dye800CW. The signal was generated via an infrared imaging system (LI-COR Biosciences). (B, C) The yeast strains were preincubated in a shake flask in YPD and subsequently induced in YPL over a period of 24 h. At the specified time points, the optical density of the yeast culture was determined and 30 OD units were harvested. (B) The pellets of VAK1283 were disrupted using glass beads and analyzed in an immunoblot. (C) The values measured for the optical density of VAK952 and VAK1283 were combined as a growth curve as a function of time and averaged from at least two independent experiments. (D) For the dot test, the yeast strains were cultivated on YPD-containing nutrient agar plates at 30°C for 48 h. Starting with 1 OD unit, the yeasts were serially diluted and subsequently dripped onto YPD-containing or YPL-containing nutrient agar plates. The plates were cultivated at 30°C for 48 h and subsequently photographed. Ponceau S: staining of total yeast protein of the respective fraction, loading control. What is shown is that VAK952 (monovalent HA) and VAK1283 (bivalent HA, M1) express the HA protein in comparable quantities. Furthermore, what is shown is that VAK1283 and VAK952 have comparable growth properties, with VAK1283 having slight advantages.

Figure 13 illustrates the antibody titer in the serum of BALB/c mice after immunization with VAK952 (monovalent HA) and VAK1283 (bivalent HA, M1) before and after exposure infection. Both yeast strains were preincubated in a shake flask with YPD and subsequently induced in YPL for 12 h (VAK952) or 6 h (VAK1283). Thereafter, the cultures were harvested, freeze-dried and the yeast material was inactivated at 90°C for 2 h. For the immunization, 9-week old, female BALB/c mice were vaccinated subcutaneously twice (prime-boost) or once (one shot) with 2 mg of yeast (VAK952, VAK1283) or with 1 mg of VAK1283 or twice with PBS (without adjuvant), at an interval

of three weeks. The adjuvant used was AddaVax. Three or six weeks after the last administration, the animals were infected intranasally with 5x MLD_{50} of the influenza A/PR/8/34 (H1N1) virus. The infection control used was mock-infected animals (Mock), to which only PBS without virus was administered intranasally. Three or six weeks after the last administration and during the exposure infection, the serum of the animals was obtained and tested for neutralizing antibodies (nAb) in a VNT. nAb $titer_{50}$: serum dilution which reduces the number of plaques by 50% in comparison with the virus-free control. The log_2 of the corresponding serum dilution is specified. Owing to the logarithmic plot, the value: $log_2(2)=1$ was assigned to serum samples without detectable antibodies. mAb: test system control (α-H1 (H37-66)). What is shown is that both immunization schemes lead to a significant induction of neutralizing Ab. Furthermore, it is clear that the neutralizing anti-HA antibody titers obtained in the case of the primer-boost vaccination experiments and one-shot vaccination experiments do not significantly differ for VAK952 and VAK1283.

Figure 14 shows the exposure infection with influenza A/PR/8/34 (H1N1) after immunization with VAK952 (monovalent HA) and VAK1283 (bivalent HA, M1). Three or six weeks after the last administration (see Fig. 13 for the immunization scheme), the BALB/c mice were infected intranasally with 5x MLD_{50} of the influenza A/PR/8/34 (H1N1) virus. The infection control used was mock-infected animals (Mock), to which only PBS without virus was administered intranasally. Thereafter, the survival (A), the weight (B) and clinical symptoms (C) of the animals were examined multiple times every day over a period of 14 days. In the case of the clinical symptoms, a score of 0-4 was defined, which was averaged for each group (0: no anomalies; 1: slightly shaggy coat; 2: shaggy coat, reduced activity; 3: shaggy coat, 15% loss of body weight; 4: shaggy coat, >20% loss of body weight). What is shown is that the prime-boost immunization method with VAK952 does not provide optimal protection against a virus exposure, whereas this is the case for VAK1283. With both vaccines, the one-shot scheme generates optimal protection with 2 mg of administered vaccine. When 1 mg is administered, a similar protection rate is achieved with VAK1283 as with 2 mg of VAK952 in the prime-boost method.

Exemplary embodiments

Example 1: Generation of a host strain having two *KlGAL4* gene copies, stably integrated, at noncoupled gene loci

A second *KlGAL4* gene copy without a selection marker was inserted at a different gene locus (ectopically). It was possible to locate the insertion in the *KlAVT3* gene *(KLLA0E13795g)* by sequencing (*Klavt3::KlGAL4-1*, SEQ ID No.: 1) (Fig. 1). The resultant strain is called VAK1111. The independent meiotic segregation of the two *KlGAL4* copies, which are on chromosome E (ectopic copy) and D (genomic copy), was confirmed by a crossing experiment. Moreover, in the same experiment, the number of exactly two *KlGAL4-1* gene copies in the genome was established.

To use VAK1111 for the targeted integration of an expression cassette at the *LAC4* locus in analogy to VAK367-D4, the *lac4::ScURA3* disruption was introduced, which makes it possible in one step, under selection for lactose growth, to integrate the desired foreign gene between *LAC4* promoter and *LAC4* reading frame by means of KIp vector technology without a marker (Krijger et al. (2012)). The resultant strain VAK1123 only differs from VAK367-D4 by the second, ectopic *KlGAL4* gene copy.

Example 1.1: Improved productivity of a yeast vaccine strain having an additionally integrated *KlGAL4* gene.

In one exemplary embodiment, the IBDV-oVP2$_{T2S}$ (Arnold et al. (2012)) gene was inserted into the *LAC4* locus of the strain VAK1123 (resultant strain VAK1130). It was possible to establish an increased production of IBDV-VP2 compared to the otherwise isogenic strain having only one *KlGAL4* copy (VAK910). As comparison, strain VAK1118, which bears only one *KlGAL4* gene, but two *CDS VP2$_{IBDV}$* copies (see below), is additionally shown (Fig. 2).

Example 2: $P_{LAC4\text{-}12LR2'}$ promoter having reduced basal activity for optimizing the expression of antigens having a cytopathic effect.

Heterologous protein production in microorganisms is problematic when this leads to a cytopathic effect (CPE). Therefore, the task faced is to find a way to decouple the antigen production phase from the biomass accumulation phase. Owing to the inducible *LAC4* promoter, this is partially possible by a fed-batch fermentation process, but is hampered because the promoter $P_{LAC4\text{-}12}$ is not completely closed down under noninducing conditions. In the case of antigens having a very strong CPE, what occurs

is a reduction in the growth rate and an induction of the cellular stress response, with disadvantageous effects on antigen production. This problem is aggravated by the doubling of the *KlGAL4* gene dose and/or the increase in the number of antigen-encoding sequences (see below). The solution was to delete the basal control region (BCR) of the promoter P*LAC4-12* (Fig. 3A) (Mehlgarten *et al.* (2015)) between -1065 and -1540 (LR2 deletion; P*LAC4-12-LR2*; SEQ ID No.: 2). Said deletion was introduced into the starting strains VAK367 (one *KlGAL4* copy) and VAK1111 (two *KlGAL4* copies) at the genomic *LAC4* locus together with the *lac4::ScURA3* disruption. The resultant strains VAK1109 and VAK1124 are suitable for the expression of antigens having CPE. The promoter P*LAC4-12LR2'* was also inserted into the integrative vectors KlpURA3-Et and KlpMET5-Et (see below).

Example 2.1: Inhibition of the basal (noninduced) expression of antigen by a modified promoter.

After integration of a tandem IBDV-VP2 expression cassette into VAK1124 (resultant yeast strain: VAK1131; see below and Fig. 7 for an explanation of the term 'tandem expression cassette'), it was possible to show that the LR2 deletion in the *LAC4-12* promoter leads to a strong reduction in VP2 protein production under noninducing conditions (Fig. 3B). With strains expressing the influenza A antigen hemagglutinin (VAK952 without LR2 deletion in the promoter, VAK1243 with LR2 deletion in the promoter), it was possible to show that the cytopathic effect of the influenza A HA antigen is suppressed and growth under noninducing conditions is improved as a result of the LR2 deletion (Fig. 3C).

Example 3: Versatile vector system for the targeted integration of multiple expression cassettes into the *K. lactis* genome

As before for VAK367-D4 (Krijger *et al.* (2012), WO 20101054649), the yeast strain VAK367 forms the genetic background of all *K. lactis* strains described here. This strain background has a need for uracil and methionine (uracil-and-methionine auxotrophy) owing to mutations in two genes, *KlURA3* (*KLLA0E22771g)* and *KlMET5 (KLLA0B03938g*), which are referred to as alleles *Klura3-20* (absent base pair at position +345) and *Klmet5-1* (G2555A; and A3682T); the alleles are thus nonfunctional gene variants.

These mutated alleles were used in order to use further loci for targeted integration besides the integration site *LAC4* already developed with the KIp3/KIp3-MCS (Krijger

et al. (2012)) and to thereby generate multivalent vaccine strains (Fig. 4A). Selection is achieved by restoring the gene function of these mutated genes without additional insertion of a selection marker. To this end, new integration vectors were created. In said vectors, the expression cassettes (under the control of the *LAC4-12* promoter or the variants thereof in each case) are flanked by gene segments which allow the upstream integration of the *KlURA3* gene and downstream integration of the *KlMET5* gene by homologous recombination and restore the wild-type sequences of these genes at the same time.
Further loci can be analogously developed as integration sites by mutagenesis and selection for auxotrophy for alternative growth substances.

Example 3.1: Vectors KlpURA3 and KlpMET5 for the targeted integration of expression cassettes (having an inducible LAC4-12 promoter) at the *KlURA3 (KLLA0E22771g)* and/or *KlMET5 (KLLA0B03938g)* loci of *K. lactis* strains having the *Klura3-20* and/or *Klmet5-1* allele.

The integrative expression vectors KlpURA3 (SEQ ID No.: 3) and KlpMET5 (SEQ ID No.: 4) were constructed by means of suitable gene fragments (*KlMET5/KlURA3* targeting sequences) which allow a targeted restoration of the functionality of the *Klura3-20* and *Klmet5-1* alleles, respectively.

The KlpMET5 expression vector contains the expression cassette consisting of the *LAC4-12* promoter ($P_{LAC4-12}$ or the variants thereof), the encoding nucleic acid sequence of the antigen to be expressed and the *Ag*TEF1 terminator; it is flanked upstream by the genomic *Kl*MET5 fragment having an introduced *Sc*CYC1 terminator and downstream by the KlAIM18 promoter having a downstream KlAIM18 gene.
The KlpURA3 expression vector contains the expression cassette consisting of the *LAC4-12* promoter ($P_{LAC4-12}$ or the variants thereof), the encoding nucleic acid sequence of the antigen to be expressed and the *Ag*TEF1 terminator; it is flanked upstream by KLLAOE22749g having an associated promoter and downstream by the KlURA3 promoter having a downstream KlURA3 fragment (Fig. 4B, C).

In each case, the antigen-encoding sequence is cloned between promoter and terminator via *Asc*I and *Not*I restriction sites. By *Eco*91I or *Kpn*I restriction of the resultant plasmid, the entire expression cassette is separated from the *Kl*pURA3 vector backbone, and by *Hind*III or *Box*I restriction of the resultant plasmid, the entire

expression cassette is separated from the KlpMET5 vector backbone, and the restriction material is transformed into *K. lactis* host strains having a *Klura3-30* and/or *Klmet5-1* allele. The foreign gene-containing expression cassette integrated in this way into *KlURA3-20* or *KlMET5-1* thus exactly corresponds to that which is also integrable into *LAC4* in VAK367-D4 with the Klp3-MCS vector (WO 20101054649). Checking for uracil-prototrophic and/or methionine-prototrophic transformants is carried out in a standard manner via colony PCR using the primers MAB6 and VK211 for *Kl*pMET5 transformants, and the primers MAB6 und VK71 for *Kl*pURA3 transformants. Integration of the expression cassette at the correct target site between *KlURA3* or *KlMET5* and the respectively adjacent gene yields products of 1652 bp in size for KlpMET5 transformants and of 1307 bp in size for KlpURA3 transformants. No indications were obtained that the functionality of the neighboring genes is impaired by the insertion.

Primers:

MAB6: 5'-CCCAGATGCGAAGTTAAGTG-3' (SEQ ID No.: 11)

VK71: 5'-TACAACAGATCACGTGATCTTTTTGTAAG-3' (SEQ ID No.: 12)

VK211: 5'-GATTTCGTAACCCTATTGTTCATGAATG-3' (SEQ ID No.: 13)

Example 3.2: Expression of a foreign antigen after integration of the encoding gene cassette at the *KlURA3* or *KlMET5* locus.

A foreign gene under the control of the $P_{LAC4-12}$ promoter is induced approximately equally strongly by lactose after integration at the *LAC4*, *KlURA3* and *KlMET5* locus. The heat-labile, nontoxic, enterotoxin subunit B (Etx.B) from *E. coli* and an $(HA)_3$ epitope at the C-terminus (Etx.B-HA) was used as test protein for evaluating the vector system. The encoding sequence was cloned into the vectors KlpMET5, KlpURA3 and Klp3-MCS and integrated at the gene loci *KlMET5* (VAK1251), *KlURA3* (VAK1235) and *LAC4* (VAK899) (Fig. 4D). As shown by western blotting, the concentration of the Etx.B-HA protein in all three strains is very similar (Fig. 4D). Therefore, it was not possible to establish any position effect, dependent on the integration site of the expression cassette in the genome, on the amount of recombinant protein production.

