Reprogramming the story: Edible insects as vaccines

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Abstract

Animal-centric scientific research during the pandemic has produced an epistemic dilemma, in which knowledge about the evolutionary nature of the SARS-CoV-2 virus and its transmission to humans produces discrimination against Asian peoples as a by-product. More constructive awareness and analysis of how frameworks that support narratives of human exceptionalism persist and lead to this conundrum are needed in order to envision ways to redistribute global ways of knowing zoonotic epidemics beyond questions concerning origins. By exploring the history of the baculovirus expression system (a biological technology relying on a moth-specific virus to mass-produce recombinant proteins) and how it came to be used in recent vaccine development, this essay explores expanding, changing uses of insects that complicate the familiar binary categories that pit them as either harmful or beneficial. The conceptual undoing of this binary illuminates possibilities for the kinds of conversations that are necessary to work against the hate- and fear-driven dehumanisation that the pandemic enabled.

Keywords: Baculovirus Expression Vector System; virus-like particles; alternatives to mammalian biomedical systems; silkworms as biomedicine and food; Covid-19 vaccines; reagent and vaccine development; Japan

Introduction

The rise in anti-Asian hate crimes and their under-reporting in many parts of the free world has been the underbelly of the beast that is Covid-19 research.[1] Dedicated scientific efforts from conservation biology to virology have been motivated by an

1 'Social commentary, racism & Covid-19: A case study on opinion pieces in Australian mainstream newspapers', October 2020, alltogethernow.org.au/wp-content/uploads/2020/10/ATN-Media-Report-2020_online.pdf, accessed 21 October 2021; David Nakamura, 'Attacks on Asian Americans during pandemic renew criticism that U.S. undercounts hate crimes', *Washington Post*, 22 February 2021, www.washingtonpost.com/national-security/asian-american-hate-crimes/2021/02/21/c28a8e04-72d9-11eb-b8a9-b9467510f0fe_story.html, accessed 28 February 2021; Angela R. Gover, Shannon B. Harper and Lynn Langton, 'Anti-Asian Hate Crime During the COVID-19 Pandemic: Exploring the Reproduction of Inequality', *American Journal of Criminal Justice* 45, no. 4 (2020): 647–67, doi.org/10.1007/s12103-020-09545-1.

interest in origin stories and developing means to model potential transmission.[2] By the same token, insecurities about the place and people responsible for the origin of the epidemic seem only to cascade from the unsettled understandings of how zoonotic transfer precisely occurred. The efforts to clarify the evolutionary nature of the SARS-CoV-2 virus at the interface of animals and humans also point to an uneasy relationship between the processes of scientific confirmation and the emboldening of public expressions of racism and xenophobia.[3]

The epistemic dilemma, in which discrimination against Asian peoples is produced alongside knowledge about the disease, will remain a by-product of animal-centric research into Covid-19 so long as frameworks that support narratives of human exceptionalism persist without constructive critique. The strategy necessary for bridging this gap does not require pausing scientific efforts to understand how zoonotic transfer works around the world, but it does require our willingness to envision ways to redistribute global attention when it comes to ways of knowing zoonotic epidemics beyond questions concerning origins. The disproportionate dehumanisation of Asian people in the history of Covid-19 so far is stark when compared to similar zoonotic outbreaks of the recent past that erupted in the United States, such as H1N1 influenza ('swine flu').[4] Still, the racism of Covid-19 does not surprise, given the precedent of SARS and creative (or even backfiring) efforts made by Chinese people to dismantle their own reputation in the Global North as proxies for a Chinese disease.[5] The need to counter dehumanisation continues as we manage the current pandemic. It specifically necessitates the development of more perspectives about the nexus of epidemics, Asian people and insects — among which some species have come to be regarded as vermin and provide the

2 Gary Wong et al., 'Zoonotic origins of human coronavirus 2019 (HcoV-19 / SARS-CoV-2): Why is this work important?', *Zoological Research* 41, no. 3 (May 2020): 213–19; Alexandre Hassanin, Philippe Grandcolas, and Géraldine Veron, 'Covid-19: Natural or Anthropic Origin?', *Mammalia* 85, no. 1 (2021): 1–7, doi.org/10.1515/mammalia-2020-0044; Beckett Sterner et al., 'Bats, Objectivity, and Viral Spillover Risk', *History and Philosophy of the Life Sciences* 43, no. 1 (2021): 7, doi.org/10.1007/s40656-021-00366-x.

