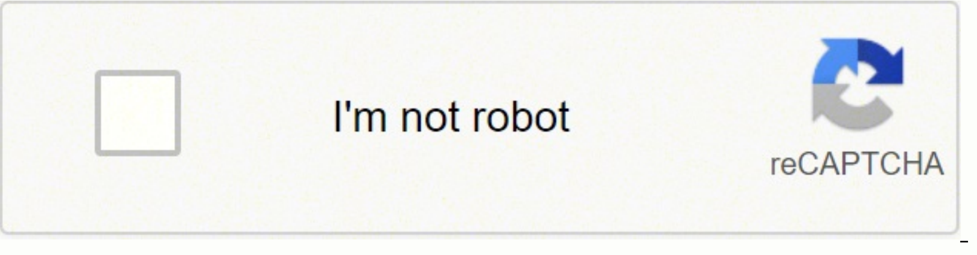

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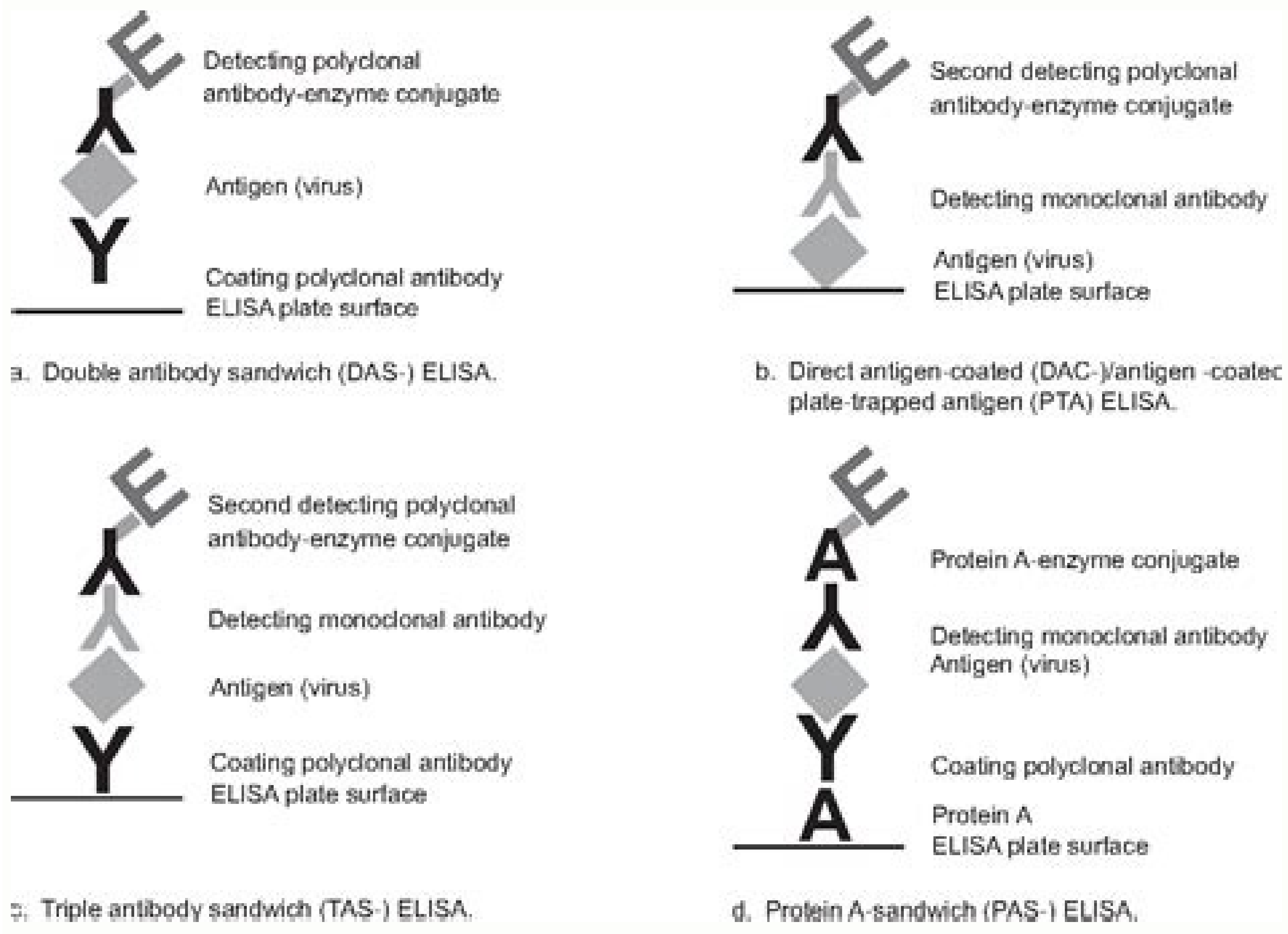
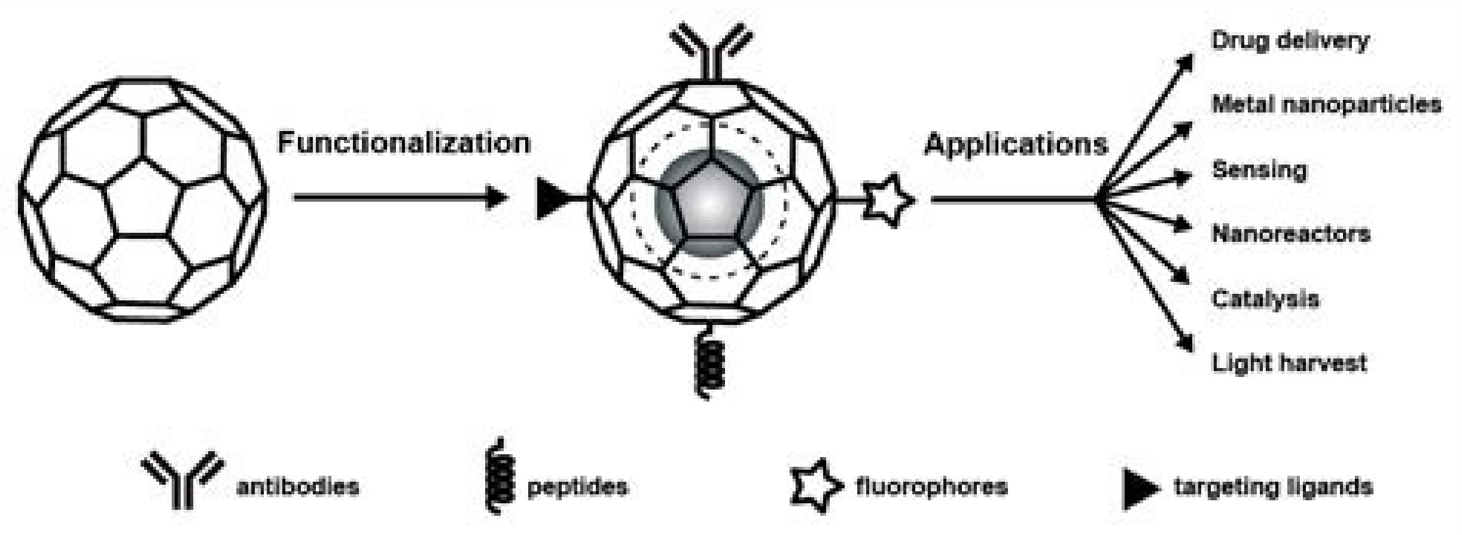


a. Double antibody sandwich (DAS-) ELISA.

b. Direct antigen-coated (DAC-)/antigen -coatec plate-trapped antigen (PTA) ELISA.

c. Triple antibody sandwich (TAS-) ELISA.

d. Protein A-sandwich (PAS-) ELISA.



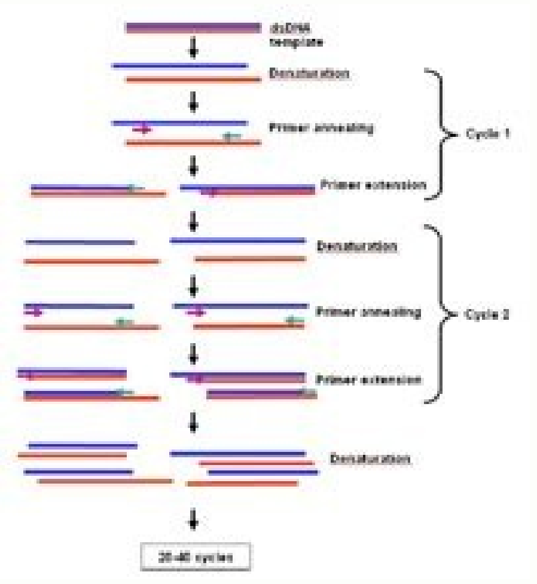
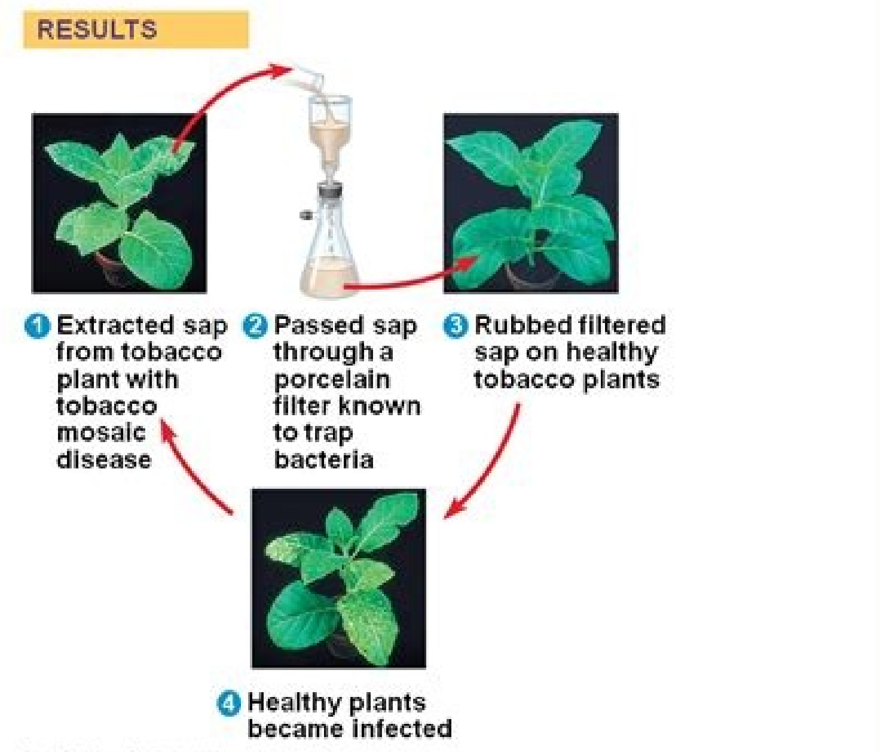


Fig. 19-2



HIV-1 evades antibody-mediated neutralization through conformational masking of receptor-binding sites. CrossRef Full Text | PubMed Abstract | Google Scholar Emerson, S. Rapid, high-yield production in plants of individualized idiotype vaccines for non-Hodgkin's lymphoma. D., Lane, T. Ser. Figure 6. (1967). (2004). E., Commandeur, U., Fischer, R., et al. B., Buonocore, L., Vogel, L., Nachbagauer, R., Krammer, F., and Rose, J. PubMed Abstract | Google Scholar Sainsbury, F., and Lomonossoff, G. Modifications of the tobacco mosaic virus coat protein gene affecting replication, movement, and symptomatology. Like all other rhabdoviruses it has the canonical N, P, M, G, and L genes in a negative sense single stranded RNA genome (Figure 6A). Table 3 provides examples of some current VNP that are being developed as agents used in gene delivery (Azizgolshani et al., 2013), chemotherapy (Sánchez-Sánchez et al., 2014), immunotherapy (Venuti et al., 2015), vaccines (Phelps et al., 2007), and plant virus-assisted sensors (reviewed in Eiben et al., 2018). Conflict of Interest Statement The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The ribonucleoprotein (RNP) unit, consisting of viral RNA associated with the N, L, and P proteins, acts as the template for viral transcription and replication (Yang et al., 1998, 1999; Kawai et al., 1999). U., Simon, I. Clinical development of plant-produced recombinant pharmaceuticals: vaccines, antibodies and beyond. E., Huot, O. Google Scholar Therien, A., Bedard, M., Carignan, D., Rioux, G., Gauthier-Landry, L., Laliberte-Gagne, M. PubMed Abstract | Google Scholar Schnell, M. Recombinant proteins from transgenic plants. D., Brunellière, J., Stephenson, K., Koshy, S., et al. (2009). Virology 214, 50–58. Further experiments revealed that replication of delRNA-2 based molecules was not essential and high yields of recombinant protein expression was still achieved in the absence of RNA-1 (Sainsbury et al., 2008). M., Chichester, J. L. Plant and animal rhabdovirus host range: a bug's view. PubMed Abstract | Google Scholar Mollentze, N., Biek, R., and Streicker, D. Google Scholar Dietzgen, R. Virology 268, 112–121. Ethics 40, 673–681. Vaccine 26, 3395–3403. Vaccines 3, 119–129. Infect. PubMed Abstract | Google Scholar Mclain, L., Porta, C., Lomonossoff, G. 13, 2814–2823. doi: 10.1371/journal.pone.0055538 PubMed Abstract | CrossRef Full Text | Google Scholar Joelson, T., Akerblom, L., Oxelfelt, P., Strandberg, B., Tomenius, K., and Morris, T. Immunotherapy of HPV-associated cancer: DNA/plant-derived vaccines and new orthotopic mouse models. Methods 231, 137–146. Cell 4, 37–43. doi: 10.1016/j.coviro.2018.11.002 PubMed Abstract | CrossRef Full Text | Google Scholar Whitt, M., Chong, L., and Rose, J. Cowpea mosaic virus-based systems for the production of antigens and antibodies in plants. (1998). PLoS Pathog. J., Tsai, C. J., Mebatsion, T., and Conzelmann, K.-K. 1, 72–77. (C) Recombinant epitope (RE) fused to the CP C-terminus using leaky UAG stop codon (Sugiyama et al., 1995). 22, 67–73. 37, D436–D442. S., Chapman, S., Torrance, L., et al. Chimeric plant virus particles administered nasally or orally induce systemic and mucosal immune responses in mice. PubMed Abstract | Google Scholar Whitfield, A. E., Taurog, R. E., Rhodes, R. Structural insights into the rhabdovirus transcription/replication complex. doi: 10.1371/journal.pone.0015559 PubMed Abstract | CrossRef Full Text | Google Scholar Lartey, R. (2002). Assembly and release of HIV-1 precursor Pr55gag virus-like particles from recombinant baculovirus-infected insect cells. U.S.A. 94, 5784–5788. Heterologous sequences greatly affect foreign gene expression in tobacco mosaic virus-based vectors. PubMed Abstract | Google Scholar Rioux, G., Babin, C., Majeau, N., and Leclerc, D. PubMed Abstract | Google Scholar Maxmen, A. E., Koukavica, I., Baz, M., et al. A., and Rose, J. Nano Lett. E., Loveland, J., Johnson, J. benthamiana. Opin. Role of the nucleocapsid protein in regulating vesicular stomatitis virus RNA synthesis. Virology 172, 285–292. However, the real challenge was the co-delivery of all plasmids needed for the recovery of recombinant viruses into a single cell. Digital memory device based on tobacco mosaic virus conjugated with nanoparticles. Vaccine 23, 5751–5759. (1996a). D., Tonks, P., Kliche, A., Kapzan, R., Heeney, J. A., Sainsbury, F., Lomonossoff, G. Most of these attempts have been performed in animal cell systems, but recently plants have also been used as platform for producing eVLPs against avian H5N1 Influenza (Landry et al., 2010). doi: 10.1016/j.biotechadv.2015.04.010 PubMed Abstract | CrossRef Full Text | Google Scholar Cañizares, M. Influenza eVLPs have been produced from the co-expression of the two major antigenic envelope proteins hemagglutinin (HA) and neuraminidase (NA) plus matrix 1 (M1) (Pushko et al., 2005) or from the co-expression of HA and M1 to enable budding (Galarza et al., 2005). 229, 20–27. The inherent genomic characteristics of rhabdoviruses, such as having well-defined transcription start/stop signals (Stillman and Whitt, 1997), and the ability to accommodate large inserts while retaining high level expression rates (Haglund et al., 2000), together with negligible seropositivity in the human population (Roberts et al., 1999) made VSV a lucrative candidate for vaccine development and as vector for a number of biomedical applications such as recombinant viral vaccines (Safronetz et al., 2015; Lauretti et al., 2016), gene delivery vectors (Beier et al., 2013), or oncolytic vectors (Bridle et al., 2009) as exemplified in Table 5. doi: 10.1371/journal.ppat.1004664 PubMed Abstract | CrossRef Full Text | Google Scholar Wang, Q., Chen, X., Luo, Z., and Fang, R. Changes to taxonomy and the international code of virus classification and nomenclature ratified by the international committee on taxonomy of viruses (2018). PubMed Abstract | Google Scholar Steinmetz, N. Furthermore, attempts to produce plant-made eVLP, such as influenza HA VLP, has been so far proven successful only because of the inherent characteristics of the influenza virus HA and its ease of detachment as eVLP from plants cell surface (D'Aoust et al., 2010); a basis for success not necessary applicable in other cases. pGD vectors: versatile tools for the expression of green and red fluorescent protein fusions in agroinfiltrated plant leaves. PubMed Abstract | Google Scholar Jones, R. Similarly, a deconstructed virus strategy was developed for the bipartite RNA1/RNA2 CPMV. Therefore, developments in reverse engineering inherently enveloped plant-viruses such as rhabdoviruses is expected to give plant molecular pharming a platform for a wide range of biotechnological applications, most relevant of which is expressing enveloped VLPs exposing chimeric and complex antigens. PubMed Abstract | Google Scholar Scholthof, H. B., Modi, G. 93, 271–279. A tobacco mosaic virus-hybrid expresses and loses an added gene. 18, 738–748. Vector Res. E. J., Hidalgo, J., Donson, J., Grill, L. The modifications included using a hybrid RdRP [from turnip vein-clearing virus (TVCV)] and Arabidopsis actin 2 (ACT2) as a promoter together with removal of cryptic thymine-rich intron sites plus selective introduction of introns (Marillonnet et al., 2004, 2005). L., Sampaio, K. M., Lima, J., Carrondo, M. doi: 10.1016/j.coviro.2014.07.004 PubMed Abstract | CrossRef Full Text | Google Scholar Moore, L., Hamorsky, K., and Matoba, N. I., Rademacher, T., et al. J., Cicala, C., Leavitt, S. Structure 3, 63–78. A., Buonocore, L., Uprichard, S. J., Alves, P. Potato yellow vein virus: its host range, distribution in South America and identification as a crinivirus transmitted by Trialeurodes vaporariorum. doi: 10.1016/j.coviro.2017.07.019 PubMed Abstract | CrossRef Full Text | Google Scholar Lu, Y., Cesar, E., Nadala, B. Plant rhabdoviruses, share such inherent characteristics, together with dispensability of the G protein for systemic plant-infection as demonstrated with SNYV (Wang et al., 2015). Such chimeric viruses are contained within the plant and require less stringent containment controls. Google Scholar Dawson, W., Lewandowski, D., Hilf, M., Bubrick, P., Raffo, A., Shaw, J., et al. Acta Crystallogr. 7:62. G., Goodin, M. AI, VO, and RK contributed to manuscript revision, and also read and approved the submitted version. Footnotes References Acosta-Ramírez, E., Pérez-Flores, R., Majeau, N., Pastelin-Palacios, R., Gil-Cruz, C., Ramírez-Saldaña, M., et al. Construction of a sonchus yellow net virus minireplicon: a step toward reverse genetic analysis of plant negative-strand RNA viruses. M., and Gelbart, W. Phytopathology 64, 840–845. Biophys. cis-Acting signals involved in termination of vesicular stomatitis virus mRNA synthesis include the conserved AUAC and the U7 signal for polyadenylation. 3, 613–620. PubMed Abstract | Google Scholar Yang, J., Koprowski, H., Dietzschold, B., and Fu, Z. Too fast or not too fast: the FDA's approval of Merck's HPV vaccine Gardasil. (2012). Vesicular stomatitis virus as a novel cancer vaccine vector to prime antitumor immunity amenable to rapid boosting with adenovirus. This hybrid design resulted in a more stable vector that succeeded in the systemic expression of the recombinant protein (Donson et al., 1991). Liquid crystalline substances from virus-infected plants. Google Scholar Albertini, A., Schoehn, G., Weissenhorn, W., and Ruigrok, R. Mutational analysis of the pseudoknot region in the 3' noncoding region of tobacco mosaic-virus RNA. U.S.A. 93, 11359–11365. Technol. Necrotic yellows: a newly recognized virus disease of lettuce. It encodes a total of four proteins two of which are involved in RNA replication plus a movement protein (MP) and a CP (Goelet et al., 1982). (D) Recombinant VSVΔG with foreign protein replacing the inherent VSV glycoprotein. doi: 10.1016/j.virol.2018.06.018 PubMed Abstract | CrossRef Full Text | Google Scholar Zhang, X., and Mason, H. Early research was based on maintaining an unmodified RNA-1 while introducing the recombinant gene to the RNA-2 construct. Moreover, and importantly, these plant-produced HA based eVLP vaccines were found to elicit durable and cross-reactive T cell responses and are currently undergoing clinical trials by Medicago (Landry et al., 2014). Drugs 63, 1021–1051. PubMed Abstract | Google Scholar Conti, M. Formation of wild-type and chimeric influenza virus-like particles following simultaneous expression of only four structural proteins. Plant Sci. doi: 10.1056/NEJMoa1102287 PubMed Abstract | CrossRef Full Text | Google Scholar Ahne, W., Jørgensen, P. Immunother. 87, 10598–10611. K., and Citovsky, V. D., and Rose, J. Figure 4. M., Lomonossoff, G. P. Aquat. G., Kondo, H., Goodin, M. E., Savard, P., et al. Plant J. (1937). doi: 10.1016/bs.aivir.2018.06.001 PubMed Abstract | CrossRef Full Text | Google Scholar Dietzgen, R. PubMed Abstract | Google Scholar Venters, C., Graham, W., and Cassidy, W. Structural aspects of rabies virus replication. M., Shoji, Y., Miura, K., Long, C. R., Jones, T., Longstaff, M., Chapman, S., Bellaby, T., Smith, H., et al. Optimization of human papillomavirus type 16 (HPV-16) L1 expression in plants: comparison of the suitability of different HPV-16 L1 gene variants and different cell-compartment localization. 151, 1075–1084. Hyg. 42, 50–56. Evaluating replication-defective vesicular stomatitis virus as a vaccine vehicle. C., Guo, M., Nasar, F., Johnson, J. B Biol. Trends Biotechnol. The role of viral evolution in rabies host shifts and emergence. doi: 10.1006/viro.1993.1107 PubMed Abstract | CrossRef Full Text | Google Scholar Hogenhout, S. doi: 10.2174/1381612811319990337 PubMed Abstract | CrossRef Full Text | Google Scholar Peyret, H., and Lomonossoff, G. J., Cameron, T. Google Scholar Emerson, S. 145, 1232–1240. (1996). 83, 51–58. Later, agRNA functions as a template for progeny negative-sense gRNA (Albertini et al., 2008; Ivanov et al., 2011). J., Taurog, R. Considering VSV as prototype, the inherent rhabdovirus characteristics of being enveloped, with defined genomic transcription units (Schnell et al., 1996b), genome stability (Walker et al., 2015), and an ability to stably incorporate recombinant glycoprotein into their envelope (Schnell et al., 1996a) make them ideal for various biotechnological applications. U. Diagrams showing different replicon-based expression systems. Table 4. 