Example 3.3: Coexpression of two foreign antigens in the same yeast cell.

The possibility of producing different heterologous proteins under the control of the $P_{LAC4-12}$ promoter in the same yeast strain via the new vector system was able to be shown by the construction of a yeast strain having an Etx.B-HA expression cassette at

the *KlURA3* locus and an expression cassette at the *LAC4* locus having two $VP2_{IBDV}$ copies present as a tandem (VAK1234; Fig. 5; see below and Fig. 7 for an explanation of the tandem cassette). Compared to yeast strains in which only one of the expression cassettes was present in the genome in each case (VAK1235 or VAK1171), it was not possible to establish any reduction in the protein concentration of Etx.B-HA or $VP2_{IBDV}$ in the case of VAK1234.

Example 4: *LAC4* promoter variants for modulating recombinant protein synthesis under similar induction conditions.

The immunogenic effect of antigens is often based on the assembling of multiple proteins in a nonstoichiometric ratio. To make this possible in yeast-based vaccines, variants of the $P_{LAC4\text{-}12LR2'}$ promoter were generated (Fig. 6A) which can be differently induced by lactose or galactose. They are characterized by the number of binding sites for the activator KlGal4 (U1, U2, U4, U5; Gödecke et al. (1991)) and the presence/absence of the basal control region BCR. In addition to the constructs shown in Fig. 3A, which were inserted into the KlpURA3 vector, it was possible to generate promoter variants having increased promoter strength by insertion of further binding sites. The result of this is synthetic, lactose-inducible promoters for expanding the vector system and it is possible to realize different protein production or gene expression rates under the same induction conditions.

Example 4.1: Expression of a foreign antigen under the control of various LAC4 promoter variants.

Expression of Etx.B-HA under the control of four *LAC4-12* promoter variants. What were tested were four *LAC4* promoter variants differing in the number of binding sites for the transcription activator KlGal4 and the presence/absence of a control region for basal expression under noninducing conditions (basal control region, BCR; Fig. 6A; SEQ ID No.: 14). Using said promoter variants, the *Kl*pURA3-Et vector variants *Kl*pURA3-PL412-Et, *Kl*pURA3-PL412LR2-Et, *Kl*pURA3-PL4-Et and *Kl*pURA3-PL4LR2 were generated and the Etx.B-HA protein was inserted as test GOI in each case. As described above, the insertion of alternative GOIs is possible via the restriction sites *Asc*I and *Not*I. The expression cassettes were integrated into the *KlURA3* locus and the protein concentration of Etx.B-HA was quantified via western blotting (Fig. 6B). What is shown is that, under identical induction conditions (4 h in complete medium containing lactose), the longest promoter variant $P_{LAC4\text{-}12}$, which

comprises the entire intergenic region between the *LAC4* and *LAC12* gene and contains four KlGal4-binding sites (U1, U2, U4, U5) (Gödecke et al. (1991)), leads to the highest protein concentration. If only the two U1 and U2 binding sites proximal to *LAC4* are present (-1064 to -10), the additional deletion of the BCR (-1540 to -1065) also has a protein-reducing effect under inducing conditions.

Example 5: Raising of antigen production by increasing the copy number of the antigen-encoding gene.

The above-described vector system was therefore modified in order to rapidly and efficiently connect multiple gene copies in series and to introduce this expression cassette in one step at one of the three gene loci (Fig. 7A).

To produce a tandem expression cassette integrable at the *LAC4* locus, three PCR-amplified fragments are fused by any desired KIp3(-MCS)-GOI template in one step (in-fusion cloning): (1 and 2) expression cassette containing $P_{LAC4\text{-}LR2}$ and T_{TEF} (primers: VK30 & VK31, and VK32 & VK33) and (3) LAC4 targeting sequence (VK34 & VK35)). After restriction, for example using *Hpa*I, the tandem expression cassette can be integrated into the *lac4::URA3* locus as described (Fig. 7). After successful integration of the expression cassette, the first foreign gene copy is regulated by either $P_{LAC4\text{-}12}$ or $P_{LAC4\text{-}12\text{-}LR2}$ depending on the starting strain and the second is regulated by $P_{LAC4\text{-}LR2}$. Alternatively, insertion of a selection marker between the two expression cassettes into the restriction sites *Smi*I, *Mlu*I or *Pme*I and removal of the *LAC4* targeting sequence via *Kpn*I give rise to a tandem cassette which can be integrated into the genome in an undirected manner via NHEJ. If the expression cassette is cut out using *Mre*I and *Ava*I, the compatible ends can be ligated and long, multiple expression cassettes can thereby be generated. By repeated restriction using *Mre*I and *Ava*I, fragments in which the expression cassettes are arranged in tandem (head to tail) are enriched in the ligation mix. They are transformed and integrated in an undirected manner under selection for the marker.

Primers:

VK30:

5'-

TATAGGGCGAATTGGAGCTCCGCCGGCGGAAGAGGTAACGCCTTTTGTTAAC-3' (SEQ ID No.: 15)

VK31: 5'-CTAAACGGAACTCGCATTTAAATCTCGTTTTCGACACTGGATGG-3' (SEQ ID No.: 16)

VK32:
5'-
GCGAGTTCCGTTTAGACGCGTTTAAACTTGTTTAATTATTATGGGGCAGGCGAG
A-3' (SEQ ID No.: 17)
VK33: 5'-CGGGGAATGCGCTGCTTTTCGACACTGGATGGCGGCGTTA-3' (SEQ ID No.: 18)
VK34: 5'-GCAGCGCATTCCCCGGGTACCGCTCTCGACTAGGTGATTAGCG-3' (SEQ ID No.: 19)
VK35: 5'-
AAAAGCTGGGTACCGGGCCCACTAGTCGAGAGTTAACCGTGACTACAGCTA-3' (SEQ ID No.: 20)

Example 5.1: Successful use of the multicopy strategy.

The strategy was confirmed using IBDV-VP2 as antigen and a KIp3-derived expression cassette containing two IBDV-VP2-encoding sequences (*CDS-VP2IBDV*) in tandem. The tandem IBDV-VP2 expression cassette (Fig. 7A) in the KIp3 vector (plasmid KIp3-tandem-oVP2T2S, SEQ ID No.: 21) consists of two *LAC4* promoter-regulated encoding sequences for *VP2IBDV* (*CDS-VP2IBDV*) from *Kl*p3-MCS-oVP2T2S (Arnold *et al.*, (2012)). The promoter sequences consist of the region -1123 to -10 of the *LAC4* promoter for the first copy, and -1099 to -10 for the second copy. Both *CDS-VP2IBDV* are flanked at the 3' end by an *AgTEF1* terminator. The plasmid *Kl*p3-tandem-oVP2T2S was cut using *Hpa*I and the restriction material was transformed into strain VAK367-D4. The yeast strain VAK1118 thus generated contains the tandem expression cassette integrated at the *LAC4* locus. As shown by western blotting, there is a higher IBDV-VP2 protein concentration in said strain compared to the isogenic strain having only one copy (Fig. 7B). The tandem expression cassette is genetically highly stable: after growth over 78 generations in inducing medium (YNB + Lactose), none of 100 colonies tested by PCR exhibited a genetic change to the expression cassette (data not shown).

Example 6: Tools for producing prototrophy in *K. lactis* strains for simplified fermentation in synthetic medium and complete medium.

In studies carried out, it had become apparent that uracil-auxotrophic yeast strains grow more poorly in complete medium than uracil-prototrophic strains, an effect which could be neutralized only in part by the addition of uracil. To simplify the fermentation

of the vaccines strains, to facilitate the establishment of the production processes and to make them more cost-efficient and to avoid growth effects due to insufficient uptake of methionine and/or uracil, what should therefore be found are ways of rapidly and reproducibly achieving the neutralization of these auxotrophies that are required for strain construction. For the reconstitution of *KlURA3* from *Klura3-20*, a DNA fragment is generated via PCR with the aid of the primers VK67 and VK69 and the wild-type *KlURA3* gene as template (**Fig. 8A**). To repair the *Klmet5-1* allele, a PCR fragment is analogously generated with the aid of the primers VK74 and VK75 and the wild-type allele *KlMET5* as template (**Fig. 8B**). Transformation of the PCR fragments into the corresponding mutated strains (individually or together) and selection on medium without methionine and/or without uracil led to reconstitution of the wild-type alleles with high efficiency. This process was carried out in order, *inter alia*, to generate the strains VAK1171 and VAK1400 (see above).

Primers

VK67: 5'-GACATCACTGTCTCTTCCCCTTAATGATC-3' (SEQ ID No.: 22)
VK69: 5'-TCAGCAAGCATCAATAATCCCCTTGGTTC-3' (SEQ ID No.: 23)
VK74: 5'-GAAAGAAAGACGTTGGTCTCTACGCTTG-3' (SEQ ID No.: 24)
VK75: 5'-AGATTATAAGTTCCTGGGGCTTTACCCAC-3' (SEQ ID No.: 25)

Example 7: Protective immunization by optimized, inactivated vaccine yeasts

The modifications and optimizations of the *K. lactis* vaccine platform that were carried out as per Examples 1 to 5 were validated in various vaccination studies.

Example 7.1: Immunogenicity of an optimized K. lactis platform, using the example of an IBDV-VP2 yeast strain (VAK1127).

The VAK1127 strain contains a tandem IBDV-VP2 expression cassette (SEQ ID No.: 21), two *KlGAL4* copies and the LR2 deletion in the *LAC4* promoter. To characterize the immunogenicity of the yeast strain, immunization experiments were carried out in the target organism chicken. In challenge experiments, complete protection of SPF chickens against the very virulent (vv) IBDV strain 89163/7.3 (AFSSA, Ploufragan, France) that has been well characterized by Eterradossi and colleagues (1997) was achieved (Table 1 and 2). To this end, in the two experiments independently carried out, 1 mg of lyophilized, heat-inactivated (2 h, 90°C) yeast (VAK1127) with incomplete Freund's adjuvant (IFA) was administered two times (Fig. 9A und B) subcutaneously (prime-boost). The administrations were carried out two weeks and four weeks after

hatching, and the viral exposure (challenge) was effected six weeks after hatching. After 19 days, high titers of anti-IBDV-VP2 antibodies are already measurable in the case of the VAK1127-vaccinated animals. In the controls, titers of anti-IBDV-VP2 antibodies only occur after challenge with vvIBDV (Fig. 9). In both experiments, complete protection (0% morbidity, 0% mortality) of the VAK1127-vaccinated animals against the challenge with vvIBDV was observed (Table 1 und 2). With these experiments, it was possible to observe protection against vvIBDV using a subunit vaccine in a classic primer-boost vaccination method.

The immunogenicity of the vaccine yeasts is not influenced by the genetic back-mutation to antigen-bearing prototrophic yeast strains. It was possible to demonstrate this in a vaccination experiment in mouse with the aid of the auxotrophic form or prototrophic form of an IBDV-VP2 yeast strain (Fig. 10C). The yeast strain VAK1127 (auxotrophic) was, as described above (Example 6; Fig. 8), made prototrophic in two steps using PCR fragments for creating VAK1171. Both strain forms exhibit no significant difference in the expression level of recombinant protein (Fig. 10A and B). The mice were vaccinated three times subcutaneously with 0.1 mg of heat-inactivated yeast subcutaneously with IFA at two-week intervals. It was not possible to establish any difference in the strength of seroconversion between the auxotrophic IBDV-VP2 strain (VAK1127) and the prototrophic descendant (VAK1171) (Fig. 10C).

Example 7.2: Complete protection by vaccination in a '*one-shot*' scheme.

A 'one-shot' vaccination, i.e., vaccination by a single administration of the vaccine, is normally not effective with subunit vaccines owing to lack of immunogenicity. However, the antibody titer-developing data obtained using the optimized strain VAK1127 in the prime/boost method (Fig. 9) indicate the possibility of obtaining protection even in a one-shot approach. This was checked by carrying out a one-shot vaccination with the prototrophic yeast strain VAK1171 (Fig. 11; Table 3). To this end, the yeast was administered only singly, in an elevated dose for this purpose (10 mg), and a challenge was then carried out at an interval of 4 weeks. It became apparent that, with VAK1171, complete protection against vvIBDV (0% morbidity, 0% mortality) can actually be achieved using 'one shot' (Table 3). This result could be attributed to the development of high, protective antibody titers, approx. 20 days after vaccination (Fig. 11). The fact that a one-shot vaccination scheme protects against vvIBDV with a high degree of

protection shows the strong immunogenic potential of the vaccine used and provides impressive validation of the optimized vaccine platform.

Example 7.3: Improved protection of a bivalent yeast vaccine compared to a monovalent yeast vaccine when used against influenza A virus infections.

