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Editorial

New Trends in Vaccine Characterization, Formulations, and Development

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More than eight decades have passed since the development of the first vaccine in the 1940s. During all those decades, the world has seen the availability and clinical use of several dozen vaccines. Not only has the number of available vaccines increased, but the pace and volume of vaccine availability have increased significantly [1]. The scale on which vaccines were manufactured during the last few years was possible only due to newer vaccine development platforms and the increased number of production units spreading throughout the world [2]. Apart from conventional ways of vaccine development, which include the attenuation and inactivation of associated pathogens, modern-day vaccine formulation avoids the growth of pathogenic entities. Today's vaccines, be they subunit, conjugate, VLPs, or mRNA-based, are much safer as these vaccines use only a few components of the pathogen, which rule out the possibility of vaccine-acquired infection and attenuated pathogens used as an immunogen in the vaccine transforming into a move infectious or virulent strain [3,4].

The use of newer platforms in vaccine formulation has also helped in the development of vaccines against diseases that were previously thought impossible. For example, a vaccine against malaria is possible only due to the use of a new platform for in-vaccine formulation. The protozoan's surface protein (acting as an immunogen) was cloned, expressed, purified, and used as an immunogen to raise immunity [5]. It will be no surprise that the world may also see vaccine availability against leprosy and tuberculosis, again, all thanks to the modern-day practice of vaccine development [6]. Furthermore, the arrival of the new platform in vaccine development helps develop vaccines preventing cancer. For example, a VLPs-based vaccine formulation under the trade name Gardisal9 is in clinical use against human papilloma. Apart from this, several other VLPs-based vaccines have been approved for clinical use [7].

The most recent and newest addition in vaccine formulation is the use of nucleic acid-based vaccines during the COVID-19 pandemic. The mRNA-based vaccine against coronavirus introduced by Pfizer and Moderna towards the end of 2020 can be seen as one of the most significant breakthroughs in vaccine development [8]. The worldwide use of mRNA-based vaccines during the pandemic showed the technology's safe and reliable nature. This is important as it shows the public's acceptance of technology and boosts more research and development in mRNA-based vaccines [9]. Surprisingly, this technology has gained significant importance in vaccine development. As a result, in a short span of a few years, several mRNA-based vaccines have entered different phases of clinical trials [10].

Another important and likely platform for vaccine development and formulation is the use of whole recombinant yeast as a micro container for the storage and delivery of immunogen/drugs [11]. This platform offers several advantages, including the long-term stability of immunogen at ambient temperatures and the stability of immunogen during freeze and thaw processes. This whole recombinant yeast approach showed promising results in both pre-clinical and clinical trials [12]. A further continuous rise in anti-fungal resistance and global fungal burden pushed the requirement for an anti-fungal vaccine. Even in this case, using inactivated whole yeast or recombinant yeast can significantly help.

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Several pre-clinical studies have shown the ability of inactivated yeast to raise a protective immune response against fungal infection [13,14].

The deployment of new platforms in vaccine development and formulation allows for the development of safe, effective, and large volumes of vaccines in a short duration. Despite this, vaccines developed using different regimes suffer from common problems, which include poor or short shelf life at ambient temperatures and the need for a continuous cold chain during transportation, storage, and final distribution before final administration [15]. Therefore, the focus of vaccine formulation should also be on improving the stability of vaccines and ways to prevent the need for a cold chain. Several methods have been tested; some look promising [16–20]. Owing to new and modern challenges in the form of geopolitics (wars, sanctions), vaccine manufacturers and developers should also pay attention to these issues [21]. Whether a given approach is specific to a given vaccine or formulation or suitable for different vaccine formulations must be tested [22].

Therefore, the world has come a long way in terms of vaccine characterization, formulations, and development; however, there are still many challenges that need to be taken care of if the world wants to make the best use of available vaccines in all socioeconomic settings, communities, or societies. Further, all efforts should be made to ensure that vaccines are available to each individual on the planet by keeping socioeconomic and geopolitics issues separate. Issues like vaccine hoarding or vaccine monopoly should be dealt with in a more appropriate way by keeping it more human-centric [23]. Therefore, apart from an improvement in the manufacturing process, we need to work on other issues (mentioned above) to make the best use of all the available vaccines.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