37, 595–611. L., and Cepko, C. 162, 126–137. Bioconjug. Table 1 lists a number of plant-made pharmaceutical proteins expressed using full-viral vectors. The ability to rescue VSV without its inherent G protein (VSVΔG) gave the opportunity to generate safer non-propagating VSV based vaccines (Roberts et al., 1999). (A) Described replicon design is capable of replication, cell-to-cell movement, transcription, and replication, while designs (B,C) are capable of all, but deficient in cell-to-cell movement. 5, 1931–1936. P., Chernish, R., and Rose, J. C., and Cunha, N. Immunoabsorbent nanoparticles based on a tobamovirus displaying protein A. Google Scholar Tremblay, A., Beauchemin, C., Séguin, A., and Laliberté, J.-F. The tobamovirus capsid protein functions as a host-specific determinant of long-distance movement. PubMed Abstract | Google Scholar Emerson, S. 9, 541–553. O., Couture, M. The family Rhabdoviridae: mono-and bipartite negative-sense RNA viruses with diverse genome organization and common evolutionary origins. Vaccine 9, 545–548. Sci. 137, 7–19. BMC Biotechnol. The production of hemagglutinin-based virus-like particles in plants: a rapid, efficient and safe response to pandemic influenza. 241, 59–67. A., Beigel, J. 17, 1289–1296. Along this idea attempts have been made to produce various eVLPs for vaccine purposes, e.g., against influenza virus (production of eVLPs in insect cells expressing influenza virus structural proteins) (Khurana et al., 2011), HIV (based on virosome, in vitro associated/spiked with an HIV1 gp41-derived peptide) (Leroux-Roels et al., 2013) and breast cancer (based on in vitro association of antigenic peptides to synthesized phospholipid membranes) (Wiedermann et al., 2010). Plant Biotechnol. 56, 473–484. Virology 179, 815–820. 9, 41–71. The production of recombinant pharmaceutical proteins in plants. Cell 106, 539–549. Reactivation of an integrated disabled viral vector using a Cre-loxP recombination system in Arabidopsis thaliana. Agroinfiltration as an effective and scalable strategy of gene delivery for production of pharmaceutical proteins. Virology 441, 12–17. A., Sabatini, B. D., Nancy, P. Google Scholar Vinson, C. PubMed Abstract | Google Scholar Marillonnet, S., Giritch, A., Gils, M., Kandzia, R., Klimyuk, V., and Gleba, Y. To build a virus capsid: an equilibrium model of the self assembly of polyhedral protein complexes. 16, 213–222. Visualization of protein-nucleic acid interactions in a virus - refined structure of intact tobacco mosaic-virus at 2.9-a resolution by X-ray fiber diffraction. SARS vaccine based on a replication-defective recombinant vesicular stomatitis virus is more potent than one based on a replication-competent vector. T., Lane, L. Immunol. doi: 10.1128/JVI.01885-17 PubMed Abstract | CrossRef Full Text | Google Scholar Thanavala, Y., Yang, Y., Lyons, P., Mason, H., and Arntzen, C. D. The first was with the full foreign protein incorporated into the VSV envelope (Figure 6B) while the second was the exoplasmic domain of the foreign protein fused upstream of the transmembrane domain and the cytoplasmic tail of the VSV glycoprotein (Figure 6C). 82, 207–219. Top. (1994). Vaccine 27, 5069–5076. A., Randolph, L. R., Hogenhout, S., Deng, M., and Bragg, J. A., Redinbaugh, M. Google Scholar Dunigan, D. E., Johnson, J. K., et al. (1999). Extremely high-level and rapid transient protein production in plants without the use of viral replication. 66, 275–279. R., Bellaby, T., Helliwell, S. Furthermore, the gRNA is flanked by UTRs termed 3′ leader and 5′ trailer (Fu, 2005) (Figure 5B). 138, 287–298. doi: 10.1021/nn1028696 PubMed Abstract | CrossRef Full Text | Google Scholar Kapadia, S. 77, 8669–8675. doi: 10.1016/j.tibtech.2013.05.013 PubMed Abstract | CrossRef Full Text | Google Scholar Arnheiter, H., Davis, N. Adv. U.S.A. 101, 6852–6857. A vesicular stomatitis virus-based hepatitis B virus vaccine vector provides protection against challenge in a single dose. Systemic expression of a bacterial gene by a tobacco mosaic virus-based vector. Barley yellow striate mosaic virus and associated viroplasms in barley cells. China Ser. doi: 10.3389/fpls.2015.01244 PubMed Abstract | CrossRef Full Text | Google Scholar Nuzzaci, M., Piazzolla, G., Vitti, A., Lapelosa, M., Tortorella, C., Stella, I., et al. L., and Wagner, R. Genet. Acta 25, 87–96. High-yield production of authentic human growth hormone using a plant virus-based expression system. 68, 713–719. 64, 3686–3693. doi: 10.1093/annonc/mdq256 PubMed Abstract | CrossRef Full Text | Google Scholar Benen, T. Extraction and downstream processing of plant-derived recombinant proteins. Clin. G., Lippard, S. PubMed Abstract | Google Scholar Denis, J., Acosta-Ramirez, E., Zhao, Y., Hamelin, M. I., Vojdani, F., Fronefield, M., Levy, R., et al. Tobacco mosaic virus delivery of phenanthriplatin for cancer therapy. Sin. Structures of the native and swollen forms of cowpea chlorotic mottle virus determined by X-ray crystallography and cryo-electron microscopy. F., Trepanier, S., Yassine-Diab, B., et al. 92:e01885-17. The leader and trailer sequences are partially complementary and contain cis-acting signals involved in transcription and replication (Zuidema et al., 1986; Choi et al., 1994; Wang et al., 1999) while short intergenic sequences regulate mRNA synthesis and sequential transcription of the canonical genes (Wetzel et al., 1994; Bandyopadhyay et al., 2010). PLoS One 5:e15559. PubMed Abstract | Google Scholar Yang, S. Virology 202, 33–40. PubMed Abstract | Google Scholar Gillitzer, E., Willits, D., Young, M., and Douglas, T. Plant Dis. Cancer doi: 10.1002/ijc.31556 [Epub ahead of print]. Engl. A., et al. Requirement for a non-specific glycoprotein cytoplasmic domain sequence to drive efficient budding of vesicular stomatitis virus. doi: 10.3390/v7082818 PubMed Abstract | CrossRef Full Text | Google Scholar Gheysen, D., Jacobs, E., de Foresta, F., Thiriart, C., Francotte, M., Thines, D., et al. Manufacturing economics of plant-made biologics: case studies in therapeutic and industrial enzymes. doi: 10.1038/nbt0893-930 PubMed Abstract | CrossRef Full Text | Google Scholar Hendy, S., Chen, Z. K., Drake, P. Immunogenicity of transgenic plant-derived hepatitis B surface antigen. PubMed Abstract | Google Scholar Avesani, L., Marconi, G., Morandini, F., Albertini, E., Bruschetta, M., Bortesi, L., et al. 19, 2288–2301. This negative-sense RNA acts as a template for the synthesis of full-length positive strands and subgenomic RNAs containing MP and CP open reading frames (ORFs) (Ishikawa et al., 1991). Randomized phase I: safety, immunogenicity and mucosal antiviral activity in young healthy women vaccinated with HIV-1 Gp41 P1 peptide on virosomes. Arch. doi: 10.1371/journal.pone.0031925 PubMed Abstract | CrossRef Full Text | Google Scholar Rioux, G., Mathieu, C., Russell, A., Bolduc, M., Laliberte-Gagne, M. doi: 10.1016/0014-5793(95)00054-D PubMed Abstract | CrossRef Full Text | Google Scholar Sun, K., Zhou, X., Lin, W., Zhou, X., Jackson, A. 30, 433–443. This difficulty was circumvented by using Agrobacterium infiltration to co-deliver vectors expressing SYNV helper proteins into N. J., Calderon, P. doi: 10.1016/bs.aivir.2018.06.008 PubMed Abstract | CrossRef Full Text | Google Scholar Jagu, S., Kwak, K., Karanam, B., Huh, W. 28, 107–108. D., and Jackson, A. PubMed Abstract | Google Scholar Speir, J. Structure of the protein disk of tobacco mosaic-virus - subunit interactions and implications for virus assembly. PubMed Abstract | Google Scholar Barr, J. Y. Plant rhabdoviruses—their origins and vector interactions. J., and Yusibov, V. Fluorescent tobacco mosaic virus-derived bio-nanoparticles for intravital two-photon imaging. 6, 82–92. Google Scholar Tomljenovic, L., and Shaw, C. (1997). Rescue of a plant negative-strand RNA virus from cloned cDNA: insights into enveloped plant virus movement and morphogenesis. Cells that express all five proteins of vesicular stomatitis virus from cloned cDNAs support replication, assembly, and budding of defective interfering particles. Nat. M., and Oliveira, R. (D) Coding region of RP cloned in place of the virus CP gene (Takamatsu et al., 1987). G., Akam, M. PubMed Abstract | Google Scholar Tezuka, K., Okuma, K., Kuramitsu, M., Matsuoka, S., Tanaka, R., Tanaka, Y., et al. Res. doi: 10.1094/PDIS.1997.81.1.63 PubMed Abstract | CrossRef Full Text | Google Scholar Cullen, L. N., Whelan, S., and Wertz, G. F., Cadena-Nava, R., Knobler, C. 19, 5587–5600. Bacterial gene inserted in an engineered RNA virus: efficient expression in monocotyledonous plant cells. PubMed Abstract | Google Scholar Chen, S., Yuan, Y., King, D., Chen, K., Lin, R., and Kao, T. doi: 10.1128/JVI.03246-14 PubMed Abstract | CrossRef Full Text | Google Scholar Sabalza, M., Christou, P., and Capell, T. Google Scholar Takamatsu, N., Ishikawa, M., Meshi, T., and Okada, Y. A., Luckay, A., Nixon, D. 33, 198–207. doi: 10.1007/Bf01379132 PubMed Abstract | CrossRef Full Text | Google Scholar Latham, L., Jones, R., and McKirdy, S. (1984). (A) The positive single-stranded RNA genome has four separate ORF(s) with a 5′ terminus methylated nucleotide cap (m7G5′pppG) and 3′-terminus tRNA-like structure. Even among plant-virus based VLP(s), for instance, alfalfa mosaic virus-based Plasmodium falciparum Pfs25 VLP, although it was shown to induce P. R., Petersson, M., van der Pluijm, G., Horninger, W., Erlmann, P., et al. 7, 313–321. 376, 330–341. Find similar proteins by: (by identity cutoff) | 3D StructureMoleculeChainsSequence LengthOrganismDetailsImagecoat proteinA,C [auth B],E [auth C],G

[auth D],I [auth E],A,C [auth B],E [auth C],G [auth D],I [auth E],K [auth F],M [auth G],O [auth H],Q [auth I],S [auth J],U [auth K],W [auth L],Y [auth M],AA [auth N],CA [auth O],EA [auth P],GA [auth Q],IA [auth R],KA [auth S],MA [auth T],OA [auth U],QA [auth V],SA [auth W],UA [auth X]281Watermelon mosaic virusMutation(s): 0 Find proteins for Q70J31 (Watermelon mosaic virus)Go to UniProtKB: Q70J31Sequence Clusters30% Identity50% Identity70% Identity90% Identity95% Identity100% IdentityUniProt GroupQ70J31Find similar nucleic acids by: Sequence | 3D Structure MoleculeChainsLengthOrganismImageRNA (5'-R(P*UP*UP*UP*UP*U)-3')B [auth a],D [auth b],F [auth c],H [auth d],J [auth e],B [auth a],D [auth b],F [auth c],H [auth d],J [auth e],L [auth f],N [auth g],P [auth h],R [auth i],T [auth j],V [auth k],X [auth l],Z [auth m],BA [auth n],DA [auth o],FA [auth p],HA [auth q],JA [auth r],LA [auth s],NA [auth t],PA [auth u],RA [auth v],TA [auth w],VA [auth x]5Watermelon mosaic virusDeposited Date: 2017-07-06 Released Date: 2017-09-27 Deposition Author(s): Zamora, M., Mendez-Lopez, E., Agirrezabala, X., Cuesta, R., Lavin, J.L., Sanchez-Pina, M.A., Aranda, M., Valle, M.Funding OrganizationLocationGrant NumberSpanish Ministry of Economy and CompetitivenessSpainBFU2015-66326-PRevision History (Full details and data files)Version 1.0: 2017-09-27Type: Initial releaseVersion 1.1: 2017-10-11Changes: Database references View PDFVolume 4, Issue 5, September 2011, Pages 813-831 rights and contentMacromolecular trafficking Virology began in 1892 with D. benthamiana cellulose-digested protoplasts were found to be suitable for studying sonchus yellow net virus (SYNV) replication (Jones and Jackson, 1990). (B) Recombinant VSV (rVSV) with foreign protein inserted between the VSV G and L genes. 34, 299–323. Biomed Res. doi: 10.1098/rstb.1999.0405 PubMed Abstract | CrossRef Full Text | Google Scholar Buyel, J., Twyman, R., and Fischer, R. An integrated protein localization and interaction map for Potato yellow dwarf virus, type species of the genus Nucleorhabdovirus. A versatile papaya mosaic virus (PapMV) vaccine platform based on sortase-mediated antigen coupling. doi: 10.1371/journal.pone.0079538 PubMed Abstract | CrossRef Full Text | Google Scholar Jones, R. PubMed Abstract | Google Scholar Donson, J., Kearney, C., Hilf, M., and Dawson, W. M., Latham, T., and Cupo, A. (1978). Nanotechnol. Google Scholar Chichester, J. A., and Matzke, A. Ther. Using transgenic plants and modified plant viruses for the development of treatments for human diseases. Table 2 lists a number of plant-made pharmaceutical proteins expressed using deconstructed-viral vectors. Transgenic Res. With the progeny gRNA assembled as RNP, the M protein converts the extended helical RNP into a condensed form (Kaptur et al., 1991), resulting in the bullet-shape morphology of rhabdoviruses (Mebatsion et al., 1999). Duvenhage virus: morphological, biochemical, histopathological and antigenic relationships to the rabies serogroup. For instance, PapMV-CP-M2e VLP can induced murine anti-M2e antibodies that recognized influenza-infected cells and provided 100% protection (Denis et al., 2008) without any PapMV VLP induced cellular toxicity (Rioux et al., 2014). The first two 5′ proximal ORF(s) encode 126 and 183 kDa readthrough proteins containing methyltransferase (MET), helicase (HEL), and polymerase (POL) domains which are involved in replication and transcription of the genome. Cell 31, 635–642. Folic acid-conjugated protein cages of a plant virus: a novel delivery platform for doxorubicin. 