To vaccinate against influenza virus type A, three different vaccines strains were generated. Firstly, VAK952 (DSM 32705) was generated, which expresses the major antigen of an influenza A strain (Puerto Rico/8/1934; PR8/34), the HA (hemagglutinin) gene. In VAK952, the gene is integrated into the genome into the LAC4 locus as described by Krijger *et al.* (2012) and Arnold *et al.* (2012). Secondly, VAK1283 (DSM 32697) was generated. Here, in addition to the HA gene from PR8/34 in the LAC4 locus, the M1 gene is additionally integrated into the URA3 locus. The M1 gene encodes a further important influenza A antigen which is distinctly more conserved than HA. Reports already published were able to show that combining both antigens can raise the immunogenicity of a vaccine against influenza A and also achieve a cross-protectivity against different influenza viruses. To also validate this aspect with a bivalent yeast vaccine, a further strain (VAK1395; DSM 32706) was generated, which likewise contains the M1 gene in the URA3 locus and where the HA gene from PR8/34 is replaced with the HA gene of the influenza virus California/4/2009. The comparable expression of HA and the additional expression of M1 of the respective strains was checked; it was also shown that the strains exhibit a comparable growth, with VAK1283 having slight advantages over VAK952 (Fig. 12). In vaccination studies in which a prime-boost scheme and one-shot scheme with different yeast concentrations in a mouse model were used in each case, it was shown that VAK952 and VAK1283 each induce comparable titers of virus-neutralizing antibodies (Fig. 13). However, in the challenge experiment, it then became clear that the bivalent VAK1283 vaccine allows maximum protection both in the prime-boost schema and in the one-shot schema, whereas this is not the case with the monovalent VAK952 vaccine. Moreover, with the vaccine VAK1283 in the one-shot experiment at half of the yeast material used, a similar protective effect was achieved as with VAK952 in the prime-boost approach (Fig. 14 and Table 3). In experiments in which VAK1395 was used as vaccine, it was also possible to establish protection against influenza PR8/34. Cross-protection against different influenza variants was thus achieved using a bivalent yeast vaccine.

Table 1

Indications for *exposure* protection in vaccinated SPF chickens

Vaccination (a)			Histopathological bursal lesion assessment					bu/bod index (c)			
Yeast strain (VAK)	VP2 amount per vaccine dose	Adjuvant	0	1	2	3	4	Exposed	Unexposed	Morbidity (%) (d)	Mortality (%) (e)
367	none	IFA	-	-	-	1	7	2.80 ± 1.32	5.36 ± 0.65	6/10 (60)	4/10 (40)
1127	4.1 ± 0.25 µg	IFA	8	-	-	1	-	4.40 ± 0.76	4.89 ± 0.63	0/10	0/10
-	PBS	IFA	-	-	-	-	10	4.08 ± 1.91	4.92 ± 0.94	10/10 (100)	8/10 (80)

Table 2

Indications for *exposure* protection in vaccinated SPF chickens

Vaccination (a)			Histopathological bursal lesion assessment					bu/bod index (c)			
Yeast strain (VAK)	VP2 amount per vaccine dose	Adjuvant	0	1	2	3	4	Exposed	Unexposed	Morbidity (%) (d)	Mortality (%) (e)
1127	4.1 ± 0.71 µg	IFA	6	-	-	-	-	5.10 ± 0.78	4.81 ± 1.20	0/9 (0)	0/9 (0)
-	PBS	IFA	-	-	-	-	8	4.09 ± 1.87	5.32 ± 0.85	9/9 (100)	7/9 (78)

DK/EP 3732293 T3

Table 3

Indications for *exposure* protection in vaccinated SPF chickens

Vaccination (a)			Histopathological bursal lesion assessment					bu/bod index (c)			
Yeast strain (VAK)	VP2 amount per vaccine dose	Adjuvant	0	1	2	3	4	Exposed	Unexposed	Morbidity (%) (d)	Mortality (%) (e)
PBS	none	MF59	-	-	-	-	9	3.73 ± 1.92	4.77 ± 1.02	9/9 (100)	6/9 (66)
VAK367	none	MF59	-	-	-	-	10	4.09 ± 1.58	3.60 ± 0.89	10/10 (100)	9/10 (90)
VAK1171	35 ± 4.2 μg	IFA	10	-	-	-	-	4.48 ± 0.37	3.96 ± 1.02	0/10 (0)	0/10 (0)

Explanatory notes for Table 1

(a) The chickens were vaccinated subcutaneously with 1 mg of yeast (or PBS) and IFA as adjuvant two weeks after hatching. Two weeks after vaccination, they were boosted in the same manner. Another two weeks later, the viral exposure test was carried out via the oculonasal route with 10^4 EID vvIBDV (very virulent 89163/7.3). Inactivated, whole yeast of the strain VAK1127 was used as vaccine yeast, and a group which was only vaccinated with PBS and IFA was used as the infection control. A group in which wild-type yeast without antigen (VAK367) was administered acted as the control for the yeast effect alone.

(b) The histopathological bursal lesion assessment was carried out using a scale of 0-4: 0: no lesions; 1: 5-25% of follicles affected; 2: 26-50% of follicles affected; 3: 51-75% of follicles affected; 76-100% bursal damage (loss of structure).

(c) The mean value of the bursa-to-body weight index (bu/bod) was calculated using the formula: (bursa weight/body weight) * 1000. The nonexposed control group consisted of at least seven chickens, the exposed group ten. The standard deviation is given.

(d) Morbidity is represented as the number of morbid chickens per number of chickens in the group overall. The percentage of morbid chickens is shown between parentheses.

(e) Mortality is represented as the number of dead chickens per number of chickens in the group overall. The percentage of dead chickens is shown between parentheses.

Explanatory notes for Table 2

(a) The chickens were vaccinated subcutaneously with 1 mg of yeast (or PBS) and IFA as adjuvant two weeks after hatching. Two weeks after vaccination, they were boosted in the same manner. Another two weeks later, the viral exposure test was carried out via the oculonasal route with 10^4 EID vvIBDV (very virulent 89163/7.3). Inactivated, whole yeast of the strain VAK1127 was used as vaccine yeast, and a group which was only vaccinated with PBS and IFA was used as the infection control.

(b) The histopathological bursal lesion assessment was carried out using a scale of 0-4: 0: no lesions; 1: 5-25% of follicles affected; 2: 26-50% of follicles affected; 3: 51-75% of follicles affected; 76-100% bursal damage (loss of structure).

(c) The mean value of the bursa-to-body weight index (bu/bod) was calculated using the formula: (bursa weight/body weight) * 1000. The nonexposed control group consisted of at least five chickens, the exposed group nine. The standard deviation is given.

(d) Morbidity is represented as the number of morbid chickens per number of chickens in the group overall. The percentage of morbid chickens is shown between parentheses.

(e) Mortality is represented as the number of dead chickens per number of chickens in the group overall. The percentage of dead chickens is shown between parentheses.

Explanatory notes for Table 3

(a) The chickens were vaccinated subcutaneously with 10 mg of yeast (or PBS) and IFA as adjuvant two weeks after hatching. Four weeks later, the viral exposure test was carried out via the oculonasal route with 10^4 EID vvIBDV (very virulent 89163/7.3). Inactivated, whole yeast of the strain VAK1171 was used as singly yeast vaccine. The infection control used was, firstly, a group vaccinated only with PBS and MF59 and, secondly, a group vaccinated with wild-type yeast and MF59; two weeks after the first vaccination, both were administered a boost containing the same amount of yeast or PBS.

(b) The histopathological bursal lesion assessment was carried out using a scale of 0-4: 0: no lesions; 1: 5-25% of follicles affected; 2: 26-50% of follicles affected; 3: 51-75% of follicles affected; 76-100% bursal damage (loss of structure).

(c) The mean value of the bursa-to-body weight index (bu/bod) was calculated using the formula: (bursa weight/body weight) * 1000. Each group consisted of at least nine chickens. The standard deviation is given.

(d) Morbidity is represented as the number of morbid chickens per number of chickens in the group overall. The percentage of morbid chickens is shown between parentheses.

(e) Mortality is represented as the number of dead chickens per number of chickens in the group overall. The percentage of dead chickens is shown between parentheses.

Sequences

The patent application contains the following sequences as part of the description:

SEQ ID. No.	Designation
1	*K. lactis avt3::LAC9*
2	P*LAC4-12-LR2*
3	*Kl*pURA3 vector
4	*Kl*pMET5 vector
5	*LAC4-12* promoter variant PLAC4-12
6	LAC4-12 promoter variant P*LAC4-12-LR2*
7	LAC4-12 promoter variant P*LAC4*
8	LAC4-12 promoter variant P*LAC4-LR2*
9	Primer sequence VK183
10	Primer sequence VK184
11	Primer sequence MAB6
12	Primer sequence VK71
13	Primer sequence VK211
14	BCR from P*LAC4-12*
15	Primer sequence VK30
16	Primer sequence VK31
17	Primer sequence VK32
18	Primer sequence VK33
19	Primer sequence VK34
20	Primer sequence VK35
21	*Kl*p3-tandem-oVP2T2S

SEQ ID. No.	Designation
22	Primer sequence VK67
23	Primer sequence VK69
24	Primer sequence VK74
25	Primer sequence VK75

References

Arnold, M.; Durairaj, V.; Mundt, E.; Schulze, K.; Breunig, K. D. & Behrens, S.-E.
Protective Vaccination against Infectious Bursal Disease Virus with Whole Recombinant Kluyveromyces lactis Yeast Expressing the Viral VP2 Subunit, *PLoS ONE, Public Library of Science,* **2012**, *7*, e42870

Berthoud, T. K.; Hamill, M.; Lillie, P. J.; Hwenda, L.; Collins, K. A.; Ewer, K. J.; Milicic, A.; Poyntz, H. C.; Lambe, T. & Fletcher, H. A.
Potent CD8+ T-cell immunogenicity in humans of a novel heterosubtypic influenza A vaccine, MVA− NP+ M1, *Clinical infectious diseases, Oxford University Press,* **2011**, *52*, 1-7

Bathurst, I. C.
Protein expression in yeast as an approach to production of recombinant malaria antigens, *The American journal of tropical medicine and hygiene, ASTMH,* **1994**, *50*, 20-26

Breunig, K. D.
Multicopy plasmids containing the gene for the transcriptional activator LAC9 are not tolerated by K. lactis cells, *Current genetics, Springer,* **1989**, *15*, 143-148

de Silva; Chandimal, U.; Tanaka, H.; Nakamura, S.; Goto, N. & Yasunaga, T.
A comprehensive analysis of reassortment in influenza A virus, *Biology open, The Company of Biologists Ltd,* **2012**, *1*, 385-390

Eterradossi, N.; Toquin, D.; Abbassi, H.; Rivallan, G.; Cotte, J. & Guittet, M.
Passive Protection of Specific Pathogen Free Chicks Against Infectious Bursal Disease by In-Ovo Injection of Semi-Purified Egg-Yolk Antiviral Immunoglobulins, *Zoonoses and Public Health, Wiley Online Library,* **1997**, *44*, 371-383

Gellissen, G. & Hollenberg, C. P.
Application of yeasts in gene expression studies: a comparison of Saccharomyces cerevisiae, Hansenula polymorpha and Kluyveromyces lactis-a review, *Gene, Elsevier,* **1997**, *190*, 87-97

Gödecke, A.; Zachariae, W.; Arvanitidis, A. & Breunig, K. D.
Coregulation of the Kluyveromyces lactis lactose permease and β-galactoidase genes is achieved by interaction of multiple LAC9 binding sites in a 2.6 kbp divergnent promoter, *Nucleic acids research, Oxford University Press,* **1991**, *19*, 5351-5358

Granzow, H.; Birghan, C.; Mettenleiter, T. C.; Beyer, J.; Köllner, B. & Mundt, E.
A second form of infectious bursal disease virus-associated tubule contains VP4., *Journal of virology, Am Soc Microbiol,* **1997**, *71*, 8879-8885

Kasanga, C. J.; Yamaguchi, T.; Wambura, P. N.; Maeda-Machang'u, A. D.; Ohya, K. & Fukushi, H.
Molecular characterization of infectious bursal disease virus (IBDV): diversity of very virulent IBDV in Tanzania, *Archives of virology, Springer,* **2007**, *152*, 783-790

Kirchenbaum, G. A. & Ross, T. M.
Eliciting broadly protective antibody responses against influenza, *Current opinion in immunology, Elsevier,* **2014**, *28*, 71-76

Kirunda, H.; Erima, B.; Tumushabe, A.; Kiconco, J.; Tugume, T.; Mulei, S.; Mimbe, D.; Mworozi, E.; Bwogi, J. & Luswa, L.
Prevalence of influenza A viruses in livestock and free-living waterfowl in Uganda, *BMC veterinary research, BioMed Central,* **2014**, *10*, 50

Krammer, F. & Palese, P.
Influenza virus hemagglutinin stalk-based antibodies and vaccines, *Current opinion in virology, Elsevier,* **2013**, *3*, 521-530