1. Gong, X.; Srivastava, V.; Naicker, P.; Khan, A.; Ahmad, A. *Candida parapsilosis* Cell Wall Proteome Characterization and Effectiveness against Hematogenously Disseminated Candidiasis in a Murine Model. *Vaccines* **2023**, *11*, 674. https://doi.org/10.3390/vaccines11030674
2. Hookham, L.; Lee, H.C.; Patel, D.A.; Coelho, M.; Giglio, N.; Le Doare, K.; Pannaraj, P.S. Vaccinating Children against SARS-CoV-2: A Literature Review and Survey of International Experts to Assess Safety, Efficacy and Perceptions of Vaccine Use in Children. *Vaccines* **2023**, *11*, 78. https://doi.org/10.3390/vaccines11010078
3. Song, Y.; Mehl, F.; Zeichner, S.L. Vaccine Strategies to Elicit Mucosal Immunity. *Vaccines* **2024**, *12*, 191. https://doi.org/10.3390/vaccines12020191
4. Shakya, A.K.; Mallick, B.; Nandakumar, K.S. A Perspective on Oral Immunotherapeutic Tools and Strategies for Autoimmune Disorders. *Vaccines* **2023**, *11*, 1031. https://doi.org/10.3390/vaccines11061031
5. Kozak, M.; Hu, J. The Integrated Consideration of Vaccine Platforms, Adjuvants, and Delivery Routes for Successful Vaccine Development. *Vaccines* **2023**, *11*, 695. https://doi.org/10.3390/vaccines11030695
6. Srivastava, V.; Nand, K.N.; Ahmad, A.; Kumar, R. Yeast-Based Virus-like Particles as an Emerging Platform for Vaccine Development and Delivery. *Vaccines* **2023**, *11*, 479. https://doi.org/10.3390/vaccines11020479
7. Okuyama, R. Trends in COVID-19 Vaccine Development: Vaccine Platform, Developer, and Nationality. *Vaccines* **2024**, *12*, 259. https://doi.org/10.3390/vaccines12030259
8. Bamouh, Z.; Elarkam, A.; Elmejdoub, S.; Hamdi, J.; Boumart, Z.; Smith, G.; Suderman, M.; Teffera, M.; Wesonga, H.; Wilson, S.; et al. Evaluation of a Combined Live Attenuated Vaccine against Lumpy Skin Disease, Contagious Bovine Pleuropneumonia and Rift Valley Fever. *Vaccines* **2024**, *12*, 302. https://doi.org/10.3390/vaccines12030302