55, 125–130. PubMed Abstract | Google Scholar Pejawar-Gaddy, S., Rajawat, Y., Hilioti, Z., Xue, J., Gaddy, D. Am. J. H., and Conzelmann, K.-K. Development of an antigen presentation system based on plum pox potyvirus. A., and Whitt, M. Studies conducted on the biodistribution and clearance of TMV (Bruckman et al., 2014), PVX and tomato bushy stunt virus (TBSV) (Blandino et al., 2015) in animal models showed no VLP induced pathological damage. They infect both monocotyledonous (Conti and Appiano, 1973) and dicotyledonous (Salazar et al., 2000) plants, harming agricultural production (Chen et al., 1979; Fang et al., 1996). (1927). Expression of an animal virus antigenic site on the surface of a plant virus particle. S. P., Butler, P. L., Ma, L. (1995). Hum. Immunogenicity and safety in newborns of a new recombinant hepatitis B vaccine containing the S and pre-S2 antigens. Plant virus gene vectors for transient expression of foreign proteins in plants. 63, 3569–3578. doi: 10.1073/pnas.79.19.5818 CrossRef Full Text | Google Scholar Goodin, M. Messenger RNA species synthesized in vitro by the virion-associated RNA polymerase of vesicular stomatitis virus. Trop. doi: 10.1007/s11103-013-0036-1 PubMed Abstract | CrossRef Full Text | Google Scholar Phelps, J. 66, 4629–4631. PubMed Abstract | Google Scholar Flanagan, E. Molecular farming of antimicrobial peptides: available platforms and strategies for improving protein biosynthesis using modified virus vectors. Plasmids harboring a positive-sense MR cassette containing two sequentially cloned reporter genes between the SYNV 3′ and 5′ termini together with SYNV helper proteins were co-infiltrated into N. J., Trépanier, S., Guay, J. Translating innate response into long-lasting antibody response by the intrinsic antigen-adjuvant properties of papaya mosaic virus. Reverse genetics on fish rhabdoviruses: tools to study the pathogenesis of fish rhabdoviruses. Virology 200, 401–412. PubMed Abstract | Google Scholar Ganesan, U., Bragg, J. PubMed Abstract | Google Scholar Gopinath, K., Wellink, J., Porta, C., Taylor, K. Plant Viruses as Biological Particles, the Case of Inherently Enveloped Viruses – Rhabdoviruses as an Example The Rhabdoviridae family contains an ecologically diverse group of viruses infecting hosts from a wide plethora of aquatic and terrestrial vertebrates and plants (Kuzmin et al., 2009); rhabdoviruses from different kingdoms are listed Table 4. Analysis of viral-coded guanylyltransferase-like activity. It is expected that the availability and exploitation of enveloped plant viruses as biological particles, in analogy to VSV, will give a boost to the exploitation of plant-based production platforms for more complex (glyco)proteins. doi: 10.1099/vir.0.82718-0 PubMed Abstract | CrossRef Full Text | Google Scholar Majid, A. 1385, 129–137. G., Callaghan, B., and Campbell, P. Life Sci. V., Stepanova, L. F., Abossolo, B. Google Scholar Fujiki, M., Kaczmarczyk, J. Virology 449, 163–173. In this system, structural viral proteins are expressed and incorporated into host membranes released as particles. 50, 125–134. A., Ruiz-Garcia, J., Koay, M. L., and Howard, J. PLoS One 8:e79538. (B) Deconstructed monopartite RNA virus, PVX-based system, where the viral CP and MP were substituted with the GOI under the control of a subgenomic promoter (Komarova et al., 2006). R., Hu, Z., et al. PubMed Abstract | Google Scholar Pattnaik, A. E., Payne, G. Figure 5. Methods 31, 189–195. PubMed Abstract | Google Scholar Kawai, A., Toriumi, H., Tochikura, T. Colloids Surf. doi: 10.1080/21645515.2016.1183857 PubMed Abstract | CrossRef Full Text | Google Scholar Le Tallec, D., Doucet, D., Elouahabi, A., Harvengt, P., Deschuyteneer, M., and Deschamps, M. Plant-produced potato virus X chimeric particles displaying an influenza virus-derived peptide activate specific CD8+ T cells in mice. Nanobiotechnology 12:19. Vaccine 23, 1788–1792. (2018). T., Combescure, C., Fernandes, J. A., Vézina, L. (2006). 441, 379–382. coli or eukaryotic-based systems (Kusnadi et al., 1997; Tusé et al., 2014), and has substantial safety advantage compared to mammalian-cells produced alternatives (Ma et al., 2003). L., Wertz, G., Schubert, M., and Lazzarini, R. 88(Pt 5), 1460–1469. C., Monger, W., Perrin, Y., Tsakiris, E., Porta, C., et al. E., Gorbalenya, A. Genomic RNA is first replicated into agRNA (positive-sense), which is used as template for the production of (accumulating amounts of) progeny gRNA (negative-sense). 89, 2820–2830. PubMed Abstract | Google Scholar Gleba, Y., Marillonnet, S., and Klimyuk, V. A., Mett, V., Jaje, J., Tottey, S., Manceva, S., et al. Lacking the CP, the deconstructed-virus based vectors lacked the ability to encapsidate into viral particles, however, they retained the ability to replicate, transcribe, and translate as shown in Figure 2. G., et al. Google Scholar Yamshchikov, G. (E) rVSV with foreign protein gene inserted upstream of the VSV N protein. Recombinant vesicular stomatitis virus-based dengue-2 vaccine candidate induces humoral response and protects mice against lethal infection. doi: 10.1073/pnas.0608869103 PubMed Abstract | CrossRef Full Text | Google Scholar Wertz, G. E., Wright, K., Calderon, P., et al. Regenmortel and B. doi: 10.1016/j.vaccine.2009.06.045 PubMed Abstract | CrossRef Full Text | Google Scholar Lindbo, J. A new tobacco mosaic-virus vector and its use for the systemic production of angiotensin-I-converting enzyme-inhibitor in transgenic tobacco and tomato. PubMed Abstract | Google Scholar Haglund, K., Forman, J., Kräusslich, H.-G., and Rose, J. Expression of bacterial chloramphenicol acetyltransferase gene in tobacco plants mediated by TMV-RNA. doi: 10.1093/nar/gkn840 PubMed Abstract | CrossRef Full Text | Google Scholar Chen, M. 2014:256135. 74, 7261–7269. Foreign glycoproteins expressed from recombinant vesicular stomatitis viruses are incorporated efficiently into virus particles. H., Koprowski, H., Dietzschold, B., and Fu, Z. PLoS Negl. An effective AIDS vaccine based on live attenuated vesicular stomatitis virus recombinants. English edition: Beijerinck MW (trans: Johnson J). The rhabdoviruses: biodiversity, phylogenetics, and evolution. PubMed Abstract | Google Scholar Fiers, W., De Filette, M., El Bakkouri, K., Schepens, B., Roose, K., Schotsaert, M., et al. E., Shanks, M., Maule, A. S., Takahashi, T., Honda, Y., and Morimoto, K. doi: 10.1128/JVI.01397-13 PubMed Abstract | CrossRef Full Text | Google Scholar Gedvilaite, A., Kucinskaite-Kodze, I., Lasickiene, R., Timinskas, A., Vaitiekaite, A., Ziogiene, D., et al. Engineering of papaya mosaic virus (PapMV) nanoparticles through fusion of the HA11 peptide to several putative surface-exposed sites. Further experiments in 1956 demonstrated that genetic information was stored in RNA molecules (Fraenkel-Conrat et al., 1957) and later the concept of self-assembly of RNA and coat protein (CP) into particles was established (Butler and Klug, 1971). Cucumber mosaic virus as a presentation system for a double hepatitis C virus-derived epitope. Plant Viruses 1, 85–92. Few plant viruses exist that have a naturally occurring envelope. Plant Physiol. (1989). Nature 229, 47–50. PubMed Abstract | Google Scholar Namba, K., Pattanayek, R., and Stubbs, G. R., Martinez-Torrecuadrada, J. J., Johnson, J. Table 2. The pEAQ vector series: the easy and quick way to produce recombinant proteins in plants. P., and Ouyang, J. J., et al. Phosphorylation of rabies virus nucleoprotein regulates viral RNA transcription and replication by modulating leader RNA encapsidation. (2014). Rice Genet. A., and Loh, P. 102, 119–148. “Plant rhabdoviruses,” in Desk Encyclopedia of Plant and Fungal Virology, eds M. 91 (Suppl. doi: 10.1111/j.1467-7652.2009.00496.x PubMed Abstract | CrossRef Full Text | Google Scholar D’Aoust, M. Plant-made proteins expressed using full viral vectors. Google Scholar Stillman, E. These findings support and strengthen the development and exploitation of enveloped plant virus-based vector systems, amenable for genetic manipulation, in plant molecular pharming. C., Bricogne, G., Champness, J. 18, 852–859. (E) Coding region of RP downstream a subgenomic RNA promoter and placed between the MP and the CP genes (Dawson et al., 1989). Dis. 123, 274–320. U.S.A. 88, 1379–1383. 74, 2343–2350. Matrix-glycoprotein interactions required for budding of a plant nucleorhabdovirus and induction of inner nuclear membrane invagination. Nanobiotechnology 15:54. G., Padhi, A., and Rupprecht, C. Plant Biol. 23, 718–723. Expression and purification of vesicular stomatitis virus NP complex from Escherichia coli: role in genome RNA transcription and replication in vitro. Y., Qian, S., et al. A., Tesh, R. Virology 202, 949–955. doi: 10.1155/2014/256135 PubMed Abstract | CrossRef Full Text | Google Scholar Uhde-Holzem, K., Schlösser, V., Viazov, S., Fischer, R., and Commandeur, U. Google Scholar Bawden, F., Pirie, N., Bernal, J., and Fankuchen, I. P., Durrani, Z., and Dimmock, N. 6, 347–357. A bipartite system for the constitutive and inducible expression of high levels of foreign proteins in plants. B. AIDS Res. 19, 913–920. Later on, as we understood more of viral structure and capsid assembly, non-enveloped plant viruses were also manipulated for the generation of chimeric viral particles, nanoagents for carriage of various compounds and nanostructures building blocks. doi: 10.1128/Jvi.77.16.8669-8675.2003 PubMed Abstract | CrossRef Full Text | Google Scholar Osman, T. Virology 197, 366–374. However, lacking the CP, the recombinant virus was unable to spread, and infection was limited to inoculated cells. doi: 10.1021/acsnano.5b07360 PubMed Abstract | CrossRef Full Text | Google Scholar D’Aoust, M. Nature 420, 678–682. On the effect of thermodynamic equilibrium on the assembly efficiency of complex multi-layered virus-like particles (VLP): the case of rotavirus VLP. Influenza virus-like particles comprised of the HA, NA, and M1 proteins of H9N2 influenza virus induce protective immune responses in BALB/c mice. Investigations on a bullet-shaped virus of cereals isolated in Italy from planthoppers. M., and Buck, K. Control of human T-cell leukemia virus type 1 (HTLV-1) infection by eliminating envelope protein-positive cells with recombinant vesicular stomatitis viruses encoding HTLV-1 primary receptor. PubMed Abstract | Google Scholar Chikungunya-vesicular stomatitis chimeric virus targets and eliminates brain tumors. Still this design was unstable and homologous recombination resulted in the loss of inserted sequence and reversion to the wild-type virus (Dawson et al., 1989). PubMed Abstract | Google Scholar Koo, M., Bendahmane, M., Lettieri, G. Cowpea mosaic virus unmodified empty viruslike particles loaded with metal and metal oxide. Precipitation of the virus of tobacco mosaic. In planta engineering of viral RNA replicons: efficient assembly by recombination of DNA modules delivered by Agrobacterium. Appl. Patterned assembly of genetically modified viral nanotemplates via nucleic acid hybridization. D., Vey, M., and Compans, R. Determinants of antibody persistence across doses and continents after single-dose rVSV-ZEBOV vaccination for Ebola virus disease: an observational cohort study. 354, 537–550. Individualized human scFv vaccines produced in plants: humoral anti-idiotype responses in vaccinated mice confirm relevance to the tumor Ig. J. M. PubMed Abstract | Google Scholar Lustig, A., and Levine, A. Google Scholar Bruckman, M. L., and Nettles, V. O., Dietzgen, R. (1980). (Maxmen, 2012). (1992). Together with biosafety concerns (Scholthof et al., 1996), these limitations lead to the development of second-generation vectors in which the virus genome was deconstructed into a replicon containing the essential viral genomic components for replication and gene expression while plant-infection was initiated exogenously. 70, 6227–6234. Philos. Vaccines 9, 805–807. (1979). 13, 4195–4203. 