Krijger, J.-J.; Baumann, J.; Wagner, M.; Schulze, K.; Reinsch, C.; Klose, T.; Onuma, O. F.; Simon, C.; Behrens, S.-E. & Breunig, K. D.
A novel, lactase-based selection and strain improvement strategy for recombinant protein expression in Kluyveromyces lactis, *Microbial Cell Factories,* **2012**, *11*, 112

Kumar, K.; Singh, K. C. P. & Prasad, C. B.
Immune responses to intermediate strain IBD vaccine at different levels of maternal antibody in broiler chickens, *Tropical animal health and production, Springer,* **2000**, *32*, 357-360

Negash, T.; Gelaye, E.; Petersen, H.; Grummer, B. & Rautenschlein, S.
Molecular evidence of very virulent infectious bursal disease viruses in chickens in Ethiopia, *Avian diseases, BioOne,* **2012**, *56*, 605-610

Rautenschlein, S.; Kraemer, C. H.; Vanmarcke, J. & Montiel, E.
Protective efficacy of intermediate and intermediate plus infectious bursal disease virus (IBDV) vaccines against very virulent IBDV in commercial broilers, *Avian diseases, BioOne,* **2005**, *49*, 231-237

Remington's Practice of Pharmacy, 13th edition and J. of Pharmaceutical Science & Technology, Vol. 52, No. 5, Sept-Oct, pages 238-311

Ridpath, J. F.
Emerging pestiviruses infecting domestic and wildlife hosts, *Animal Health Research Reviews, Cambridge University Press,* **2015**, *16*, 55-59

RKI, *Influenza (Teil 2): Erkrankungen durch zoonotische Influenzaviren* [Influenza (part 2): diseases due to zoonotic influenza viruses], **2016**
Schrauwen, E. J. A. & Fouchier, R. A. M.
Host adaptation and transmission of influenza A viruses in mammals, *Emerging microbes & infections, Nature Publishing Group,* **2014**, *3*, e9

Short, K. R.; Richard, M.; Verhagen, J. H.; van Riel, D.; Schrauwen, E. J. A.; van den Brand, J. M. A.; Mänz, B.; Bodewes, R. & Herfst, S.
One health, multiple challenges: The inter-species transmission of influenza A virus, *One health, Elsevier,* **2015**, *1*, 1-13

Steel, J.; Lowen, A. C.; Wang, T. T.; Yondola, M.; Gao, Q.; Haye, K.; García-Sastre, A. & Palese, P.
Influenza virus vaccine based on the conserved hemagglutinin stalk domain, *MBio, Am Soc Microbiol,* **2010**, *1*, e00018-10

WHO, Influenza (Seasonal), **2016**

WHO, Biologicals, Influenza, **2017**

P A T E N T K R A V

1. *Kluyveromyces lactis (K. lactis)*-stamme til målrettet kloning af fremmed antigen og/eller fremmed proteinkodende nukleinsyre i gærgenomet i *K. lactis*-stammen, kendetegnet ved, at *K. lactis*-stammen ud over *KlLAC4*-locus omfatter integrerede ekspressionskassetter for fremmede antigener ved *KlURA3-20-locus* (*KLLA0E22771g*) og/eller ved *KlMETS-1-locus* (*KLLA0B03938g*), hvor ekspressionskassetterne indeholder *K. lactis LAC4-12*-promotoren (*PLAC4-12*) eller varianter af denne promotor, herunder den intergene region mellem *LAC12* og *LAC4*, den antigen- eller fremmedproteinkodende region og *Ag-TEF1*-terminatoren, og hvor *K. lactis LAC4-12*-promotorvarianterne (*PLAC4-12*) er valgt blandt

- en *LAC4-12*-promotor med en ændret promotorstruktur, som tillader intet eller kun lavt udtryk af fremmed protein under ikke-inducerede betingelser, kendetegnet ved, at den *basale kontrolregion* (BCR) af *PLAC4-12*-promotoren er slettet mellem -1065 og -1540 (LR2-deletion; *PLAC4-12-LR2'*(SEQ ID No.:2)); og
- en *LAC4-12*-promotor med en ændret promotorstruktur, der muliggør en modulering af fremmedproteinekspressionen, kendetegnet ved, at antallet af bindingssteder for promotorens aktivator KlGal4 (»*opstrøms aktiverende sekvenser*« 1, 2 og 4, 5) varierer, og enten 1, 2, 3 eller 4 KlGal4-bindingssteder er til stede.

2. *K.lactis*-stamme ifølge krav 1, kendetegnet ved, at flere kopier af en fremmed antigen-kodende nukleinsyre er indsat i *KILAC4-locus* eller i *KlURA3-20-locus* eller i *KlMET5-1-locus* i de resulterende *K. lactis*-stammer via tandem- eller flere ekspressionskassetter; eller

at en eller flere kopier af forskellige fremmede antigen-kodende nukleinsyrer er indsat i *KILAC4-locus* og/eller *KIURA3-20-locus* og/eller *KIMET5-1-locus* via enkelt-, tandem- eller flere ekspressionskassetter.

3. *K.lactis*-stamme ifølge kravene 1 eller 2, kendetegnet ved, at de kodende gener for de fremmede antigener influenza A/Puerto Rico/8/1934(H1N1) HA og influenza A/Puerto Rico/8/1934(H1N1) M1 er indsat og udtrykt ved *KILAC4*- og *KIURA3-20-loci* i *K. lactis*-stammen.

4. *K.lactis*-stamme ifølge et hvilket som helst af de foregående krav, kendetegnet ved, at *K. lactis*-stammen ud over det genomiske *KIGAL4*-gen indeholder en anden ektopisk kopi af *KIGAL4*-genet.

5. *K.lactis*-stamme ifølge et hvilket som helst af de foregående krav, kendetegnet ved, at genfunktionen af allelerne *Kllac4*, *Klura3-20* og *Klmet5-1* er genoprettet, og at *K. lactis*-stammen er prototrof.

6. *K.lactis*-stamme ifølge et hvilket som helst af de foregående krav, kendetegnet ved, at generne for de fremmede antigener BVDV E2 ectodomain (type 1, CP7), BVDV E2 ectodomain (type 2, New York 93) og BVDV Npro-NS3 (type 1, CP7) er indsat *i KILAC4-, KIURA3-20-* og *KIMet5-1-loci* i *K. lactis*-stammen.

7. *K. lactis*-stamme er valgt fra stammerne:

VAK1283	DSM 32697;
VAK1395	DSM 32706 og
VAK1400	DSM 32698

8. Farmaceutisk sammensætning, der indeholder en *K. lactis* stamme ifølge kravene 1 til 7.

9. *K. lactis-stamme* ifølge et hvilket som helst af kravene 1 til 7 til anvendelse i vaccination.

10. *K. lactis*-stamme til anvendelse ifølge krav 9, kendetegnet ved, at vaccinationen er en beskyttende vaccination.

11. *K. lactis*-stamme til anvendelse ifølge et hvilket som helst af krav 9 eller 10, der omfatter indgivelse til et individ af en *K. lactis*-stamme ifølge et hvilket som helst af krav 1 til 7 i en mængde, der er tilstrækkelig til at fremkalde et beskyttende immunrespons hos individet mod et eller flere fremmede antigener.

12. *K. lactis*-stamme til anvendelse ifølge et hvilket som helst af kravene 9 til 11, kendetegnet ved, at *K. lactis*-stammen indgives subkutant, intramuskulært eller oralt/mukosalt.

13. *K. lactis*-stamme til anvendelse ifølge et af kravene 9 til 11, kendetegnet ved, at *K. lactis*-stammen udløser et beskyttende immunrespons mod et patogen ved en enkelt påføring/immunisering (»*one shot*«) eller ved en dobbelt påføring/immunisering (»*prime-*

boost«).

14. *K. lactis*-stamme til anvendelse ifølge et af kravene 9 til 11, kendetegnet ved, at *K. lactis*-stammen udløser et krydsbeskyttende immunrespons mod forskellige varianter af et patogen i en enkelt påføring/immunisering (»*one shot*«) eller i en dobbelt påføring/immunisering (»*prime-boost*«).

15. *K. lactis*-stamme ifølge et af kravene 9 til 11, kendetegnet ved, at *K. lactis*-stammen udløser et beskyttende immunrespons mod forskellige patogener i en enkelt påføring/immunisering (»*one shot*«) eller i en dobbelt påføring/immunisering (»*prime-boost*«).

Figure 1

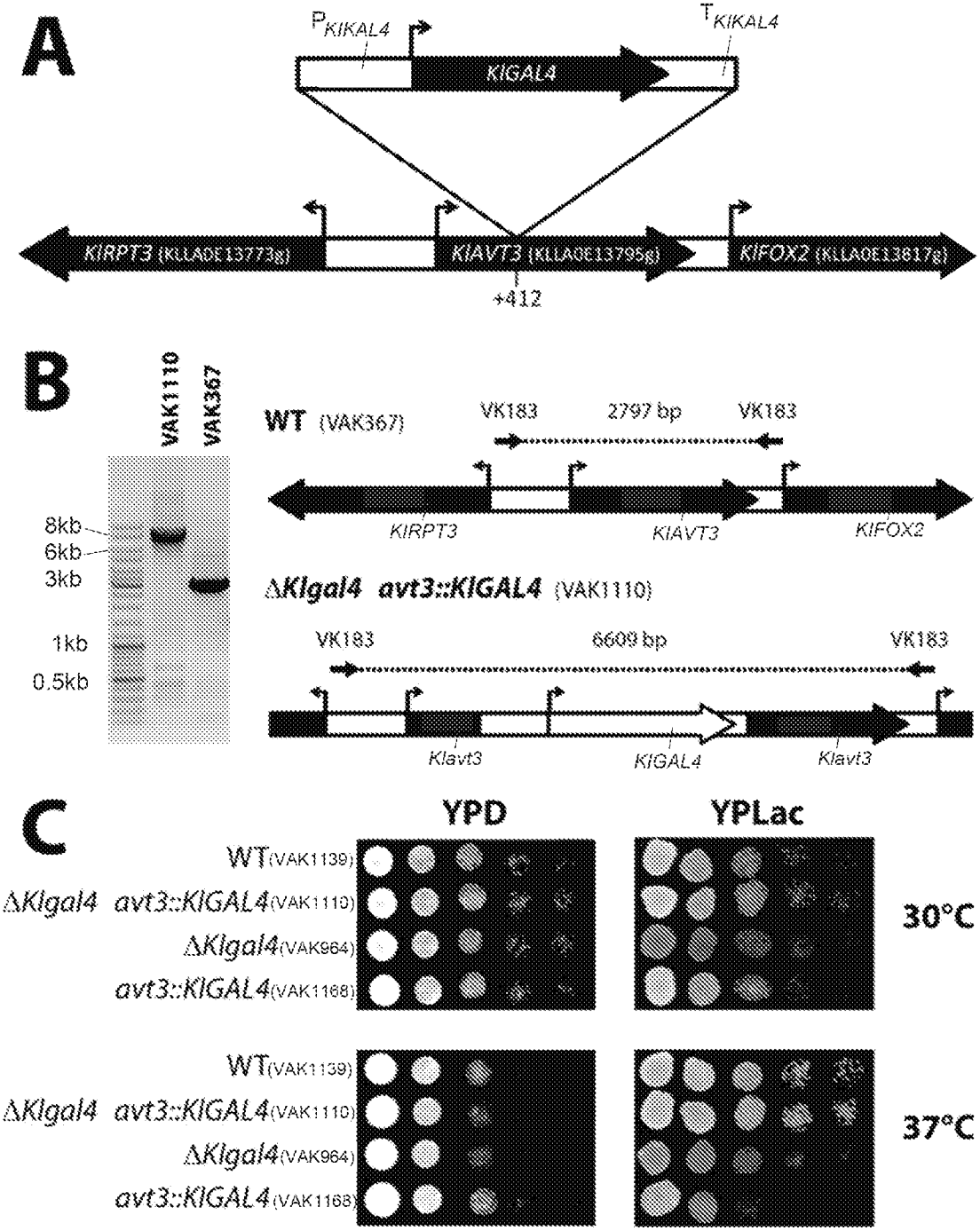

A
P KIKAL4
T KIKAL4
KlGAL4
KlRPT3 (KLLA0E13773g)
KlAVT3 (KLLA0E13795g)
KlFOX2 (KLLA0E13817g)
+412
B
VAK1110
VAK367
8kb
6kb
3kb
1kb
0.5kb
WT (VAK367)
VK183
2797 bp
VK183
KlRPT3
KlAVT3
KlFOX2
ΔKlgal4 avt3::KlGAL4 (VAK1110)
VK183
6609 bp
VK183
Klavt3
KlGAL4
Klavt3
C
YPD
YPLac
WT (VAK1139)
ΔKlgal4 avt3::KlGAL4 (VAK1110)
ΔKlgal4 (VAK964)
avt3::KlGAL4 (VAK1168)
30°C
WT (VAK1139)
ΔKlgal4 avt3::KlGAL4 (VAK1110)
ΔKlgal4 (VAK964)
avt3::KlGAL4 (VAK1168)
37°C