3 Jon Cohen, 'Wuhan seafood market may not be source of novel virus spreading globally', *Science*, 26 January 2020, doi.org/10.1126/science.abb0611; Michelle T. King, 'Say No to Bat Fried Rice: Changing the Narrative of Coronavirus and Chinese Food', *Food and Foodways* 28, no. 3 (July 2020): 237–49, doi.org/10.1080/07409710.2020.1794182; Drew Hinshaw, Betsy McKay and Jeremy Page, 'Inquiry Into Covid-19's Origins Splits U.S. and China', *Wall Street Journal*, 25 May 2021, www.wsj.com/articles/inquiry-into-covid-19s-origins-splits-u-s-and-china-11621969480, accessed 21 October 2021.

4 Matthew Sparke and Dimitar Anguelov, 'H1N1, globalization and the epidemiology of inequality', *Health & Place* 18, no. 4 (July 2012): 726–36, doi.org/10.1016/j.healthplace.2011.09.001; Lindsay Y. Dhanani and Berkeley Franz, 'Unexpected Public Health Consequences of the COVID-19 Pandemic: A National Survey Examining Anti-Asian Attitudes in the USA', *International Journal of Public Health* 65, no. 6 (July 2020): 747–54, doi.org/10.1007/s00038-020-01440-0; Tiffany Karalis Noel, 'Conflating Culture with COVID-19: Xenophobic Repercussions of a Global Pandemic', *Social Sciences & Humanities Open* 2, no. 1 (January 2020): 100044, doi.org/10.1016/j.ssaho.2020.100044.

5 Ho-fung Hung, 'The Politics of SARS: Containing the Perils of Globalization by More Globalization', *Asian Perspective* 28, no. 1 (2004): 19–44, doi.org/10.1353/apr.2004.0032; Katherine A. Mason, 'H1N1 Is Not a Chinese Virus: The Racialization of People and Viruses in Post-SARS China', *Studies in Comparative International Development* 50, no. 4 (1 December 2015): 500–18, doi.org/10.1007/s12116-015-9198-y.

basis for problematic discriminatory language. For instance, in a rich account of the subordination of Asian Americans since the turn of the twentieth century, the historian Jeannie Shinozuka has shown how the US Government and the mass media perpetuated a message that cast both Japanese beetles (*Popillia japonica*) and human bodies as 'yellow perils'.[6]

The entrenchment of a gap between animals and humans has profited from the recognition that animals can help spread diseases. The narrowness and unidirectionality of a vector relationship between a reservoir and its potential, as mediated by the Covid-19 pandemic, can direct how well we notice different kinds of cultural and historical multi- or interspecies relationships. These relationships with animals—as companions, ecological partners, scientific objects and tools, or resources for food, ritual, medicine, sport or clothing, to name a few—have all entered the foreground in various ways and moments during the unfurling pandemic. Moreover, the crisis has destabilised how people 'care' about animals. For example, an uptick in the adoption of pets to combat loneliness has been accompanied by the abandonment of animals for fear of contracting illness from them.[7] Related to the exclusionary issues that acts of categorising engender, the tension between the harmful and beneficial is productive for identifying how else to examine Covid-19 in order to elicit different, critical appreciation of animals beyond their simply being seen as vectors.

Scholarship at the crossroads of environmental history and the history of the life sciences can productively variegate our understandings of how animals (including humans) are discussed in relation to infectious diseases such as Covid-19. In the next section, I discuss the baculovirus expression system (a biological technology relying on a moth-specific virus to mass-produce recombinant proteins) and how a historical view of research into silkworm disease directs us to insights about the more recent deployment of vaccines. The use of insects in these systems is related to environmental and medical alternatives to animal serums used in life sciences technologies that are derived from by-products of the meatpacking industry. Highlighting the expanding, changing uses of insects beyond traditions like sericulture or apiculture complicates the familiar binary categories that pigeonhole

6 Shinozuka, Jeannie N. 'Deadly Perils: Japanese Beetles and the Pestilential Immigrant, 1920s–1930s', *American Quarterly* 65, no. 4 (2013): 831–52, doi.org/10.1353/aq.2013.0056.