11, 264–271. They classify within the orders Bunyavirales and Mononegavirales, of which the family Rhabdoviridae, and have a negative strand RNA genome (King et al., 2018). doi: 10.1016/j.jmb.2012.05.032 PubMed Abstract | CrossRef Full Text | Google Scholar Yi, H. Generation and characterization of NV gene-knockout recombinant viral hemorrhagic septicemia virus (VHSV) genotype IVa. Dis. Recovery of Rhabdoviruses From cDNA Initial attempts to generate rhabdoviruses from cDNA were based on mammalian rhabdoviruses. PubMed Abstract | Google Scholar Ryder, A. C., Wunner, W. C., and Melcher, U. PubMed Abstract | Google Scholar Agnandji, S. B., Spall, V. Virion-associated L protein transcribes the NC into mRNA of distinct proteins (Moyer and Banerjee, 1975; Toriyama and Peters, 1980). doi: 10.1016/j.virol.2008.03.002 PubMed Abstract | CrossRef Full Text | Google Scholar Kaptur, P. (1990). Infectivity of viral nucleic acid. New viral vector for efficient production of target proteins in plants. A., Reinl, S. (2008). PubMed Abstract | Google Scholar Buonaguro, F. D., Doyle, M. Vaccine 23, 2042–2048. S., Fernandes, J. Commun. R., Adams, M. (C) Deconstructed bipartite RNA plant virus, CPMV-based system, where the RNA-1 component supplies the viral RdRp, virus genome-linked protein, helicase, and protease, while the modified RNA-2 contains the GOI, replacing those of the viral MP and CP (Cañizares et al., 2006). H., Donson, J., della-Cioppa, G., and Grill, L. Organ. 21, 2420–2427. Construction of transgenic rice plants resistant to rice yellow stunt virus, a plant rhabdovirus. Biology and genomics of lettuce necrotic yellows virus. doi: 10.1080/21645515.2017.1329069 PubMed Abstract | CrossRef Full Text | Google Scholar Czapar, A. N., and Johnson, K. 18, 836–843. benthamiana leaves (Goodin et al., 2002). doi: 10.1016/j.vaccine.2014.04.051 PubMed Abstract | CrossRef Full Text | Google Scholar Khurana, S., Wu, J., Verma, N., Verma, S., Raghunandan, R., Manischewitz, J., et al. Biochim. PubMed Abstract | Google Scholar Greber, R. “Transcription of vesicular stomatitis virus,” in The Rhabdoviruses, ed. L., and Atabekov, J. M., and Peluso, R. Tobacco mosaic virus efficiently targets DC uptake, activation and antigen-specific T cell responses in vivo. Immunogenicity and protective efficacy of candidate universal influenza A nanovaccines produced in plants by tobacco mosaic virus-based vectors. 1:103. PubMed Abstract | Google Scholar Smolenska, L., Roberts, I. 292, 119–141. Lettuce big-vein disease: sources, patterns of spread, and losses. Detection and sequence of plus-strand leader RNA of sonchus yellow net virus, a plant rhabdovirus. Plant viruses are not pathogenic to mammals but are recognized by the pathogen associated molecular pattern (PAMP) receptors of the innate immune system (Acosta-Ramírez et al., 2008). Google Scholar Butler, P. (1973). Nature 393, 152–155. PubMed Abstract | Google Scholar Séveno, M., Bardor, M., Paccalet, T., Gomord, V., Lerouge, P., and Faye, L. 43, 623–660. Y., Powers, M. Surprisingly, vector systems based on deleted regions of RNA-2 (delRNA-2) achieved higher expression yields than those obtained with full-length RNA-2 vectors (Sainsbury et al., 2008). Expression of multiple proteins using full-length and deleted versions of cowpea mosaic virus RNA-2. Agric. R., Guzman, H., Wood, T. Viral Immunol. 71, 4264–4271. 422, 263–273. The isolation and some properties of liquid crystalline substances from solanaceous plants infected with three strains of tobacco mosaic virus. Later, Vinson (1927) succeeded in precipitating the pathogen of tobacco mosaic disease, and experiments in 1936 by Bawden and Pirie revealed that this pathogen contained RNA and protein components (Bawden et al., 1936; Bawden and Pirie, 1937). Google Scholar Franken, E., Teuschel, U., and Hain, R. Role of intermolecular interactions of vesicular stomatitis virus nucleoprotein in RNA encapsidation. Recombivax-HB: perspectives past, present and future. (2001). Infectious rabies viruses from cloned cDNA. Nowadays VSV is commonly considered a very successful and widely used platform for heterologous expression of more complex and interesting pharmaceuticals and biomolecules, and for the generation of (pseudo) typed eVLPs for vaccine purposes. doi: 10.1073/pnas.0405844101 PubMed Abstract | CrossRef Full Text | Google Scholar Zhang, X., Green, T. 60, 24–31. 84, 7513–7522. PubMed Abstract | Google Scholar Fang, R.-X., Zhu, H.-T., Wang, Q., Mang, K.-Q., Gao, D.-M., Qin, W.-S., et al. Wagner (Boston, MA: Springer), 245–269. doi: 10.1038/nnano.2007.76 PubMed Abstract | CrossRef Full Text | Google Scholar Carrillo-Tripp, M., Shepherd, C. C., Barker, H., Cruz, S. I., and Garcìa, J. Rapid high-yield expression of full-size IgG antibodies in plants coinfected with noncompeting viral vectors. M., Jones, T. P., Conzelmann, C., et al. J., and Lomonossoff, G. Google Scholar Kemnade, J. Influenza virus-like particles produced by transient expression in Nicotiana benthamiana induce a protective immune response against a lethal viral challenge in mice. Efficient recovery of infectious vesicular stomatitis virus entirely from cDNA clones. U.S.A. 92, 3358–3361. doi: 10.1038/mt.2009.154 PubMed Abstract | CrossRef Full Text | Google Scholar Brisson, N., Paszkowski, J., Penswick, J., Gronenborn, B., Potrykus, I., and Hohn, T. (2016). Evol. PubMed Abstract | Google Scholar Brennan, F. J., Stewart, D., Hitzeroth, I. (2011). V., Gasanova, T. Google Scholar Beier, K. 4, 183–193. U.S.A. 103, 14701–14706. Matrix protein of rabies virus is responsible for the assembly and budding of bullet-shaped particles and interacts with the transmembrane spike glycoprotein G. For instance, the detailed molecular structure knowledge of filamentous viruses such as TMV (Namba et al., 1989), PVX (Parker et al., 2002), TVCV (Lartey et al., 1994), and PapMV (Yang et al., 2012) permitted their use for various applications such as vaccines (Smolenska et al., 1998; Petukhova et al., 2013; Therien et al., 2017), fluorescent markers (Yi et al., 2005), biocatalysts (Carette et al., 2007), nanoparticles for biologics purification (Werner et al., 2006), nanoparticles for in vivo imaging (Niehl et al., 2015), and assembly units for memory devices (Tseng et al., 2006), as shown in Figure 4. doi: 10.3354/dao02394 PubMed Abstract | CrossRef Full Text | Google Scholar Kimpel, J., Urbiola, C., Koske, I., Tober, R., Banki, Z., Wollmann, G., et al. PubMed Abstract | Google Scholar Wiedermann, U., Wiltschke, C., Jasinska, J., Kundi, M., Zurbriggen, R., Garner-Spitzer, E., et al. M., and Noble, S. Vaccine 32, 4228–4233. 31, 530–538. Cell 41, 259–267. Heterologous expression of the modified coat protein of Cowpea chlorotic mottle bromovirus results in the assembly of protein cages with altered architectures and function. M., Bu, F., Knell, J., Robinson, R., and Smith, G. Tech. 72, 3827–3836. With better understanding of particle architecture, biophysical properties, and ability to manipulate their genomic material, these viruses also became exploited as virus-like particles (VLP), self-assembled structures devoid of any genomic material (Huang et al., 2009) and further developed as virus-based nanoparticles (VNP) (Steinmetz et al., 2009). doi: 10.1016/j.enzmictec.2014.04.003 PubMed Abstract | CrossRef Full Text | Google Scholar Schnell, M. Assembly of SIV virus-like particles containing envelope proteins using a baculovirus expression system. Cell 59, 103–112. Coat protein regulates formation of replication complexes during tobacco mosaic virus infection. A., Vardhan, G. doi: 10.1016/j.vaccine.2018.08.033 PubMed Abstract | CrossRef Full Text | Google Scholar Choi, T.-J., Wagner, J. Cell 90, 849–857. PubMed Abstract | Google Scholar Yusibov, V., Streatfield, S. PubMed Abstract | Google Scholar Cobleigh, M. N., and Wertz, G. Google Scholar Aljabali, A. F., Moretto, W. doi: 10.1128/jvi.75.13.6154-6165.2001 PubMed Abstract | CrossRef Full Text | Google Scholar Lauretti, F., Chattopadhyay, A., de Oliveira França, R. M., and Lim, L.-Y. V., Novella, I. W., and Jamin, M. PubMed Abstract | Google Scholar Kumagai, M. Expert Rev. B., Schoeb, T. 163, 2601–2631. J., Wilson, T. Phytopathol. A plant-produced Pfs25 VLP malaria vaccine candidate induces persistent transmission blocking antibodies against Plasmodium falciparum in immunized mice. Production of recombinant snakehead rhabdovirus: the NV protein is not required for viral replication. B., Costa, F. PubMed Abstract | Google Scholar Carette, N., Engelkamp, H., Akpa, E., Pierre, S. (A) Deconstructed monopartite RNA virus, TMV-based system, where the viral CP was substituted with the GOI under the control of a subgenomic promoter (Lindbo, 2007). E., Buonocore, L., and Rose, J. TRBO: a high-efficiency tobacco mosaic virus RNA-based overexpression vector. PubMed Abstract | Google Scholar Fu, Z. F., Castro-Jorge, L., Rose, J., and da Fonseca, B. PubMed Abstract | Google Scholar Roder, J., Fischer, R., and Commandeur, U. Methods 278, 95–104. J., Buonocore, L., Kretzschmar, E., Johnson, E., and Rose, J. Breast Cancer Res. Tobacco mosaic virus belongs to the Tobamovirus genus with a positive sense, single-stranded genomic RNA (gRNA) with a 7-methylguanosine-5-triphosphate cap at the 5′ terminus (Dunigan and Zaitlin, 1990) and a 3′ untranslated region (UTR) harboring a transfer RNA (tRNA)-like structure (Takamatsu et al., 1990) as shown in Figure 1A. E., Zheng, Y.-R., Riddell, I. (1985). Nature 485:160. (1987). Pharm. 24, 233–234. 359, 247–250. G., Freitas-Astúa, J., Chabi-Jesus, C., Ramos-González, P. PubMed Abstract | Google Scholar Huang, Y.-W., Geng, Y.-F., Ying, X.-B., Chen, X.-Y., and Fang, R.-X. Google Scholar Vitti, A., Piazzolla, G., Condelli, V., Nuzzaci, M., Lanorte, M., Boscia, D., et al. The minimal conserved transcription stop-start signal promotes stable expression of a foreign gene in vesicular stomatitis virus. 2002, 2390–2391. doi: 10.1016/j.vaccine.2009.07.007 PubMed Abstract | CrossRef Full Text | Google Scholar Finke, S., Cox, J. M., Schmidt, M. Figure 2. F., et al. D., Kamstrup, S., Dalsgaard, K., et al. doi: 10.1371/journal.pntd.0003736 PubMed Abstract | CrossRef Full Text | Google Scholar Sahithi, K. III, 201–205. N., and Deng, M. 81, 2056–2064. Moreover, further attenuation strategies based on malleability of the rhabdovirus genome, strategies such as decreasing the expression level of viral genes by manipulating their position down the expression gradient (Flanagan et al., 2003) or by G gene truncations and N gene translocations (Clarke et al., 2007) were also considered. Specific cessation of minus-strand RNA accumulation at an early stage of tobacco mosaic-virus infection. doi: 10.3389/fncir.2013.00011 PubMed Abstract | CrossRef Full Text | Google Scholar Beijerinck, M. Sequence analysis of the trailer region of sonchus yellow net virus genomic RNA. 31, 375–383. Table 3. 18, 244–251. Inside the plant cell, the gRNA acts as a messenger RNA (mRNA) template for expressing a 126 kDa protein containing methyltransferase and helicase domains plus a 183 kDa (readthrough) protein containing a polymerase domain (Osman and Buck, 1996; Lewandowski and Dawson, 2000). Sequence analysis of leader and trailer regions of rice yellow stunt rhabdovirus and characterization of their in vivo transcripts. doi: 10.1016/j.virol.2008.08.022 PubMed Abstract | CrossRef Full Text | Google Scholar Galarza, J. A DNA replicon system for rapid high-level production of virus-like particles in plants. A. PubMed Abstract | Google Scholar La Ferla, F. Cienc. doi: 10.1056/NEJMoa1414216 PubMed Abstract | CrossRef Full Text | Google Scholar Ren, Y., Wong, S. E., Douglas, T., and Young, M. (C) Legend of panel (B). Law Med. doi: 10.1016/j.vetmic.2018.12.008 PubMed Abstract | CrossRef Full Text | Google Scholar Sainsbury, F., Lavoie, P. A viable recombinant rhabdovirus lacking its glycoprotein gene and expressing influenza virus hemagglutinin and neuraminidase is a potent influenza vaccine. doi: 10.1016/j.colsurfb.2015.03.039 PubMed Abstract | CrossRef Full Text | Google Scholar Bloomer, A. The importance of RSV F protein conformation in VLPs in stimulation of neutralizing antibody titers in mice previously infected with RSV. 7, 182–188. 