Figure 2

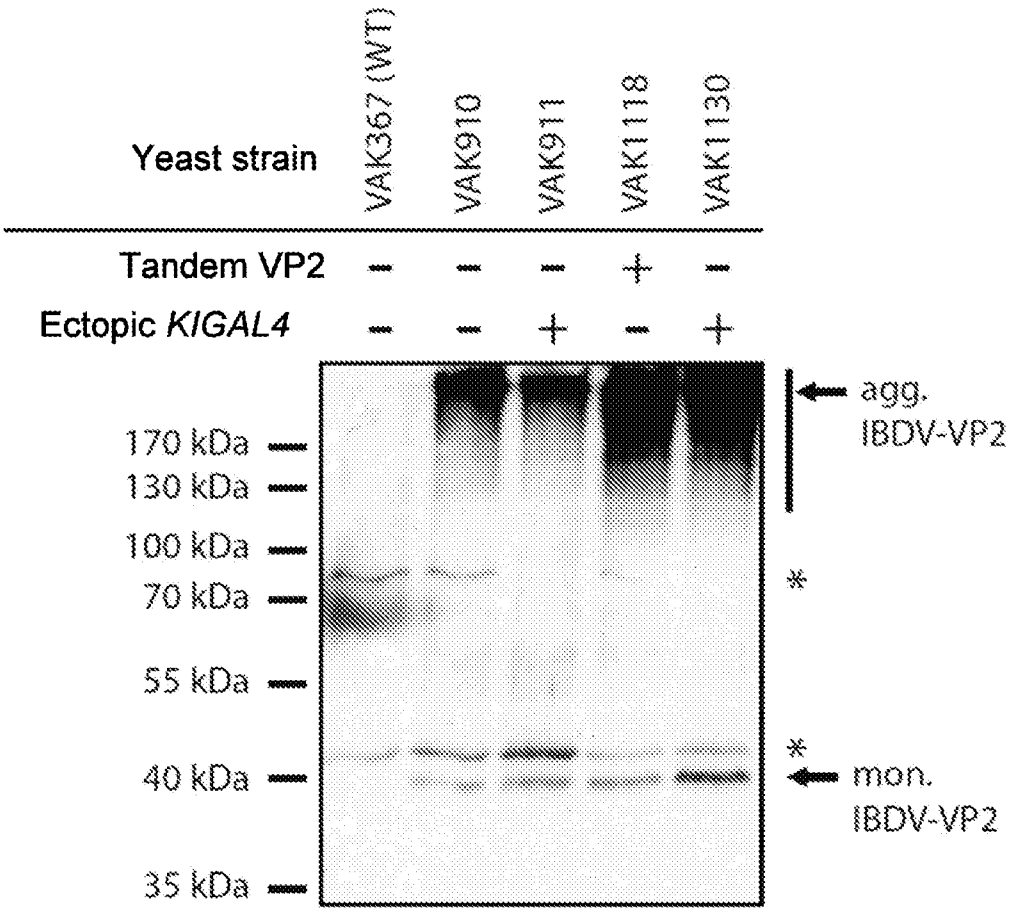

Yeast strain
VAK367 (WT)
VAK910
VAK911
VAK1118
VAK1130
Tandem VP2
Ectopic KIGAL4
170 kDa
130 kDa
100 kDa
70 kDa
55 kDa
40 kDa
35 kDa
agg. IBDV-VP2
*
*
mon. IBDV-VP2

Figure 3

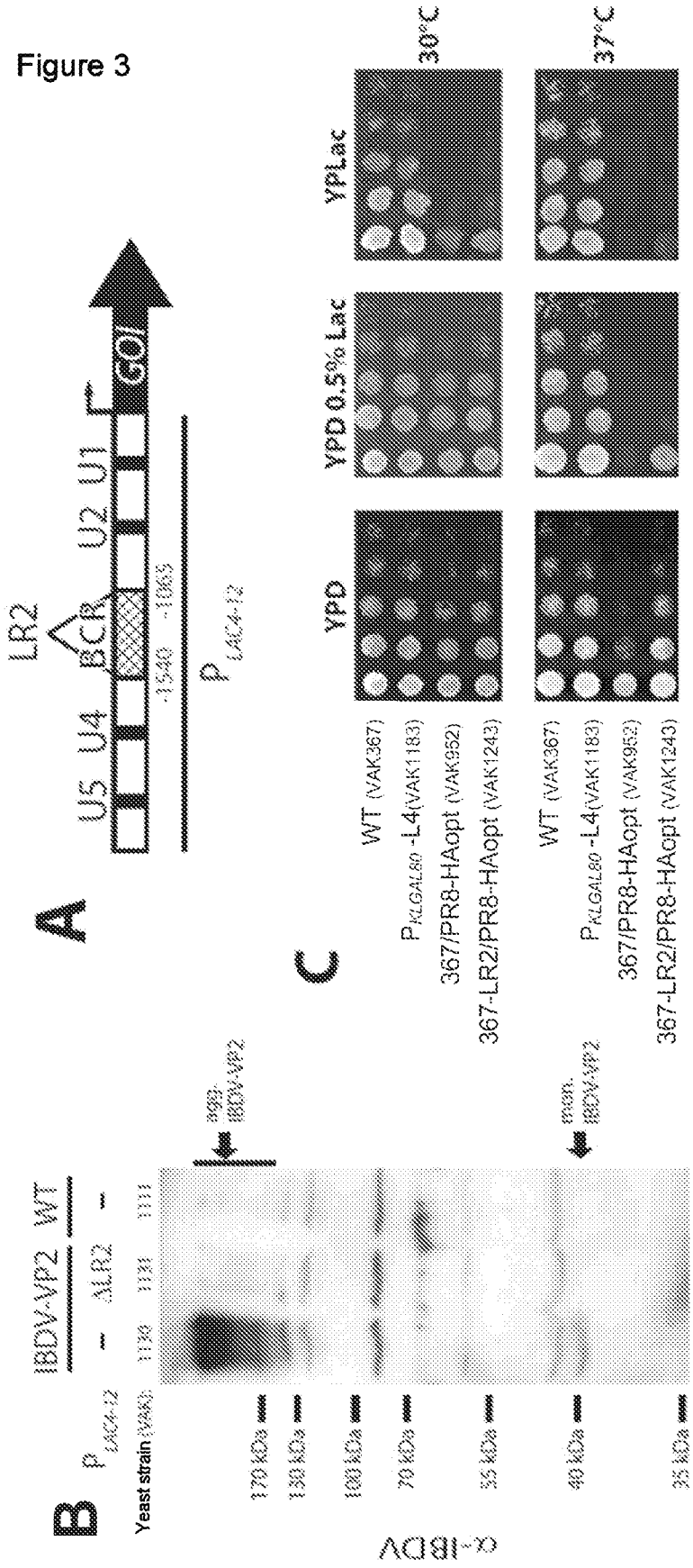

A
LR2
BCR
U5 U4
U2 U1
GOI
-1540
-1063
$P_{LAC4-12}$
B
$P_{LAC4-12}$
IBDV-VP2
WT
-
ΔLR2
-
Yeast strain (VAK)
1130
1131
1111
170 kDa
130 kDa
100 kDa
70 kDa
55 kDa
40 kDa
35 kDa
exp. IBDV-VP2
man. IBDV-VP2
α-IBDV
α-Nopt
Reference (Nopt1)
C
YPD
YPD 0.5% Lac
YPLac
30°C
37°C
WT (VAK367)
$P_{KLGAL80}$-L4(VAK1183)
367/PR8-HAopt (VAK952)
367-LR2/PR8-HAopt (VAK1243)

Figure 4

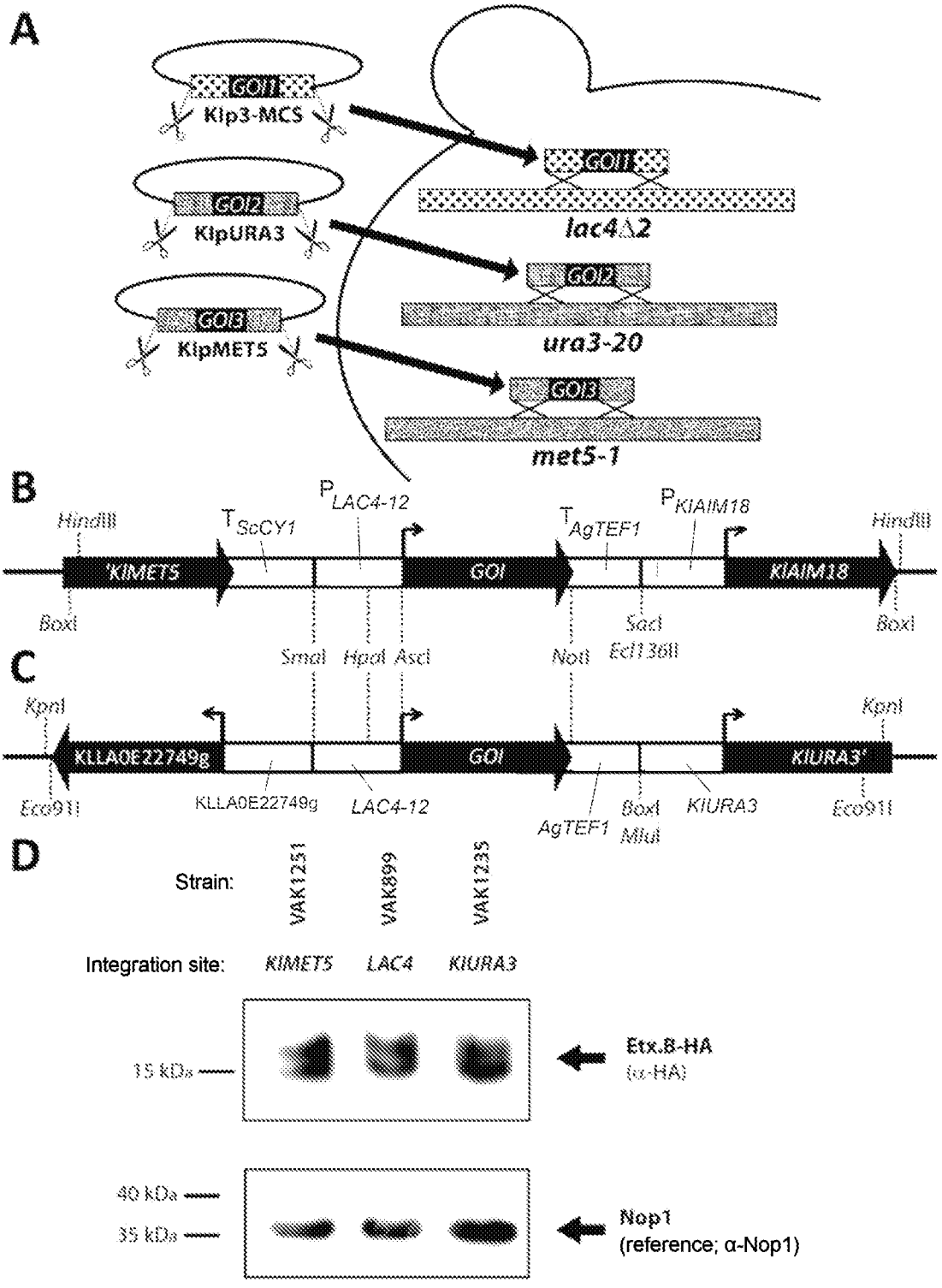

A
GOI1
Klp3-MCS
GOI2
KlpURA3
GOI3
KlpMET5
lac4Δ2
ura3-20
met5-1
B
HindIII
TScCY1
PLAC4-12
TAgTEF1
PKIAIM18
HindIII
'KIMET5
GOI
KIAIM18
BoxI
SacI
Ecl136II
BoxI
SmaI
HpaI
AscI
NotI
C
KpnI
KpnI
KLLA0E22749g
GOI
KIURA3'
Eco91I
KLLA0E22749g
LAC4-12
AgTEF1
BoxI
MluI
KIURA3
Eco91I
D
Strain:
VAK1251
VAK899
VAK1235
Integration site:
KIMET5
LAC4
KIURA3
15 kDa
Etx.B-HA
(α-HA)
40 kDa
35 kDa
Nop1
(reference; α-Nop1)