References

1. Saleh, A.; Qamar, S.; Tekin, A.; Singh, R.; Kashyap, R. Vaccine Development Throughout History. *Cureus* **2021**, *13*, e16635. [CrossRef]
2. Mukherjee, S.; Kalra, K.; Phelan, A.L. Expanding global vaccine manufacturing capacity: Strategic prioritization in small countries. *PLoS Glob. Public Health* **2023**, *3*, e0002098. [CrossRef] [PubMed]
3. Burchill, M.A.; Tamburini, B.A.; Pennock, N.D.; White, J.T.; Kurche, J.S.; Kedl, R.M. T cell vaccinology: Exploring the known unknowns. *Vaccine* **2013**, *31*, 297–305. [CrossRef] [PubMed]
4. Heidary, M.; Kaviar, V.H.; Shirani, M.; Ghanavati, R.; Motahar, M.; Sholeh, M.; Ghahramanpour, H.; Khoshnood, S. A Comprehensive Review of the Protein Subunit Vaccines Against COVID-19. *Front. Microbiol.* **2022**, *13*, 927306. [CrossRef] [PubMed]
5. Available online: https://www.who.int/initiatives/malaria-vaccine-implementation-programme (accessed on 26 February 2023).
6. Duthie, M.S.; Pena, M.T.; Ebenezer, G.J.; Gillis, T.P.; Sharma, R.; Cunningham, K.; Polydefkis, M.; Maeda, Y.; Makino, M.; Truman, R.W.; et al. LepVax, a defined subunit vaccine that provides effective pre-exposure and post-exposure prophylaxis of *M. leprae* infection. *NPJ Vaccines* **2018**, *3*, 12. [CrossRef] [PubMed]
7. Srivastava, V.; Nand, K.N.; Ahmad, A.; Kumar, R. Yeast-Based Virus-like Particles as an Emerging Platform for Vaccine Development and Delivery. *Vaccines* **2023**, *11*, 479. [CrossRef]
8. Szabó, G.T.; Mahiny, A.J.; Vlatkovic, I. COVID-19 mRNA vaccines: Platforms and current developments. *Mol. Ther.* **2022**, *30*, 1850–1868. [CrossRef]
9. El-Elimat, T.; AbuAlSamen, M.M.; Almomani, B.A.; Al-Sawalha, N.A.; Alali, F.Q. Acceptance and attitudes toward COVID-19 vaccines: A cross-sectional study from Jordan. *PLoS ONE* **2021**, *16*, e0250555. [CrossRef]
10. Kumar, R.; Srivastava, V.; Nand, K.N. The Two Sides of the COVID-19 Pandemic. *COVID* **2023**, *3*, 1746–1760. [CrossRef]
11. Tan, Y.; Chen, L.; Li, K.; Lou, B.; Liu, Y.; Liu, Z. Yeast as carrier for drug delivery and vaccine construction. *J. Control. Release* **2022**, *346*, 358–379. [CrossRef]
12. Ardiani, A.; Higgins, J.P.; Hodge, J.W. Vaccines based on whole recombinant *Saccharomyces cerevisiae* cells. *FEMS Yeast Res.* **2010**, *10*, 1060–1069. [CrossRef]
13. Kumar, R.; Srivastava, V. Application of anti-fungal vaccines as a tool against emerging anti-fungal resistance. *Front. Fungal Biol.* **2023**, *4*, 1241539. [CrossRef]
14. Fisher, M.C.; Alastruey-Izquierdo, A.; Berman, J.; Bicanic, T.; Bignell, E.M.; Bowyer, P.; Bromley, M.; Brüggemann, R.; Garber, G.; Cornely, O.A.; et al. Tackling the emerging threat of antifungal resistance to human health. *Nat. Rev. Microbiol.* **2022**, *20*, 557–571. [CrossRef]
15. Chen, D.; Kristensen, D. Opportunities and challenges of developing thermostable vaccines. *Expert Rev. Vaccines* **2009**, *8*, 547–557. [CrossRef]
16. Kunda, N.K.; Peabody, J.; Zhai, L.; Price, D.N.; Chackerian, B.; Tumban, E.; Muttil, P. Evaluation of the thermal stability and the protective efficacy of spray-dried HPV vaccine, Gardasil® 9. *Hum. Vaccine Immunother.* **2019**, *15*, 1995–2002. [CrossRef]
17. Braun, L.J.; Jezek, J.; Peterson, S.; Tyagi, A.; Perkins, S.; Sylvester, D.; Guy, M.; Lal, M.; Priddy, S.; Plzak, H.; et al. Characterization of a thermostable hepatitis B vaccine formulation. *Vaccine* **2009**, *27*, 4609–4614. [CrossRef]
18. Smith, T.G.; Siirin, M.; Wu, X.; Hanlon, C.A.; Bronshtein, V. Rabies vaccine preserved by vaporization is thermostable and immunogenic. *Vaccine* **2015**, *33*, 2203–2206. [CrossRef]
19. Leung, V.; Mapletoft, J.; Zhang, A.; Lee, A.; Vahedi, F.; Chew, M.; Szewczyk, A.; Jahanshahi-Anbuhi, S.; Ang, J.; Cowbrough, B.; et al. Thermal Stabilization of Viral Vaccines in Low-Cost Sugar Films. *Sci. Rep.* **2019**, *9*, 7631. [CrossRef] [PubMed]
20. Zhou, H.; Wang, G.; Li, X.F.; Li, Y.; Zhu, S.Y.; Qin, C.F.; Tang, R. Alumina-encapsulated vaccine formulation with improved thermostability and immunogenicity. *Chem. Commun.* **2016**, *52*, 6447–6450. [CrossRef] [PubMed]
21. Tsagkaris, C.; Laubscher, L.; Papadakis, M.; Vladychuk, V.; Matiashova, L. Immunization in state of siege: The importance of thermostable vaccines for Ukraine and other war-torn countries and territories. *Expert Rev. Vaccines* **2022**, *21*, 1007–1008. [CrossRef] [PubMed]
22. Ulmer, J.B.; Valley, U.; Rappuoli, R. Vaccine manufacturing: Challenges and solutions. *Nat. Biotechnol.* **2006**, *24*, 1377–1383. [CrossRef] [PubMed]
23. Li, Z.; Lu, J.; Lv, J. The Inefficient and Unjust Global Distribution of COVID-19 Vaccines: From a Perspective of Critical Global Justice. *Inquiry* **2021**, *58*, 469580211060992. [CrossRef] [PubMed]