2, 226–229. Nucleocapsid formation and/or subsequent conformational change of rabies virus nucleoprotein (N) is a prerequisite step for acquiring the phosphatase-sensitive epitope of monoclonal antibody 5-2-26. Plant rhabdoviruses, like all other viruses of the Rhabdoviridae family are enveloped, negative-sense RNA viruses (Jackson et al., 2005). V., Olesen, N. Animal Rhabdoviruses as a Potential Model for Plant Rhabdoviruses in Plant Molecular Pharming As mentioned earlier, mammalian rhabdoviruses, and in particular vesicular stomatitis virus (VSV), remains the prototype for reverse engineering and molecular adaptation of rhabdoviruses. PLoS One 8:e55438. E., Barker, P. 73, 3723–3732. Magnifection of hybrid TMV-based vectors yielded 4 g/kg of fresh weight tissue (FWT) of recombinant protein and 4.8 g/kg FWT of full immunoglobulin G (IgG) in less than 2 weeks (Bendandi et al., 2010). Table 5. doi: 10.1016/j.jviromet.2010.01.017 PubMed Abstract | CrossRef Full Text | Google Scholar Urbiola, C., Santer, F. “The role of proteins in vesicular stomatitis virus RNA replication,” in The Rhabdoviruses, ed. PubMed Abstract | Google Scholar Leite, M. A., Venkataraman, S., Lander, G., Natarajan, P., et al. Differential transcription attenuation of rabies virus genes by intergenic regions: generation of recombinant viruses overexpressing the polymerase gene. doi: 10.1128/jvi.05406-11 PubMed Abstract | CrossRef Full Text | Google Scholar Kim, M. (2019). M., Bragg, J. doi: 10.1093/emboj/19.5.913 PubMed Abstract | CrossRef Full Text | Google Scholar Chen, Q., Lai, H., Hurtado, J., Stahnke, J., Leuzinger, K., and Dent, M. (1963). Development and immunological assessment of VLP-based immunogens exposing the membrane-proximal region of the HIV-1 gp41 protein. Antigens produced in plants by infection with chimeric plant viruses immunize against rabies virus and HIV-1. List of some of the non-enveloped plant viruses that have been produced for VLP or VNP applications. A., Potapchuk, M. 16, 587–597. Aphid-borne rhabdoviruses–relationships with their vectors. (B) LNYV gRNA (negative-sense) showing the 3′ leader, the N, P, 4b, M, G, and L genes, the 5′ trailer (sequential genes separated by a gene junction) and the transcription gradient. Expression of a bacterial gene in plants by using a viral vector. L., Dias, S. The Red clover necrotic mosaic virus capsid as a multifunctional cell targeting plant viral nanoparticle. Production of a functional single chain antibody attached to the surface of a plant virus. The production of plant virus based VLP(s) were not limited to plants, and a variety of heterologous systems such as insect cells (Lamb et al., 1996), yeast (Brumfield et al., 2004) or Escherichia coli (Denis et al., 2008) have been employed to produce recombinant potato leafroll virus (PLRV), CCMV, and PapMV CP that assemble into viral particles indistinguishable from their plant produced counterparts. PubMed Abstract | Google Scholar Liu, L., Cañizares, M. Evaluation of trichodysplasia spinulosa-associated polyomavirus capsid protein as a new carrier for construction of chimeric virus-like particles harboring foreign epitopes. PubMed Abstract | Google Scholar Sugiyama, Y., Hamamoto, H., Takemoto, S., Watanabe, Y., and Okada, Y. J., Buonocore, L., Boritz, E., Ghosh, H. S., and Johnson, J. Engineering viral expression vectors for plants: the ‘full virus’ and the ‘deconstructed virus’ strategies. Identification of a movement protein of rice yellow stunt rhabdovirus. doi: 10.1007/s10529-014-1621-3 PubMed Abstract | CrossRef Full Text | Google Scholar Safronetz, D., Mire, C., Rosenke, K., Feldmann, F., Haddock, E., Geisbert, T., et al. 75, 6154–6165. Science 66, 357–358. Among the monopartite RNA viruses, potato virus X (PVX) (Komarova et al., 2006) and TMV (Lindbo, 2007) were first to be adopted as a deconstructed-virus vectors. J., Mushegian, A. B., Corn, J. (2017). Transmission of sorghum stunt mosaic rhabdovirus by the leafhopper vector, Graminella sonora (Homoptera: Cicadellidae). A., Rusova, O. doi: 10.1016/j.addr.2018.08.011 [Epub ahead of print]. Production of antibodies in transgenic plants. (2003). 59, 1685–1696. Other applications included development of dormant viral cassettes which can be activated at a custom-chosen stage using chemical inducers, such as ethanol (Zhang and Mason, 2006), or via a Cre-LoxP recombination system (Tremblay et al., 2007). M., Borelli, I. PubMed Abstract | Google Scholar Lockney, D. Methods 166, 12–20. doi: 10.1007/BF02881747 PubMed Abstract | CrossRef Full Text | Google Scholar Wang, Q., Ma, X., Qian, S., Zhou, X., Sun, K., Chen, X., et al. U.S.A. 101, 15556–15560. doi: 10.1016/j.vaccine.2008.04.052 PubMed Abstract | CrossRef Full Text | Google Scholar Dietzgen, R. Assembly of virus-like particles in insect cells infected with a baculovirus containing a modified coat protein gene of potato leafroll luteovirus. Turnip yellow mosaic virus as a chemoaddressable bionanoparticle. Vaccine 17, 1846–1857. Peptide-based candidate vaccine against respiratory syncytial virus. E., Kim, C. Similarly to VSV-recombinant design, plant rhabdovirus vector constructs can also be constructed containing a GOI at different gene positions for various expression purposes (Figure 6). M., and Christou, P. (1957). Google Scholar Jackson, A. doi: 10.1007/978-1-4939-3289-4_9 PubMed Abstract | CrossRef Full Text | Google Scholar Moyer, S. 6, 307–311. Ivanovsky’s paper describing the retention of virulence in leaf sap extracted from Crimean tobacco with mosaic leaf disease (Lustig and Levine, 1992). Recombinant expression was achieved using this methodology with both full-length and defective versions of RNA-2 coding plasmids (Liu et al., 2005). L., Casper, D. J., and Karn, J. (1974). Google Scholar Conti, M., and Appiano, A. Although viral vectors based on a full-genome demonstrated success in producing recombinant proteins, constructs with large inserts showed instability and low systemic spread (Shivprasad et al., 1999; Avesani et al., 2007). The G protein is required for virus entry and subsequent propagation within the arthropods vector (Hogenhout et al., 2003), while only the carboxyl-terminal domain of the G protein, together with M protein are required for the morphogenesis and the budding of the enveloped particles (Sun et al., 2018). (2013). Attenuated vesicular stomatitis viruses as vaccine vectors. The transcription direction and gradient follow the order of genes in the virus genome and are controlled by the untranslated 3′ – leader sequence (Emerson, 1982) and the non-translated inter-genomic regions respectively as shown in Figure 5B (Barr et al., 1997; Finke et al., 2000). A 34, S396–S396. (1936). doi: 10.1016/0022-2836(89)90391-4 PubMed Abstract | CrossRef Full Text | Google Scholar Niehl, A., Appaix, F., Bosca, S., van der Sanden, B., Nicoud, J. Recombinant plant-derived pharmaceutical proteins: current technical and economic bottlenecks. 82, 674–682. Front. Mahy (Cambridge, MA: Academic Press), 270. Methods 169, 332–340. Proc. A virosomal formulated Her-2/neu multi-peptide vaccine induces Her-2/neu-specific immune responses in patients with metastatic breast cancer: a phase I study. G., Schichnes, D., Ruzin, S., and Jackson, A. “Genetic comparison of the rhabdoviruses from animals and plants,” in The World of Rhabdoviruses, ed. P., and Lomonossoff, G. LB, left border; RB, right border of the T-DNA region. A recombinant vesicular stomatitis virus-based Lassa fever vaccine protects guinea pigs and macaques against challenge with geographically and genetically distinct Lassa viruses. 6, 930–940. doi: 10.1111/mpp.12699 PubMed Abstract | CrossRef Full Text | Google Scholar Sylvester, E. Cell 60, 637–647. PubMed Abstract | Google Scholar Zhang, X., Mao, G., and van den Pol, A. J., Cameron, N. 71, 8718–8725. doi: 10.1104/pp.108.126284 PubMed Abstract | CrossRef Full Text | Google Scholar Salazar, L., Müller, G., Querci, M., Zapata, J., and Owens, R. L., and Patton, J. Rapid, high-level expression of glycosylated rice α-amylase in transfected plants by an RNA viral vector. HA-based influenza VLPs were found to be budding from the plasma membrane of plant cells expressing HA only, without the need of further viral proteins (D’Aoust et al., 2008), due to the absence of glycoprotein sialylation in plants (Séveno et al., 2004). PubMed Abstract | Google Scholar Johnson, M. Figure 1. Rev. N., Graham, J., Klug, A., and Staden, R. F., Mertens, M. PubMed Abstract | Google Scholar Wolanski, B., Francki, R., and Chambers, T. Transmission of a bacilliform virus of sowthistle and Bidens pilosa. M., Voell, J., Castellano, A. 73, 1661–1664. Concluding Remarks Plant molecular pharming has materialized as a reliable and cost-effective platform for the production of pharmaceuticals, vaccines, and biobetter products with a number of plant-produced proteins starting to be commercialized (Ratner, 2010; Yusibov et al., 2011). Ann. (B) Recombinant protein (RP) fused to the CP N-terminus using fusion peptide (FP) (Roder et al., 2017). Presentation of a foreign peptide on the surface of tomato bushy stunt virus. PubMed Abstract | Google Scholar Marillonnet, S., Thoeringer, C., Kandzia, R., Klimyuk, V., and Gleba, Y. Development of a new cucumber mosaic virus-based plant expression vector with truncated 3a movement protein. Mutational analyses of the intergenic dinucleotide and the transcriptional start sequence of vesicular stomatitis virus (VSV) define sequences required for efficient termination and initiation of VSV transcripts. Furthermore, recently enveloped plant viruses, such as rhabdoviruses, have been recovered from agroinfiltrated cDNA, adding a viral particle with an amendable lipid envelope to the arsenal of available systems. L., Casal, J. 65, 1057–1065. Finally, the G protein tail is incorporated into the assembled M-RNP complex, aiding the budding of progeny virus particles (Whitt et al., 1989; Schnell et al., 1998). M., and McCormick, A. The modified delRNA-2-based mRNA was “hyper-translated” providing approximately 0.3 g/kg FWT of fully assembled monoclonal antibody within 6 days after agroinfection (Sainsbury and Lomonossoff, 2008). A recombinant vesicular stomatitis virus Ebola vaccine. Human-immunodeficiency-virus type-1-neutralizing antibodies raised to a glycoprotein-41 peptide expressed on the surface of a plant-virus. Small 6, 818–821. L., and Bittner, A. F., Ito, S., Wong, D. Production of plant virus based VLPs as vaccines received the attention since the early 1990 (Usha et al., 1993). The typical symptoms of viral infection are necrosis, mosaic mottling of leaf tissue, and vein clearing (Jackson et al., 2009). PubMed Abstract | Google Scholar Cooper, D., Wright, K. Reconstituted plant viral capsids can release genes to mammalian cells. H. 36, 2367–2379. PubMed Abstract | Google Scholar Lamb, J., Duncan, G., Reavy, B., Gildow, F., Mayo, M., and Hay, R. K. P., and Evans, D. Soc. Plant Viruses as Biological Particles, the Case of Non-Enveloped Viruses The plant viruses first exploited in biotechnology were non-enveloped and consist of CP subunits that have the ability to self-assemble into filamentous structures such as TMV (Alonso et al., 2013) or hollow symmetric icosahedral structures such as CCMV (Zandi et al., 2004) as shown in Figures 3A,B. Safety and immunogenicity of a plant-produced Pfs25 virus-like particle as a transmission blocking vaccine against malaria: a Phase 1 dose-escalation study in healthy adults. 154, 164–177. Hepatitis C virus structural proteins assemble into viruslike particles in insect cells. Lett. K., Nasar, F., Lee, M., Johnson, J. In vitro and in vivo toxicity evaluation of plant virus nanocarriers. A., and Buck, K. 96, 7774–7779. doi: 10.1128/JVI.00200-10 PubMed Abstract | CrossRef Full Text | Google Scholar Comer, J. Systemic production of foreign peptides on the particle surface of tobacco mosaic-virus. PubMed Abstract | Google Scholar Douglas, T., and Young, M. J., and Kushnir, N. Cucumber mosaic virus as the expression system for a potential vaccine against Alzheimer’s disease. Sequences of the vesicular stomatitis virus matrix protein involved in binding to nucleocapsids. Research on VSV revealed that genomic RNA must be encapsidated with the viral N protein to be a functional template for RNA-dependent RNA polymerase (Emerson and Wagner, 1972). M., et al. M., Kondo, H., et al. (1977). PubMed Abstract | Google Scholar Osman, T. Maize fine streak virus, a new leafhopper-transmitted rhabdovirus. Reconstitution studies detect a single polymerase entry site on the vesicular stomatitis virus genome. The expression of a nopaline synthase—human growth hormone chimaeric gene in transformed tobacco and sunflower callus tissue. J. Google Scholar Conzelmann, K.-K., and Schnell, M. 4, 194–196. 1):e20180124. (1996b). PubMed Abstract | Google Scholar Tseng, R. U., and Wagner, R. 8, 68–72. 102, 23–57. Virology 522, 244–259. K., and Banerjee, A. (1898). Google Scholar Sánchez-Sánchez, L., Cadena-Nava, R. Assembly of the particle of tobacco mosaic virus from RNA and disks of protein. This promising success culminated in 2015 when infectious SYNV was recovered from the upper leaves of N. Considering that monopartite rhabdoviruses are easier to handle and a reverse genetics system has recently been established for a plant infecting rhabdovirus, they present the most attractive platform for development of pseudotyped viral-vaccines upon which their inherent envelope will provide the needed flexibility to incorporate large and complex antigens. Cell. They were shown to elicit a humoral response when administered by parenteral (Brennan et al., 1999b) or mucosal routes (Brennan et al., 1999a) and a cell mediated response (Yusibov et al., 2005; Kemnade et al., 2014). 