Figure 5

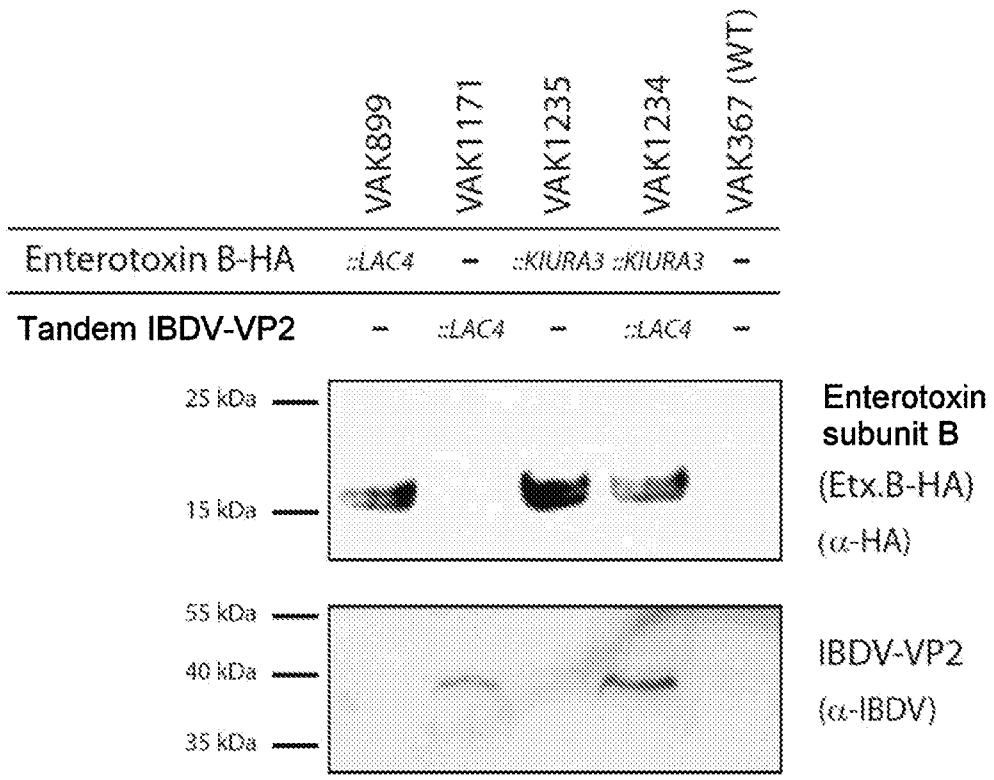

VAK899
VAK1171
VAK1235
VAK1234
VAK367 (WT)
Enterotoxin B-HA
::LAC4
-
::KIURA3
::KIURA3
-
Tandem IBDV-VP2
-
::LAC4
-
::LAC4
-
25 kDa
15 kDa
Enterotoxin subunit B
(Etx.B-HA)
(α-HA)
55 kDa
40 kDa
35 kDa
IBDV-VP2
(α-IBDV)

Figure 6

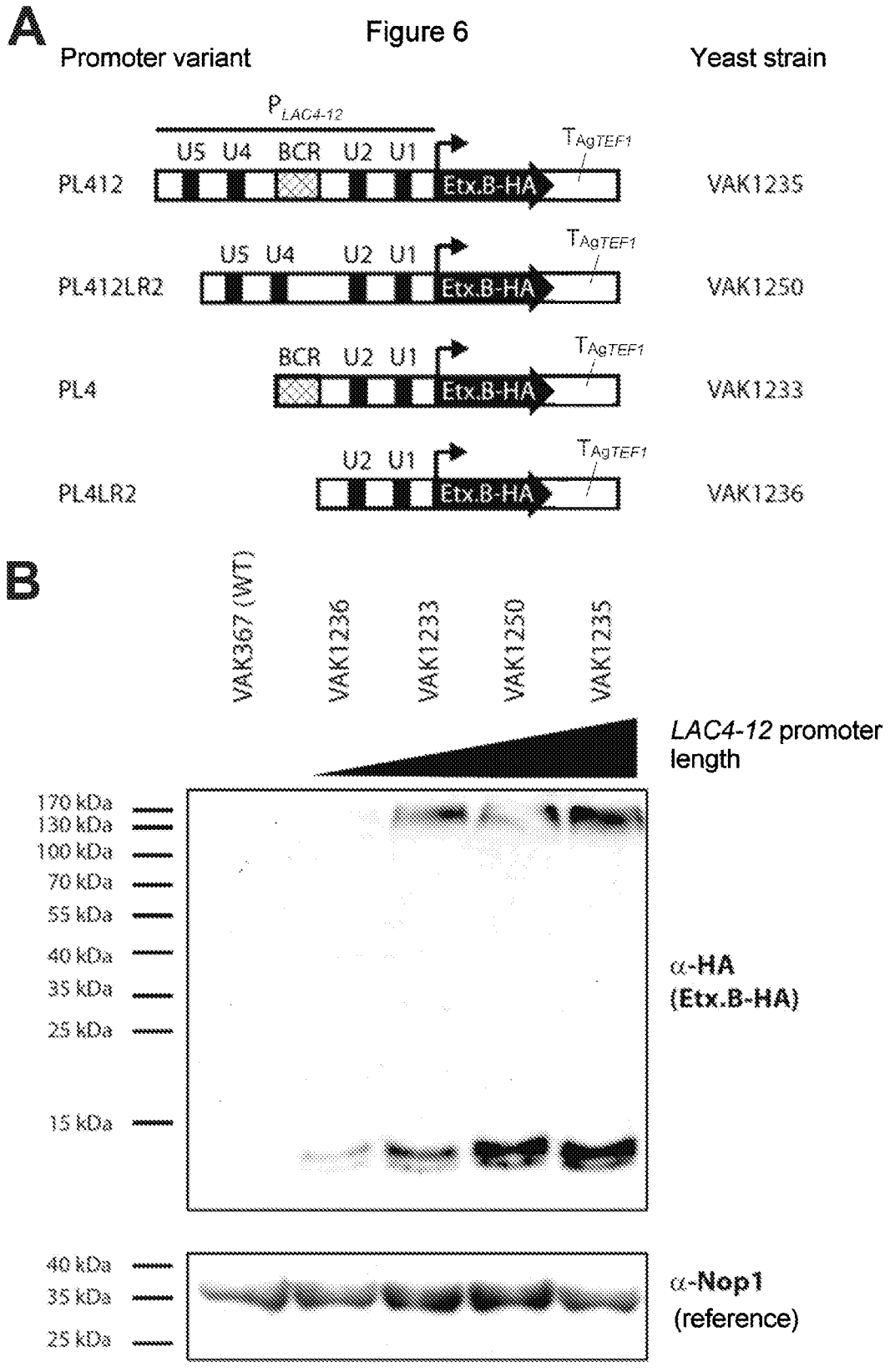

A
Promoter variant
Yeast strain
P LAC4-12
U5 U4 BCR U2 U1
T AgTEF1
Etx.B-HA
PL412
VAK1235
PL412LR2
VAK1250
PL4
VAK1233
PL4LR2
VAK1236
B
VAK367 (WT)
VAK1236
VAK1233
VAK1250
VAK1235
LAC4-12 promoter length
170 kDa
130 kDa
100 kDa
70 kDa
55 kDa
40 kDa
35 kDa
25 kDa
15 kDa
α-HA
(Etx.B-HA)
40 kDa
35 kDa
25 kDa
α-Nop1
(reference)

Figure 7

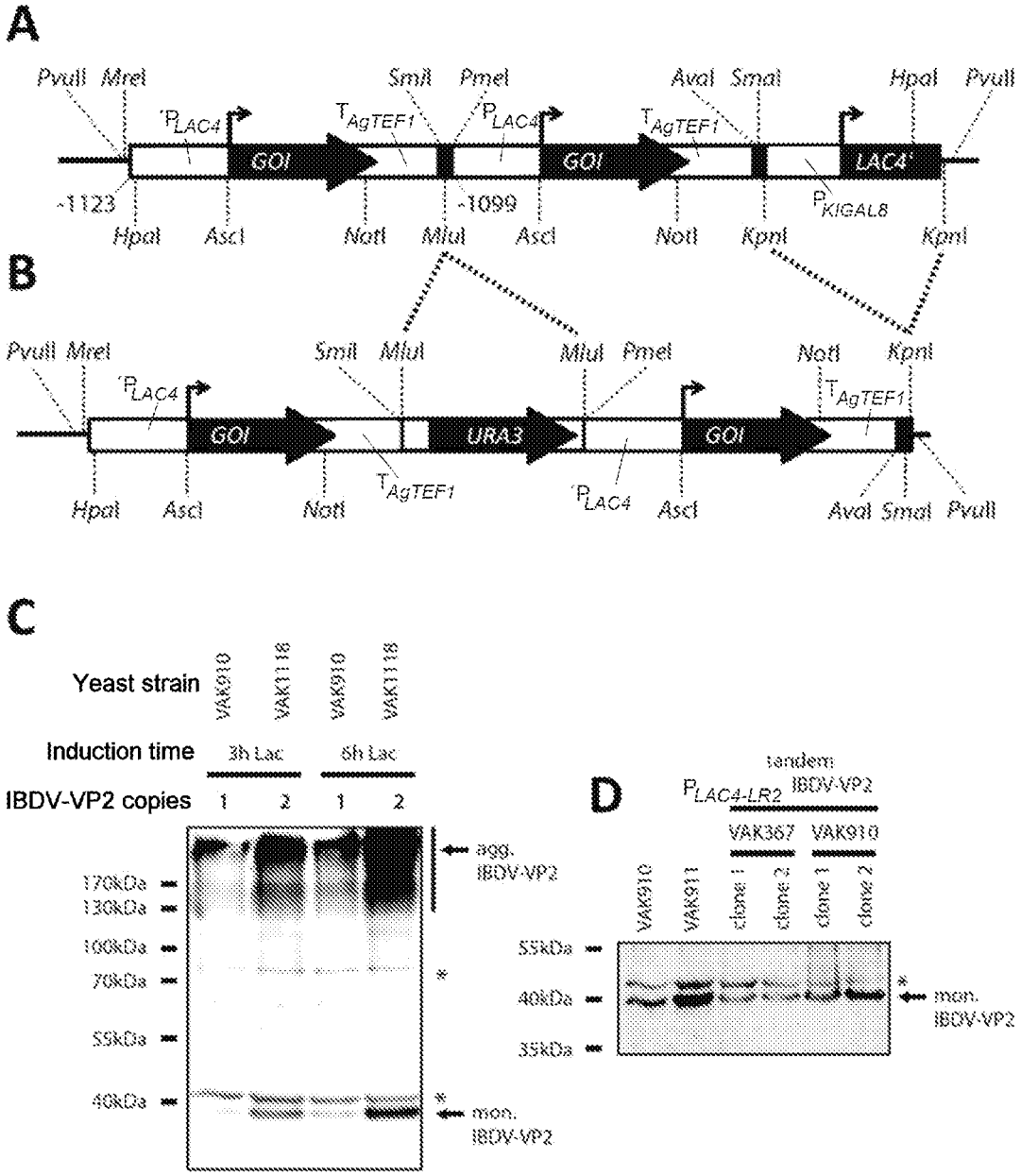

A
PvuII MreI
PLAC4
GOI
TAgTEF1
SmiI PmeI
PLAC4
GOI
TAgTEF1
AvaI SmaI
LAC4'
HpaI PvuII
PKIGAL8
-1123
-1099
HpaI AscI NotI MluI AscI NotI KpnI KpnI
B
PvuII MreI
PLAC4
GOI
SmiI MluI
URA3
MluI PmeI
GOI
NotI KpnI
TAgTEF1
HpaI AscI NotI
TAgTEF1
PLAC4 AscI
AvaI SmaI PvuII
C
Yeast strain
VAK910
VAK1118
VAK910
VAK1118
Induction time
3h Lac
6h Lac
IBDV-VP2 copies
1 2 1 2
170kDa
130kDa
100kDa
70kDa
55kDa
40kDa
agg. IBDV-VP2
*
*
mon. IBDV-VP2
D
tandem
PLAC4-LR2 IBDV-VP2
VAK367
VAK910
VAK910
VAK911
clone 1
clone 2
clone 1
clone 2
55kDa
40kDa
35kDa
*
mon. IBDV-VP2

Figure 8

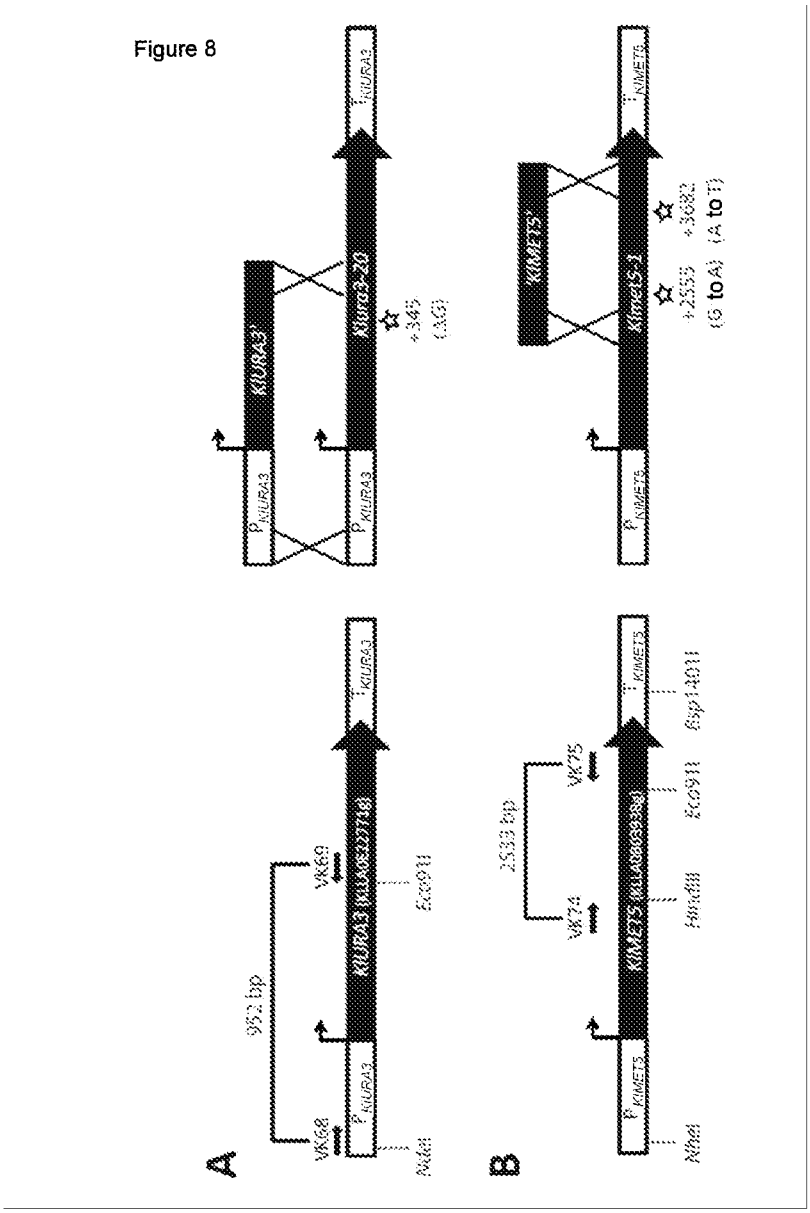

A
B
KURA3
KlmetS-20
KlmetS-1
KMETS'
+365
(ΔG)
+2555
(G to A)
+3682
(A to T)
952 bp
2533 bp
VK68
VK69
VK74
VK75
NdeI
Eco911
HindIII
Eco911
Bsp1407I
NheI

Figure 9

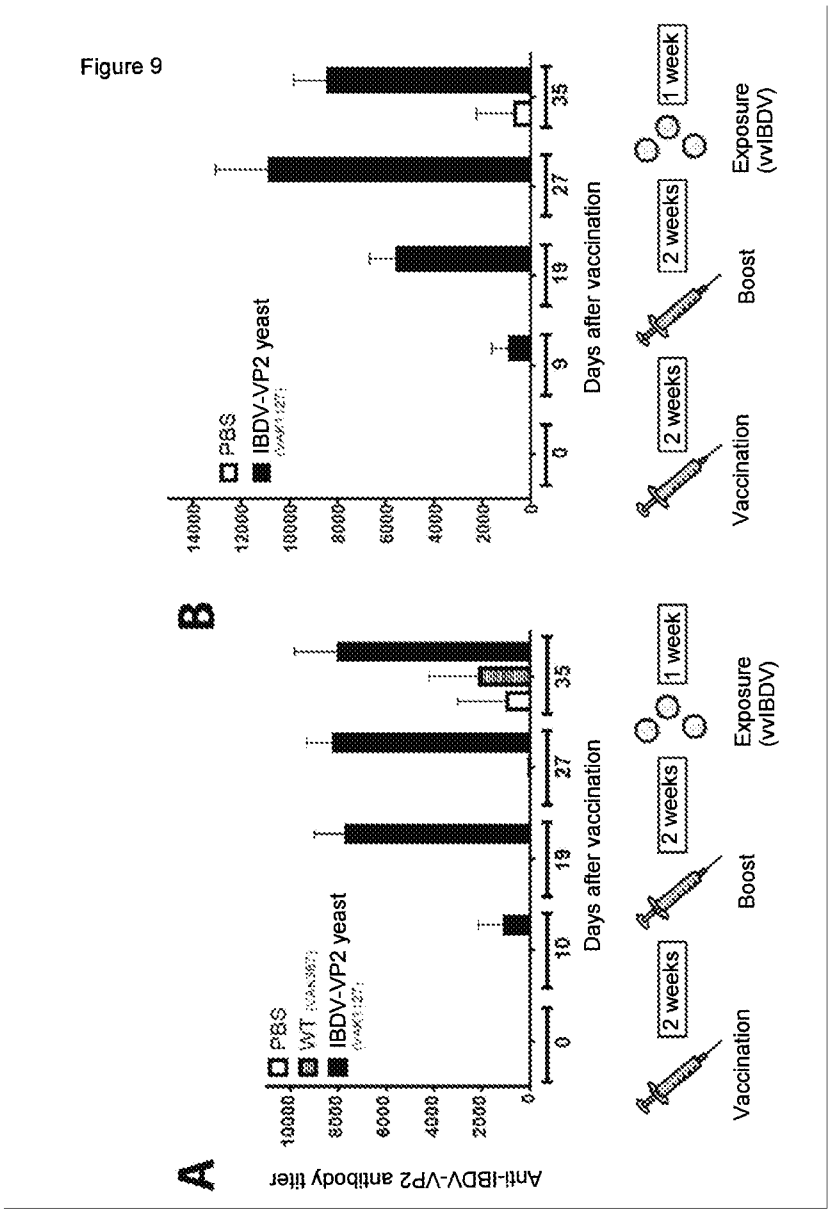

A
Anti-IBDV-VP2 antibody titer
PBS
IBDV-VP2 yeast
Days after vaccination
Vaccination
2 weeks
Boost
2 weeks
Exposure (vvIBDV)
1 week
B
PBS
IBDV-VP2 yeast
Days after vaccination
Vaccination
2 weeks
Boost
2 weeks
Exposure (vvIBDV)
1 week

Figure 10

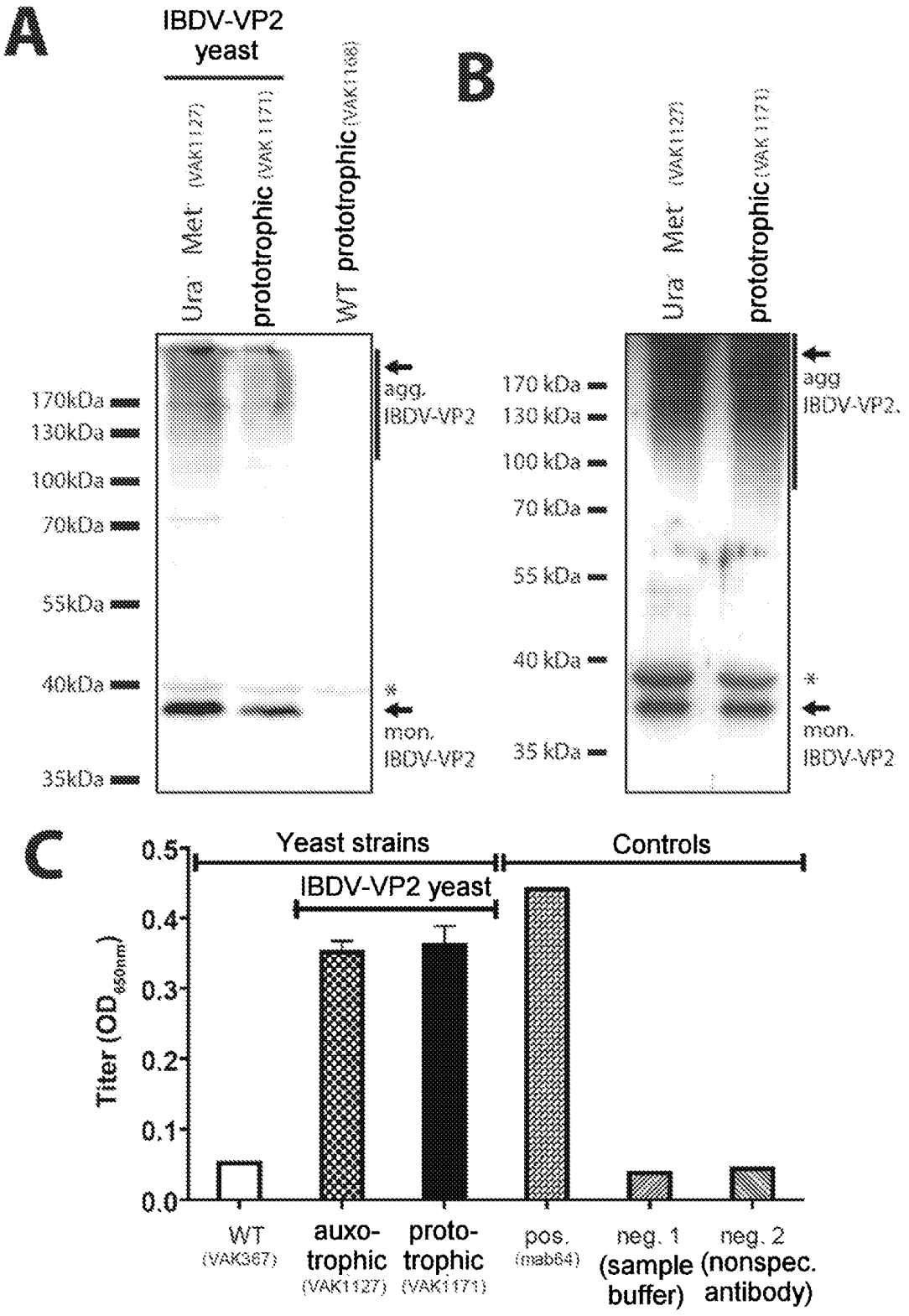

A
IBDV-VP2 yeast
Ura Met (VAK1127)
prototrophic (VAK1171)
WT prototrophic (VAK1168)
170kDa
130kDa
100kDa
70kDa
55kDa
40kDa
35kDa
agg. IBDV-VP2
*
mon. IBDV-VP2
B
Ura Met (VAK1127)
prototrophic (VAK1171)
170 kDa
130 kDa
100 kDa
70 kDa
55 kDa
40 kDa
35 kDa
agg IBDV-VP2.
*
mon. IBDV-VP2
C
Yeast strains
Controls
IBDV-VP2 yeast
Titer (OD650nm)
0.5
0.4
0.3
0.2
0.1
0.0
WT (VAK367)
auxo-trophic (VAK1127)
proto-trophic (VAK1171)
pos. (mab64)
neg. 1 (sample buffer)
neg. 2 (nonspec. antibody)

Figure 11

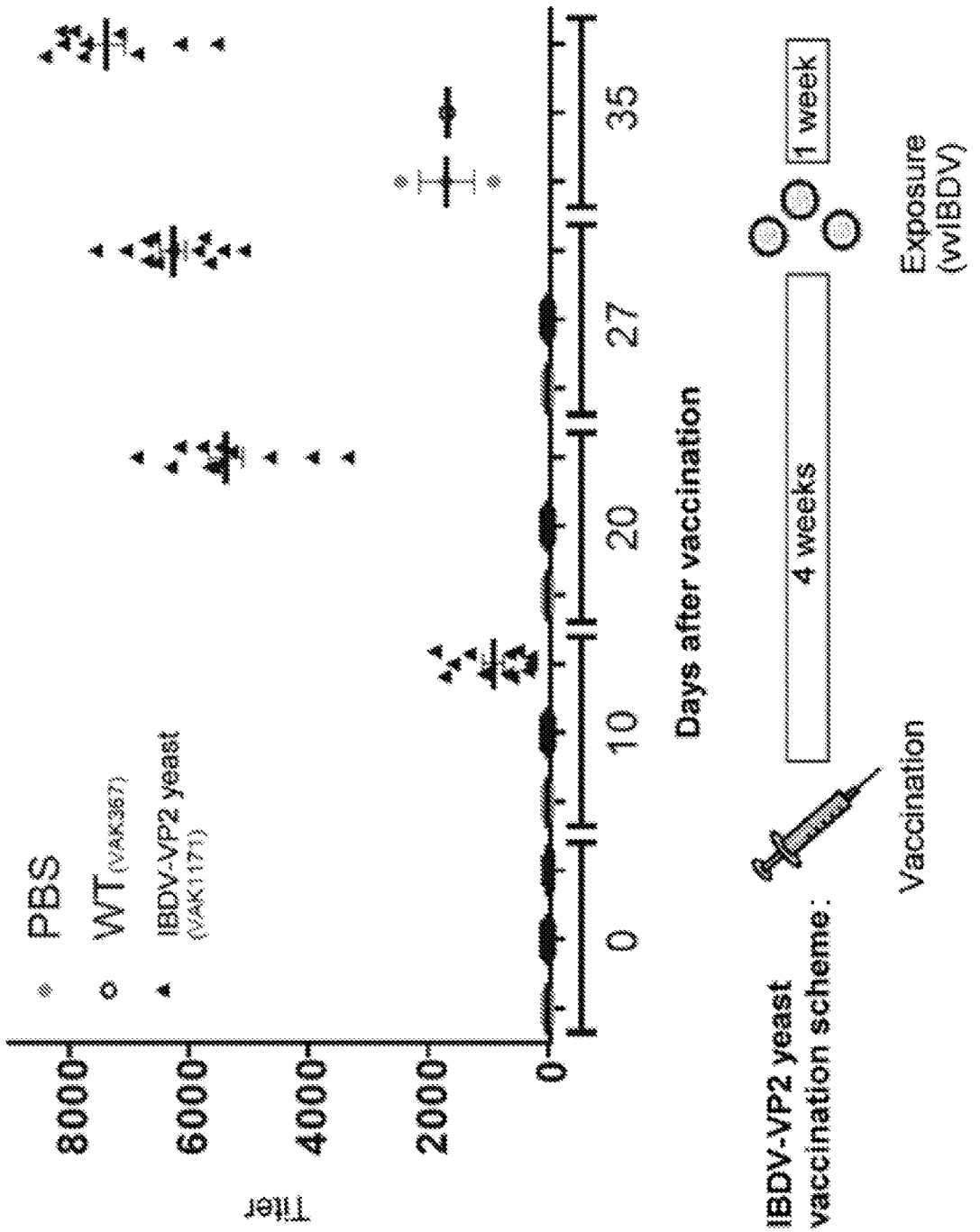

PBS
WT (VAK367)
IBDV-VP2 yeast (VAK1171)
Titer
8000
6000
4000
2000
0
0
10
20
27
35
Days after vaccination
IBDV-VP2 yeast vaccination scheme:
4 weeks
1 week
Vaccination
Exposure (wIBDV)