9:e0003736. Plant rhabdovirus gRNA encodes the rhabdoviruses canonical genes: Nucleoprotein (N), Phosphoprotein (P), Matrix (M), Glycoprotein (G), and Large Polymerase (L) (Jackson et al., 2018), in addition to accessory genes (Walker et al., 2011) such as those coding for a cell-to-cell MP such as the 4b gene in lettuce necrotic yellow virus (LNYV) (Dietzgen et al., 2007), gene 3 of rice yellow stunt rhabdovirus (RYSV) (Huang et al., 2005). A., Barr, J. M., Kurath, G., and Vasilakis, N. Virology 193, 106–114. List of some of the animal rhabdoviruses that have been reverse engineered for various medical applications. (2010). Potato virus X as a novel platform for potential biomedical applications. Drug Deliv. Virology 242, 107–117. Production of recombinant cholera toxin b subunit in Nicotiana benthamiana using GENEWARE® tobacco mosaic virus vector. PubMed Abstract | Google Scholar Kusnadi, A. Methods 141, 146–153. Adoption of the 2A ribosomal skip principle to tobacco mosaic virus for peptide display. The physics of tobacco mosaic virus and virus-based devices in biotechnology. PubMed Abstract | Google Scholar Brémont, M. 64, 2948–2957. (1982). doi: 10.1016/S0014-5793(98)01586-5 PubMed Abstract | CrossRef Full Text | Google Scholar Soulie, J., Devillier, P., Santarelli, J., Goudeau, A., Vermeulen, P., Guellier, M., et al. G., Blasdell, K. Bean yellow dwarf virus replicons for high-level transgene expression in transgenic plants and cell cultures. Optical nano-constructs composed of genome-depleted brome mosaic virus doped with a near infrared chromophore for potential biomedical applications. 64, 1329–1338. Acs Nano 5, 1243–1252. Plant Pathol. Concerning a contagium vivum fluidum as a cause of the spot-disease of tobacco leaves. Acad. Gene 245, 169–174. P., Dang, N., and Rasochova, L. doi: 10.1094/PHYTO.2002.92.11.1167 PubMed Abstract | CrossRef Full Text | Google Scholar Regules, J. Oncol. (1971). Rhabdoviruses Transcription Theoretical models that explain rhabdovirus transcription and replication were built upon experiments on mammalian rhabdoviruses, and one of the most well studied is Vesicular Stomatitis virus (VSV) (Emerson, 1987; Wertz et al., 1987). Research on rabies virus (RABV) demonstrated the expression of a reporter gene cloned between the viral 3′ and 5′ termini in cells co-transfected with plasmids encoding for the three helper proteins N, P, and L (Conzelmann and Schnell, 1994). H., Sheng, J. A., Paoletti, A. F., Yusibov, V., and Rabindran, S. Nucleotide-sequence of tobacco mosaic-virus RNA. Google Scholar Fernández-Fernández, M. T., Lell, B., Soulanoudjingar, S. PubMed Abstract | Google Scholar Pushko, P., Tumpey, T. (2007). The first published virus-based vector was a gene-replacement model in which the GOI replaced the CP of brome mosaic virus (BMV) (French et al., 1986). D., and Zaitlin, M. However, the generation and selection of stably transformed plants for heterologous protein expression is quite elaborate and time-consuming which lead scientists to research exploiting viruses for this purpose. E., Fitchen, J. doi: 10.1016/j.virol.2010.03.013 PubMed Abstract | CrossRef Full Text | Google Scholar Barnhill, H. H., Paolino, K. K., and Robek, M. PapMV nanoparticles improve mucosal immune responses to the trivalent inactivated flu vaccine. PubMed Abstract | Google Scholar Gleba, Y., Klimyuk, V., and Marillonnet, S. Many of the plant rhabdoviruses are transmitted by arthropods in a persistent propagative way in which the virus enters and replicates within the insect before transmission (Sylvester and Richardson, 1992; Creamer et al., 1997; Redinbaugh et al., 2002) while dichorhaviruses are transmitted by mites (Dietzgen et al., 2018) and varicosaviruses by soil-borne fungi (Latham et al., 2004). PubMed Abstract | Google Scholar Takamatsu, N., Watanabe, Y., Meshi, T., and Okada, Y. R. The fluorescence signal was detected in 5–6 days post-infiltration and was restricted to single cells only. ACS Nano 10, 4119–4126. Phytopathology 78, 783–789. Replication and amplification of defective interfering particle RNAs of vesicular stomatitis virus in cells expressing viral proteins from vectors containing cloned cDNAs. J. C., Liu, L., Perrin, Y., Tsakiris, E., and Lomonossoff, G. Vaccin. PubMed Abstract | Google Scholar Zandi, R., Reguera, D., Bruinsma, R. E., Lichty, B. doi: 10.1016/j.virol.2013.10.035 PubMed Abstract | CrossRef Full Text | Google Scholar Brumfield, S., Willits, D., Tang, L., Johnson, J. PubMed Abstract | Google Scholar Zlotnick, A. Vet. 97, 25–35. Virol. The CPMV RNA2-based expression system allowed an elegant extension in which the genome-integrated cDNA of RNA-2 was amplified using agroinfiltrated RNA-1 constructs or by crossing with RNA-1 transgenic plants (Cañizares et al., 2006). Google Scholar Gupta, A. (1993). M., Learmonth, D., Porter, A. Vesicular stomatitis virus with the rabies virus glycoprotein directs retrograde transsynaptic transport among neurons in vivo. Q., Wang, T., Bohon, J., Gagne, M. U.S.A. 92, 8388–8392. coli (Fiers et al., 2009). doi: 10.1186/s12951-017-0289-y PubMed Abstract | CrossRef Full Text | Google Scholar Tignor, G., Murphy, F., Clark, H., Shope, R., Madore, P., Bauer, S., et al. M., Kondo, H., and Dietzgen, R. Google Scholar McCormick, A. Annu. 14, 439–459. 265, 7779–7786. PubMed Abstract | Google Scholar Fraenkel-Conrat, H., Singer, B., and Williams, R. 427, 229–235. E., et al. PubMed Abstract | Google Scholar Whelan, S., Ball, L. W., Boudreau, J. PubMed Abstract | Google Scholar Bridle, B. 21, 315–322. 5, 467–474. PubMed Abstract | Google Scholar Yusibov, V., Modelska, A., Steplewski, K., Agadjanyan, M., Weiner, D., Hooper, D. Later in the same year, recombinant VSV (rVSV) was successfully produced incorporating a foreign protein, in addition to the VSV inherent glycoprotein, in viral envelope (Schnell et al., 1996a). 81, 63–65. doi: 10.1016/S1473-3099(18)30165-8 PubMed Abstract | CrossRef Full Text | Google Scholar Ishikawa, M., Meshi, T., Ohno, T., and Okada, Y. B., Martin, K. PubMed Abstract | Google Scholar Venuti, A., Curzio, G., Mariani, L., and Paolini, F. doi: 10.1186/1472-6750-7-62 PubMed Abstract | CrossRef Full Text | Google Scholar Yang, J., Hooper, D. Google Scholar Redinbaugh, M., Seifers, D., Meulia, T., Abt, J., Anderson, R., Styer, W., et al. In this system, viral MP and/or CP genes were replaced by the recombinant GOI and the vector was introduced into plants as part of Agrobacterium delivered T-DNA (Gleba et al., 2004), biolistic bombardment (Komarova et al., 2006) or as chromosome-inserted replicon (Cañizares et al., 2006). C., et al. N., Loo, L., Overton, W., Antonelli, R., Clark, J., et al. Non-enveloped plant viruses have been engineered in three different ways: modification of the outer capsid (whether through genetic manipulation, chemical modification of capsid’s amino acids moieties, or through a combination of both), incorporation of heterologous cargo in the inner cavity, or particle integration into multivalent structures. J., Trepanier, S., Montomoli, E., Dargis, M., Lapini, G., et al. T., and Lilly, T. B., Kabwende, L., et al. Immunogenicity of peptides derived from a fibronectin-binding protein of S. 78, 1213–1217. Google Scholar Citovsky, V., Knorr, D., Schuster, G., and Zambryski, P. B., and Lyles, D. 119, 673–683. PubMed Abstract | Google Scholar Clarke, D. Biodistribution, pharmacokinetics, and blood compatibility of native and PEGylated tobacco mosaic virus nano-rods and -spheres in mice. Viruses 10:E108. Biotechnology 11, 930–932. Electron-microscopic and molecular characterization of turnip vein-clearing virus. doi: 10.1016/j.clim.2014.08.003 PubMed Abstract | CrossRef Full Text | Google Scholar Landry, N., Ward, B. Table 1. Mol. doi: 10.1016/S0022-1759(99)00150-7 PubMed Abstract | CrossRef Full Text | Google Scholar Hiatt, A., Caffferkey, R., and Bowdish, K. K., Damotharan, V., Chivukula, S. Glycoprotein cytoplasmic domain sequences required for rescue of a vesicular stomatitis virus glycoprotein mutant. Construction of a novel virus that targets HIV-1-infected cells and controls HIV-1 infection. First results of phase 3 trial of RTS,S/AS01 malaria vaccine in African children. Generation of a tumor vaccine candidate based on conjugation of a MUC1 peptide to polyionic papillomavirus virus-like particles. Jr., Brock, J. 9, 313–341. (A) Diagram representing an LNYV particle showing the transmembrane glycoprotein, lipid bilayer, matrix protein, and genomic RNA together with the nucleoprotein forming the ribonucleoprotein coil. doi: 10.1111/j.1467-7652.2008.00384.x PubMed Abstract | CrossRef Full Text | Google Scholar Dawson, W., Bubrick, P., and Grantham, G. LNYV bullet-shape structure and its genomic RNA organization, replication and transcription strategy. 8:1125. Transcription of the viral genes results in the generation of monocistronic 5′-capped and polyadenylated mRNAs. Rhabdoviruses Replication Later during the infection, the N-P complex inhibits transcription and switches the function of the L protein from that of transcription to replication (La Ferla and Peluso, 1989; Gupta and Banerjee, 1997). Virology 376, 165–172. P., Lewandowski, D. C Life Sci. 65, 282–294. M., Gorzny, M. Plant RNA viruses such as TMV (Koo et al., 1999), CPMV (Mclain et al., 1995), CMV (Nuzzaci et al., 2007), plum pox potyvirus (PPV) (Fernández-Fernández et al., 1998), potato virus X (PVX) (Lico et al., 2009), and tomato bushy stunt virus (TBSV) (Joelson et al., 1997) have been adapted for the production of vaccines and tested in various animal models. Cereal chlorotic mottle virus—a rhabdovirus of Gramineae in Australia transmitted by Nesoclutha pallida (Evans). Biology of plant rhabdoviruses. Currently, several proteins manufactured in plants are commercialized such as bovine trypsin TrypZean expressed in maize and commercialized by Sigma-Aldrich (#T3568, Sigma-Aldrich Corporation, United States), the 2006 USDA approved Newcastle disease virus for poultry produced in tobacco cell-suspension by Dow AgroSciences (Vermij and Waltz, 2006), and the 2012 FDA approved taliglucerase alfa (Elelyso®) for the management of type 1 Gaucher’s disease produced in carrot cells by Protalix Biotherapeutics Inc. A third approach was to create a hybrid virus-vector containing different subgenomic promoter sequences from two tobamoviruses [TMV and odontoglossum ringspot virus (ORSV)]. Rapid production of single-chain Fv fragments in plants using a potato virus X episomal vector. F. S., Kim, D. 85, 10945–10954. Science 175, 1477–1479. A., Lavoie, P. 21:79. PubMed Abstract | Google Scholar Tesh, R. Capping of tobacco mosaic virus RNA. An. Acad. L., and Anvari, B. Q., Lefkowitz, E. 148, 1212–1218. A., Couture, M. V., Korotkov, A. U.S.A. 88, 7204–7208. The 1: 1 N-NS protein complex of vesicular stomatitis virus is essential for efficient genome replication. R., and Wertz, G. Development of model systems for plant rhabdovirus research. Google Scholar Alonso, J. Virus Res. M., Dietzgen, R. Virology 255, 312–323. doi: 10.1021/nl051254r PubMed Abstract | CrossRef Full Text | Google Scholar Yusibov, V., Mett, V., Mett, V., Davidson, C., Musiychuk, K., Gilliam, S., et al. A schematic representation of wild type VSV and recombinant VSV designs. PubMed Abstract | Google Scholar Barta, A., Sommergruber, K., Thompson, D., Hartmuth, K., Matzke, M. PubMed Abstract | Google Scholar Landry, N., Pillet, S., Favre, D., Poulin, J. R., Christianen, P. Electron microscopy of negatively stained preparations. Engineering cowpea mosaic virus RNA-2 into a vector to express heterologous proteins in plants. E., and Dawson, W. (2005). PubMed Abstract | Google Scholar Asurmendi, S., Berg, R., Koo, J., and Beachy, R. Further attempts followed using TMV-based vectors in which the GOI was inserted upstream the inherent CP gene and controlled by an additional subgenomic RNA promoter (the inherent CP subgenomic promoter was duplicated) (Dawson et al., 1988). Vesicular stomatitis virus, New Jersey serotype: replication in and transmission by Lutzomyia shannoni (Diptera: Psychodidae). Systemic Agrobacterium tumefaciens–mediated transfection of viral replicons for efficient transient expression in plants. S., Hind, G., Handa, A. This finding was followed by the recovery of infectious, enveloped rabies virus particles from cDNA (Schnell et al., 1994). doi: 10.1371/journal.pone.0055438 PubMed Abstract | CrossRef Full Text | Google Scholar Lico, C., Mancini, C., Italiani, P., Betti, C., Boraschi, D., Benvenuto, E., et al. doi: 10.1038/nnano.2006.55 PubMed Abstract | CrossRef Full Text | Google Scholar Tusé, D., Tu, T., and McDonald, K. 85, 1049–1053. Gen. M., and Rudnick, J. S., Dietzgen, R. (1969). Expression of human immunodeficiency virus type 1 Gag protein precursor and envelope proteins from a vesicular stomatitis virus recombinant: high-level production of virus-like particles containing HIV envelope. B., Oldenburg, I. Nevertheless, producing VLPs whether through genetic fusion or chemical conjugation remains challenging, especially for complex multimeric antigens (Jagu et al., 2013; Benen et al., 2014), full length glycoproteins that adopt different conformations (Kwong et al., 2002; Cullen et al., 2017), large epitopes (Werner et al., 2006), or have termini that are involved in protein folding (Pejawar-Gaddy et al., 2010) and might interrupt the capsid synchronized assembly (Zlotnick, 1994; Roldão et al., 2012), while post-expression chemical conjugation has the drawback of further increasing downstream processing costs (Buonaguro and Butler-Ransohoff, 2010; Wilken and Nikolov, 2012; Sabalza et al., 2014; Buyel et al., 2015). Natl. doi: 10.1016/j.virol.2013.03.001 PubMed Abstract | CrossRef Full Text | Google Scholar Bandyopadhyay, A., Kopperud, K., Anderson, G., Martin, K., and Goodin, M. 8, 607–619. VIPERdb(2): an enhanced and web API enabled relational database for structural virology. doi: 10.1016/j.virusres.2016.10.010 PubMed Abstract | CrossRef Full Text | Google Scholar Dohi, K., Nishikiori, M., Tamai, A., Ishikawa, M., Meshi, T., and Mori, M. M., Dargis, M., et al. 80, 6993–7008. A., Bentley, W. Self-assembly of tobacco mosaic virus: the role of an intermediate aggregate in generating both specificity and speed. (2000). (1972). This discovery was followed by a set of experiments that enabled the first rescue (reverse genetics system) of VSV defective interfering (DI) particles from cells co-transfected with the five canonical proteins (Pattnaik and Wertz, 1990, 1991). S., Cornelissen, J. Optimization of multimeric human papillomavirus L2 vaccines. 22, 1351–1352. F., Bolze, F., et al. Treat. Google Scholar Butler, P., and Klug, A. PubMed Abstract | Google Scholar Creamer, R., He, X., and Styer, W. Furthermore, chimeric VLPs expressing recombinant peptides were found to induce reduced neutralizing antibodies titre when compared to the full domain vaccines (Gedvilaite et al., 2015). Virology 402, 61–71. P., and van Kammen, A. N. F., Gelbart, W. Viruses 7, 4204–4229. Biol. Nucleic Acids Res. doi: 10.3389/fpls.2017.01125 PubMed Abstract | CrossRef Full Text | Google Scholar Roldão, A., Mellado, M. J., Buonocore, L., Whitt, M. Glycoprotein sialylation in plants? Curr. (1999a). 73, 242–250. O., and Li, Z. This method of an inducible-replicon system, or dormant viral cassette, was also applied with a tomato mosaic virus (ToMV) system in suspension-cultured plant cells (Dohi et al., 2006). Genomic organization and expression strategy of TMV and different strategies adapted to express recombinant protein or heterologous epitope using the full virus genome. Biochemistry 71, 846–850. Google Scholar Wetzel, T., Dietzgen, R., and Dale, J. PubMed Abstract | Google Scholar Bawden, F., and Pirie, N. Z. O., Seethammagari, M., Collinson-Pautz, M., Kaur, H., Spencer, D. A., and Banerjee, A. Vaccine 23, 2261–2265. doi: 10.1111/j.1748-7O2X.2012.00698.x PubMed Abstract | CrossRef Full Text | Google Scholar Toriyama, S., and Peters, D. 17, 1814–1821. V., Kumanan, K., Vijayarani, K., and Hema, M. D., Palomares, L. 73, 930–938. Lancet Infect. Similarly, this strategy was subsequently used to rescue other vertebrate rhabdoviruses, such as VSV (Whelan et al., 1995), Snakehead rhabdovirus (SHRV) (Johnson et al., 2000), infectious haematopoietic necrosis virus (IHHNV) (Brémont, 2005), and haemorrhagic septicaemia virus (VHSV) (Kim et al., 2011). During the 1980s, the field of plant molecular pharming was born (Franken et al., 1997) and various pharmaceuticals such as human hormones (Barta et al., 1986), antibodies (Hiatt et al., 1989), and vaccines (Thanavala et al., 1995), were produced using transgenic plants. M., and Li, Z. (1986). Google Scholar Kwong, P. 152, 915–928. Similar attempts to reconstitute a plant rhabdovirus started at Jackson’s laboratory, where N. Chemical modification of a viral cage for multivalent presentation. doi: 10.1002/bit.22299 PubMed Abstract | CrossRef Full Text | Google Scholar Huttner, A., Agnandji, S. (2015). PubMed Abstract | Google Scholar Ivanov, I., Yabukarski, F., Ruigrok, R. 77, 1349–1358. U.S.A. 101, 1415–1420. ORF 3 and 4 are translated from separate subgenomic promoters and encode the 30 kDa movement protein (MP) and 17 kDa coat protein (CP) respectively. PLoS One 7:e31925. Classics 65, 33–52. F., Franco, O. Enzyme Microb. R., and Morrison, T. Dissociation and reconstitution of the transcriptase and template activities of vesicular stomatitis B and T virions. N., Deng, M., Marr, S., Lee, M. EMBO J. The P30 movement protein of tobacco mosaic virus is a single-strand nucleic acid binding protein. PubMed Abstract | Google Scholar Maclean, J., Koekemoer, M., Olivier, A. PubMed Abstract | Google Scholar Keating, G. Studies on the development and epiphytotics of the rice yellow stunt disease. Interaction between the tobacco mosaic virus movement protein and host cell pectin methylesterases is required for viral cell-to-cell movement. First, the gRNA is replicated into an antigenomic sense RNA (agRNA) template, which is full positive-sense RNA without a cap and poly (A) tail and is encapsidated by the N protein (Arnheiter et al., 1985; Zhang et al., 2008). Google Scholar Goelet, P., Lomonossoff, G. Des. Hence these additional characteristics will enable large scale production of recombinant rhabdovirus based eVLP in which the (exposed) ectodomain of the G has been exchanged for another gene-of-interest (GOI) glycoprotein. M., Guenther, R. Vesicular stomatitis virus (Indiana serotype): transovarial transmission by phlebotomine sandlies. All these advantages together with the establishment of plant molecular pharming as cost effective and reliable production platform, make plant rhabdoviruses promising candidates in biotechnology in general and in the field of plant-made recombinant viral vaccines in specific. W. (F) Coding region of RP cloned downstream TMV subgenomic RNA promoter and placed between TMV MP gene and a heterogeneous CP (H-CP) gene. N., Reuther, R., Ferguson, P. M., Ezelle, H., Shah, S., and Barber, G. W., Davis, N. (F) rVSV with the gene for foreign protein inserted upstream of the VSV N protein and with truncated VSV glycoprotein. falciparum blocking antibodies in mice (Jones et al., 2013), in Phase I clinical trial it was shown to provide a low protection level (Chichester et al., 2018). Acta Phytopathol. doi: 10.1002/(SICI)1097-0290(19971205)56:5 PubMed Abstract | CrossRef Full Text | Google Scholar Kuzmin, I. Nevertheless, plant-produced VLPs remain the most economical choice, as plant production is scalable and cost-effective with production costs lower than those in E. PubMed Abstract | Google Scholar Jackson, A. Simultaneously, the development of viral vectors, together with agroinfection, culminated in rapid transient expression systems that successfully express high levels of large and complex pharmaceutical proteins and antimicrobial peptides (Fischer and Emans, 2000; Chen et al., 2013; Peyret and Lomonossoff, 2013; Loh et al., 2017; Leite et al., 2019) and enabled the production of plant-virus based VLPs against chronic and infectious diseases (Hefferon, 2018; Sahithi et al., 2019). Google Scholar Latham, T., and Galarza, J. In these recombinant VSV particles, two designs were considered. Neural Circuits 7:11. Identification of a region of the tobacco mosaic virus 126-and 183-kilodalton replication proteins which binds specifically to the viral 3 ′-Terminal tRNA-like structure. L., Bolduc, M., Leclerc, D., et al. PubMed Abstract | Google Scholar Stubbs, L., and Grogan, R. Development of cowpea mosaic virus as a high-yielding system for the presentation of foreign peptides. J., Dutilh, B. Plant viruses such as TMV (Takamatsu et al., 1987) and cowpea mosaic virus (CPMV) (Gopinath et al., 2000) were first adapted as full-virus vector then as a deconstructed-virus vector for recombinant protein expression. (1991). PubMed Abstract | Google Scholar Christie, S., Christie, R., and Edwardson, J. PubMed Abstract | Google Scholar Azizgolshani, O., Garmann, R. Evolution of genome size and complexity in the Rhabdoviridae. Nature 342, 76–78. Complete replication in vitro of tobacco mosaic virus RNA by a template-dependent, membrane-bound RNA polymerase. They have proven to be immunogenic and few are currently available on the market such as Engerix® [for hepatitis B virus (HBV)] (Keating and Noble, 2003), and Cervarix® [for human papillomavirus (HPV)] (Szarewski, 2010), produced by GlaxoSmithKline, or their respective equivalents Recombivax HB® (Venters et al., 2004), and Gardasil® (Tomljenovic and Shaw, 2012) produced by Merck. doi: 10.1021/bc100361z PubMed Abstract | CrossRef Full Text | Google Scholar Loh, H.-S., Green, B. Biomed. PLoS One 8:e55538. 33, 902–913. The specificity of rabies virus RNA encapsidation by nucleoprotein. Protective immunity against murine hepatitis virus (MHV) induced by intranasal or subcutaneous administration of hybrids of tobacco mosaic virus that carries an MHV epitope. Various filamentous plant viruses engineered for different biological applications. J., Harris, W. 63, 3852–3857. Lond. L., Rose, J. Crystal structure of the coat protein of the flexible filamentous papaya mosaic virus. Replication of sonchus yellow net virus in infected protoplasts. O., D’Aoust, M. C., Simon, B. Rescue of synthetic genomic RNA analogs of rabies virus by plasmid-encoded proteins. PubMed Abstract | Google Scholar Hamamoto, H., Sugiyama, Y., Nakagawa, N., Hashida, E., Matsunaga, Y., Takemoto, S., et al. Oncolytic activity of the rhabdovirus VSV-GP against prostate cancer. Plant virus-based materials for biomedical applications: trends and prospects. Plant Viruses in Recombinant Expression Technology, First-Generation Vectors Adopting plant viruses as vectors for transient expression offered many advantages over the transgenic system such as ability for application in various plant species (Hamamoto et al., 1993), reduced gene-to-product time (Hendy et al., 1999), and increased yields (Maclean et al., 2007). 8:e1002367. PubMed Abstract | Google Scholar Gils, M., Kandzia, R., Marillonnet, S., Klimyuk, V., and Gleba, Y. 103, 706–714. F., Bache, E. Other designs included fusing the recombinant protein to the TMV CP either at the C-terminal (Roder et al., 2017) or at the N-terminal downstream a leaky stop codon (Sugiyama et al., 1995). E., Gait, M. doi: 10.1590/0001-3765201820180124 PubMed Abstract | CrossRef Full Text | Google Scholar Leroux-Roels, G., Maes, C., Clement, F., van Engelenburg, F., van den Dobbelsteen, M., Adler, M., et al. L., Goodin, M. The latter was cloned into the TMV vector together with its heterogeneous subgenomic promoter from odontoglossum ringspot virus (ORSV) (Donson et al., 1991). doi: 10.1007/BF00034942 PubMed Abstract | CrossRef Full Text | Google Scholar Baumert, T. Pfizer stakes a claim in plant cell-made biopharmaceuticals. F., Finn, O. Vesicular stomatitis viruses with rearranged genomes have altered invasiveness and neuropathogenesis in mice. Origin of icosahedral symmetry in viruses. B., Chaniotis, B. Wagner (Boston, MA: Springer), 271–296. 65, 861–868. VSV was successfully rescued from cDNA in 1995 (Whelan et al., 1995) and in 1996 it was first engineered to express a reporter gene placed between those of the viral glycoprotein and the polymerase (Schnell et al., 1996b). G. M., Nisar, S., Lee, S. J., Firth, C., Widen, S. Vaccine 36, 5865–5871. W., and Jackson, A. N., VanMeter, A., Hern, S., Shoffstall, A. doi: 10.1007/s00705-018-3847-1 PubMed Abstract | CrossRef Full Text | Google Scholar Komarova, T., Skulachev, M., Zvereva, A., Schwartz, A., Dorokhov, Y. CervarixTM, the GSK HPV-16/HPV-18 AS04-adjuvanted cervical cancer vaccine, demonstrates stability upon long-term storage and under simulated cold chain break conditions. doi: 10.3390/v10030108 PubMed Abstract | CrossRef Full Text | Google Scholar King, A. Plant-made proteins expressed using deconstructed viral vectors. 10, 297–309. However, as with their comparative systems counterparts, plant-virus based VLP(s) are inherently constrained in their ability to present complex antigens and glycoproteins. 11:e1005223. V. Dichorhaviruses in their host plants and mite vectors. Their spread is correlated with that of the vector (Sylvester and Richardson, 1992), and no seed transmission has been reported. Structure of lettuce necrotic yellows virus: I. Recombinant hepatitis B vaccine (Engerix-B®). Toward Enveloped Virus Like Particles In the last decade, VLPs have been extensively developed as recombinant vaccines in different systems whether in plants or mammalian (Soulie et al., 1991), insects (Le Tallec et al., 2009), yeast (Agnandji et al., 2011), and E. L., Dreher, T., and Wang, Q. Author Contributions AI wrote the first draft of the manuscript. T., Saunders, A. doi: 10.1371/journal.pcbi.1002367 PubMed Abstract | CrossRef Full Text | Google Scholar Rose, N. Detection of infectious bursal disease virus (IBDV) antibodies using chimeric plant virus-like particles. 