Figure 12

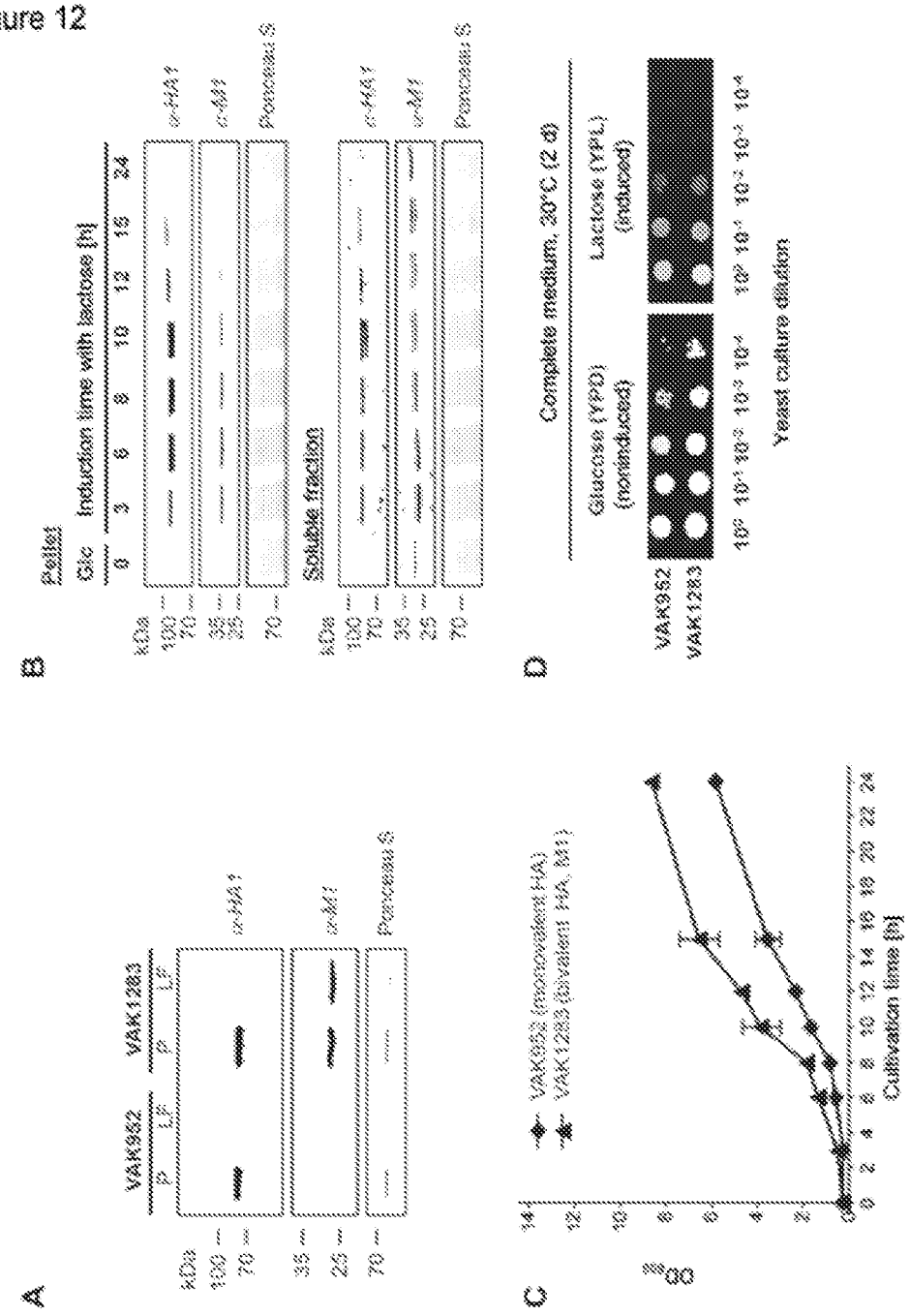

A
VAK952
VAK1283
P
LF
kDa
100
70
35
25
α-HA1
α-M1
Pronase S
B
Pellet
Glc
Induction time with lactose [h]
0
3
6
8
10
12
15
24
Soluble fraction
C
VAK952 (monovalent HA)
VAK1283 (bivalent HA, M1)
OD600
Cultivation time [h]
D
Complete medium, 30°C (2 d)
Glucose (YPD) (noninduced)
Lactose (YPL) (induced)
Yeast culture dilution

Figure 13

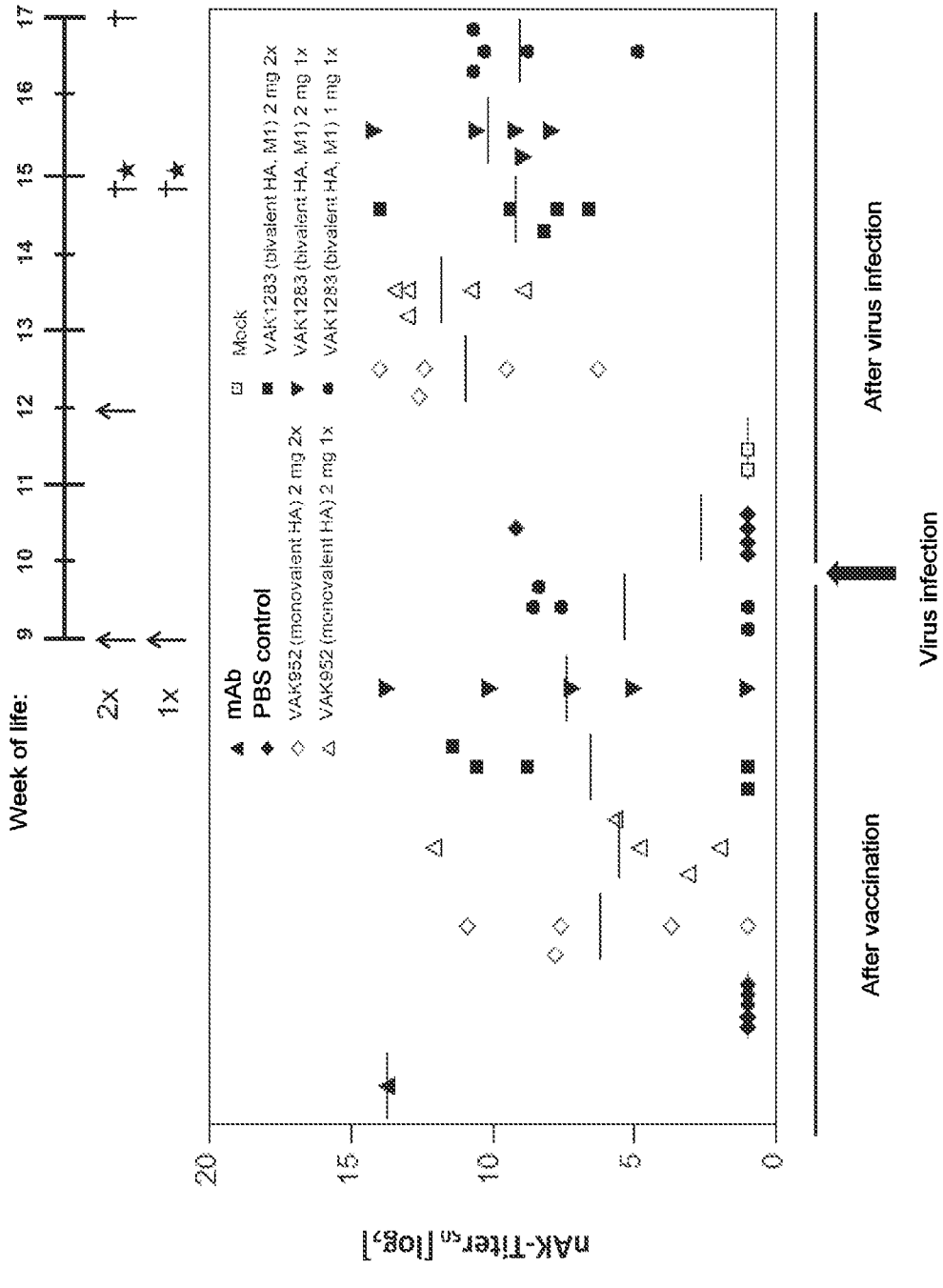
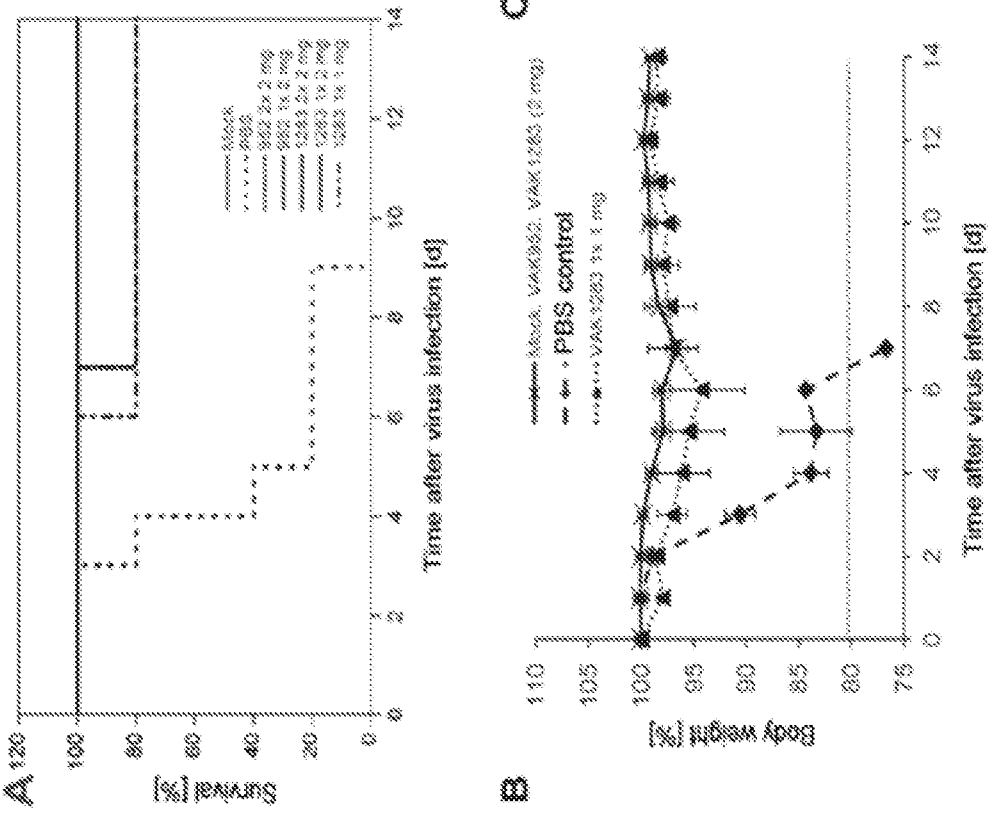

Week of life:
9
10
11
12
13
14
15
16
17
2x
1x
mAb
PBS control
VAK852 (monovalent HA) 2 mg 2x
VAK852 (monovalent HA) 2 mg 1x
Mock
VAK1283 (bivalent HA, M1) 2 mg 2x
VAK1283 (bivalent HA, M1) 2 mg 1x
VAK1283 (bivalent HA, M1) 1 mg 1x
nAk-Titers [log2]
20
15
10
5
0
After vaccination
Virus infection
After virus infection

Figure 14

Treatment	Symptoms		Survival	
PBS control	3/3	100 %	0/3	0 %
Mock	0/5	0 %	5/5	100 %
VAK962 2x 2 mg	1/5	20 %	4/5	80 %
VAK962 1x 2 mg	5/5	0 %	5/5	100 %
VAK1283 2x 2 mg	5/5	0 %	5/5	100 %
VAK1283 1x 2 mg	5/5	0 %	5/5	100 %
VAK1283 1x 1 mg	1/5	20 %	4/5	80 %



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