42, 483–490. Trans. A new virus isolate from infectious hypodermal and hematopoietic necrosis virus (IHHNV)-infected penaeid shrimps. For instance, inserting the foreign gene upstream of the VSV N gene (Figure 6E), or inserting the foreign gene upstream the N gene while relocating the N gene downstream the M gene and truncating VSV G protein (Figure 6F) were also adapted to rescue a recombinant VSV based HIV-1 vaccine (Cooper et al., 2008). 12, 2327–2333. Trends Microbiol. Int. Bras. Attenuation of recombinant vesicular stomatitis virus-human immunodeficiency virus type 1 vaccine vectors by gene translocations and g gene truncation reduces neurovirulence and enhances immunogenicity in mice. Fu (Berlin: Springer), 1–24. In 2013, the same group demonstrated the success of the first plant rhabdovirus SYNV minireplicon (MR) strategy (Ganesan et al., 2013). PubMed Abstract | Google Scholar Eiben, S., Koch, C., Altintoprak, K., Southan, A., Tovar, G., Laschat, S., et al. PubMed Abstract | Google Scholar Huang, Z., Chen, Q., Hjelm, B., Arntzen, C., and Mason, H. J., Charland, N., Trepanier, S., Landry, N., Ors, F., et al. Bioeng. G., and Jackson, A. Crop Pasture Sci. The envelope provides the flexibility for integration of complete envelope-proteins and glycoproteins resembling the native virus (Yamshchikov et al., 1995; Baumert et al., 1998; Latham and Galarza, 2001). M., and Butler-Ransohoff, J.-E. Influenza virus-like particle vaccines made in Nicotiana benthamiana elicit durable, poly-functional and cross-reactive T cell responses to influenza HA antigens. aureus expressed on two different plant viruses. One hundred years of virology. O. 10, 305–312. Preclinical and clinical development of plant-made virus-like particle vaccine against avian H5N1 influenza. Verhandelingen der koninklijke akademie wetenschappen te Amsterdam 1898; 65: 3–21. C. R., Nikolov, Z. doi: 10.1016/j.virusres.2011.09.025 PubMed Abstract | CrossRef Full Text | Google Scholar Jackson, A., Dietzgen, R., Fang, A. Serological examination of a rhabdovirus isolated from snakehead (Ophicephalus striatus) in Thailand with ulcerative syndrome. Furthermore, in 1997, recombinant VSV lacking its inherent glycoprotein and expressing CD4 receptor to infect and kill HIV-1 infected T-cells was successfully rescued (Schnell et al., 1997) (Figure 6D). (1975). doi: 10.1371/journal.ppat.1005223 PubMed Abstract | CrossRef Full Text | Google Scholar Werner, S., Marillonnet, S., Hause, G., Klimyuk, V., and Gleba, Y. Virology 263, 395–407. le, leader; tr, trailer; insP, gene for inserted protein; Gtrc, truncated glycoprotein. doi: 10.1006/viro.1995.9955 PubMed Abstract | CrossRef Full Text | Google Scholar Yang, C.-D., Liao, J.-T., Lai, C.-Y., Jong, M.-H., Liang, C.-M., Lin, Y.-L., et al. PLoS Comput. 11:e1004664. 77, 5740–5748. Phytopathology 92, 1167–1174. A., Majeed, S., et al. 79, 2108–2114. Host–guest encapsulation of materials by assembled virus protein cages. Immunology 124, 186–197. U.S.A. 103, 17678–17683. V., Ritter, G. PubMed Abstract | Google Scholar Porta, C., Spall, V. 6:1244. Figures 1B–F, show the above described modification approaches applied to TMV. Induction of protective immunity in swine by recombinant bamboo mosaic virus expressing foot-and-mouth disease virus epitopes. Moreover, in the case of rapidly evolving viruses, such as influenza, selective pressure will drive viral evasion of immune response induced by VLP vaccines based on few amino acids or antigens that cannot reproduce native conformational epitopes. U.S.A. 79, 5818–5822. doi: 10.1089/aid.1995.11.327 PubMed Abstract | CrossRef Full Text | Google Scholar Mebatsion, T., Weiland, F., and Conzelmann, K.-K. Inactivation and purification of cowpea mosaic virus-like particles displaying peptide antigens from Bacillus anthracis. A., Hanau, R., and Jackson, A. K., and Wertz, G. 4, 794–805. S., and Richardson, J. 227, 158–170. doi: 10.1007/s00262-010-0895-0 PubMed Abstract | CrossRef Full Text | Google Scholar Petukhova, N. In line with those difficulties and limitations, and considering that some of these are not encountered with enveloped VLPs (eVLPs), there has been a growing trend toward the use of eVLPs as production platform (Gheysen et al., 1989). In vitro synthesis of RNA by dissociated lettuce necrotic yellows virus particles. PubMed Abstract | Google Scholar Zuidema, D., Heaton, L. CrossRef Full Text | PubMed Abstract | Google Scholar Usha, R., Rohll, J. Biotechnol. A., Shukla, S., Awuah, S. PubMed Abstract | Google Scholar French, R., Janda, M., and Ahlquist, P. H., and Leong, J.-A. (A) 3′ to 5′ negative-strand genomic RNA organization of wild type VSV. doi: 10.1186/1477-3155-12-19 PubMed Abstract | CrossRef Full Text | Google Scholar Roberts, A., Buonocore, L., Price, R., Forman, J., and Rose, J. M2e-based universal influenza A vaccine. Nature 138, 1051–1052. Cancer Immunol. Chem. Virology 33, 287–296. At first, the host cells were infected with a full copy of plant virus (either DNA or in vitro transcribed RNA) into which the heterogenous sequence or gene of interest (GOI) was cloned. Even though the extracted sap had been passed through bacteria-retaining filters, the filtrate retained the ability to replicate within living plants (Beijerinck, 1898). Immunogenic properties of chimeric potato virus X particles displaying the hepatitis C virus hypervariable region I peptide R9. B Biointerfaces 129, 130–136. PubMed Abstract | Google Scholar Jung, B., Rao, A. Currently, there are a number of on-going clinical trials based on VSV, such as Phase I/II clinical trials for VSV based Ebola virus vaccines (rVSV-ZEBOV) (Huttner et al., 2018). (1988). 8, 411–416. PubMed Abstract | Google Scholar Ratner, M. Vaccine 27, 6280–6283. Virus-like particle (VLP) vaccine conferred complete protection against a lethal influenza virus challenge. B., Scholthof, K.-B. They have a bacilliform shape defined by two major structural components: an outer envelope made of the host lipid bilayer embedded with surface projections of the virus glycoprotein and a tightly coiled internal nucleocapsid composed of genomic RNA (gRNA) together nucleoprotein, phosphoprotein, and the polymerase protein (Wolanski et al., 1967) (Figure 5, traditionally, plant rhabdoviruses were divided into Cytorhabdovirus or Nucleorhabdovirus genera, depending on the virus propagation sites within the cell while recently two new genera Dichorhavirus and Varicosavirus, with bipartite genomes, were added (Dietzgen et al., 2017; Whitfield et al., 2018). (1999b). Production of recombinant proteins in transgenic plants: practical considerations. Inducible virus-mediated expression of a foreign protein in suspension-cultured plant cells. Methods Protoc. USDA approves the first plant-based vaccine. J., Jones, R. Synergistic attenuation of vesicular stomatitis virus by combination of specific G gene truncations and N gene translocations. Ichthyol. A., Green, B. Google Scholar Ma, J. The MP is an RNA binding protein involved in cell-to-cell spreading of the virus (Citovsky et al., 1990; Chen et al., 2000) while the CP enhances the formation of replication complexes (Asurmendi et al., 2004), long-distance movement (Saito et al., 1990; Hilf and Dawson, 1993), and viral particle assembly (Bloomer et al., 1978; Butler, 1999). Microbiol. F., Marx, P. A., Munshi, S., Wang, G., Baker, T. doi: 10.1186/s12929-014-0079-x PubMed Abstract | CrossRef Full Text | Google Scholar Blandino, A., Lico, C., Baschieri, S., Barberini, L., Cirotto, C., Blasi, P., et al. Virology 267, 159–173. Google Scholar Bendandi, M., Marillonnet, S., Kandzia, R., Thieme, F., Nickstadt, A., Herz, S., et al. A virus-based biocatalyst. Aust. PubMed Abstract | Google Scholar Hilf, M. Google Scholar Brennan, F. U.S.A. 83, 5019–5023. The oncolytic virus VSV-GP is effective against malignant melanoma. This pathogen is known as tobacco mosaic virus (TMV) and is one of the prominent viruses in plant molecular pharming. H., et al. Plant Mol. 70, 2318–2323. J., Donahoe, S. Science 231, 1294–1298. Genomic organization of lettuce necrotic yellows rhabdovirus. List of some rhabdoviruses including plant Cytorhabdoviruses and Nucleorhabdoviruses together with their host, host class, and vectors. J., Tsao, J., Qiu, S., and Luo, M. Chemotherapy pro-drug activation by biocatalytic virus-like nanoparticles containing cytochrome P450. Drug-making plant blooms. V., et al. J., and Wattanavijarn, W. G., and Ammar, E.-D. Magnifection—a new platform for expressing recombinant vaccines in plants. doi: 10.1007/s00262-015-1734-0 PubMed Abstract | CrossRef Full Text | Google Scholar Vermij, P., and Waltz, E. Nature 310, 511–514. The 126 kDa and the 183 kDa replication proteins bind to the terminal tRNA-like structure initiating transcription of complementary (negative-sense) template (Lewandowski and Dawson, 2000; Osman and Buck, 2003). 26, 81–89. Google Scholar Shivprasad, S., Pogue, G. 208, 307–325. benthamiana plants agroinfiltrated with four plasmids harboring positive-sense SYNV cDNA together with helper protein plasmids (Wang et al., 2015). Med. Development of a universal influenza A vaccine based on the M2e peptide fused to the papaya mosaic virus (PapMV) vaccine platform. doi: 10.1016/j.jviromet.2010.07.039 PubMed Abstract | CrossRef Full Text | Google Scholar Walker, P. H5N1 virus-like particle vaccine elicits cross-reactive neutralizing antibodies that preferentially bind to the oligomeric form of influenza virus hemagglutinin in humans. PubMed Abstract | Google Scholar Giritch, A., Marillonnet, S., Engler, C., van Eldik, G., Botterman, J., Klimyuk, V., et al. FEBS Lett. 71, 2127–2137. Retroviruses 11, 327–334. PharmaPlant: the new frontier in vaccines. Virology 381, 136–142. Deconstructed-TMV based vectors were further commercially pursued by Icon Genetics as magnifection technology (trademarked as magnICON®) (Gleba et al., 2005). S., and Kim, K. Stability of Potato virus X expression vectors is related to insert size: implications for replication models and risk assessment. (C) rVSV with foreign protein fused to the inherent VSV glycoprotein. 365, 1863–1875.

12.04.2022 · Wild birds may harbor and transmit viruses that are potentially pathogenic to humans, domestic animals, and other wildlife. Using the viral metagenomic approach, we investigated the virome of cloacal swab specimens collected from 3182 birds (the majority of them wild species) consisting of > 87 different species in 10 different orders within the Aves ... Tobacco mosaic virus (TMV) is a positive-sense single-stranded RNA virus species in the genus Tobamovirus that infects a wide range of plants, especially tobacco and other members of the family Solanaceae.The infection causes characteristic patterns, such as "mosaic"-like mottling and discoloration on the leaves (hence the name). TMV was the first virus to be discovered. 12.04.2022 · Wild birds may harbor and transmit viruses that are potentially pathogenic to humans, domestic animals, and other wildlife. Using the viral metagenomic approach, we investigated the virome of cloacal swab specimens collected from 3182 birds (the majority of them wild species) consisting of > 87 different species in 10 different orders within the Aves ... A bacteriophage (/ b æ k ˈ t ɪər i oʊ f eɪ dʒ /), also known informally as a phage (/ ˈ f eɪ dʒ /), is a virus that infects and replicates within bacteria and archaea.The term was derived from "bacteria" and the Greek φαγεῖν (phagein), meaning "to devour".Bacteriophages are composed of proteins that encapsulate a DNA or RNA genome, and may have structures that are either ... A bacteriophage (/ b æ k ˈ t ɪər i oʊ f eɪ dʒ /), also known informally as a phage (/ ˈ f eɪ dʒ /), is a virus that infects and replicates within bacteria and archaea.The term was derived from "bacteria" and the Greek φαγεῖν (phagein), meaning "to devour".Bacteriophages are composed of proteins that encapsulate a DNA or RNA genome, and may have structures that are either ... 12.04.2022 · Wild birds may harbor and transmit viruses that are potentially pathogenic to humans, domestic animals, and other wildlife. Using the viral metagenomic approach, we investigated the virome of cloacal swab specimens collected from 3182 birds (the majority of them wild species) consisting of > 87 different species in 10 different orders within the Aves ... Tobacco mosaic virus (TMV) is a positive-sense single-stranded RNA virus species in the genus Tobamovirus that infects a wide range of plants, especially tobacco and other members of the family Solanaceae.The infection causes characteristic patterns, such as "mosaic"-like mottling and discoloration on the leaves (hence the name). TMV was the first virus to be discovered.

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