7 Elena Ratschen et al., 'Human–Animal Relationships and Interactions during the Covid-19 Lockdown Phase in the UK: Investigating Links with Mental Health and Loneliness', *PLOS ONE* 15, no. 9 (2020): e0239397, doi.org/10.1371/journal.pone.0239397; Lyle Fearnley, *Virulent Zones: Animal Disease and Global Health at China's Pandemic Epicenter* (Durham, NC: Duke University Press, 2020), 209–12, doi.org/10.1515/9781478012580; Nicola M. A. Parry, 'COVID-19 and Pets: When Pandemic Meets Panic', *Forensic Science International: Reports* 2 (December 2020): 100090, doi.org/10.1016/j.fsir.2020.100090; Liat Morgan et al., 'Human–Dog Relationships during the COVID-19 Pandemic: Booming Dog Adoption during Social Isolation', *Humanities and Social Sciences Communications* 7, no. 1 (24 November 2020): 1–11, doi.org/10.1057/s41599-020-00649-x; Jianzhong Shi et al., 'Susceptibility of Ferrets, Cats, Dogs, and Other Domesticated Animals to SARS–Coronavirus 2', *Science* 368, no. 6494 (29 May 2020): 1016–20, doi.org/10.1126/science.abb7015.

insects as either harmful or beneficial. The conceptual undoing of such a binary illuminates some possibilities for the kind of conversations that are necessary to work against the hate- and fear-driven dehumanisation that was enabled during the pandemic.

The baculovirus insect system in Covid-19 context

Research that uses animal bodies to advance antibody testing and vaccine development knits the days of SARS to the present. Scientists have commonly used animals to develop and test vaccines but less known are the uses of insect systems. Closer attention to the bioscience of the development of vaccines, not just their deployment or objectives, will help us comprehend how and why the environmental and technical choices to use insect cells and bodies may be viewed as productive responses to the legacy of the interconnections between animal slaughter and biomedical supply chains.[8]

Covid-19 vaccine research and development provide an opportunity to recognise the multifaceted role of insects in biotechnology research and rebalance the negativity that mires how we talk about bugs. The use of insect bodies and cells are linked to increasing biological efficacy and convenience; these are also tied intimately to issues of sustainability and the material limitations of mammalian systems used historically to combat human and veterinary diseases. In contrast to the mRNA technologies of vaccines that instruct the human body to create spike proteins, the main antigen component in all structural proteins of SARS-CoV-2, other vaccines like that produced by Novavax, Inc., have relied upon a nanoparticle technology to directly create the proteins with the help of moth cells.[9] As baculovirus insect systems involving the silkworm and alfalfa looper moth (*Autografo californica*) are used globally to synthesise proteins of biomedical interest, we must pay more attention to their histories. Integrating historical analysis of biomedical research with

8 Donna Haraway, 'Awash in Urine: DES and Premarin® in Multispecies Response-ability', *Women's Studies Quarterly* 40, no. 1/2 (2012): 301–16, doi.org/10.1353/wsq.2012.0005; Alex Blanchette, *Porkopolis: American Animality, Standardized Life, and the Factory Farm* (Durham, NC: Duke University Press, 2020), doi.org/10.2307/j.ctv11cw0x4.

9 Adar Poonawalla, 'Covovax trials finally begin in India; the vaccine is made through a partnership with @Novavax and @SerumInstIndia. It has been tested against African and UK variants of #COVID19 and has an overall efficacy of 89 %. Hope to launch by September 2021! https://T.Co/GyV6AQZWdV', Tweet, @adarpoonawalla (blog), 27 March 2021, twitter.com/adarpoonawalla/status/1375710734508695552, accessed 25 October 2021. Novavax, which uses insect cell technology, signed an exclusive deal to license production rights to the Serum Institute of India (which also produces and distributes Covishield). Covovax began clinical trials in India in March 2021. See SEC filing, NOVAVAX, Inc., Commission file no. 0-26770, 30 July 2020, www.sec.gov/Archives/edgar/data/1000694/000110465920090911/tm2026730d1_8k.htm, accessed 25 October 2021.

environmental history in order to link specific experimental choices to environmental externalities should deepen our appreciation of how and why entomologically based approaches to vaccine development present appealing alternatives for many.

Since the coronavirus epidemic broke out, scientists in Japan have endeavoured to develop silkworm pupae that could double as edible Covid-19 vaccines. KAICO Ltd, established in 2018 by Kusakabe Takahiro, a professor in the Faculty of Agriculture at Kyushu University, has been utilising a biotechnological system that coaxes silkworms to generate made-to-order proteins that can function as useful reagents in regenerative medicine, diagnostic reagents for diseases, and vaccines. They too were positioned to respond uniquely during the unfolding Covid-19 crisis because of their location near a historic silkworm gene bank situated on the Kyushu University campus that permitted easy selection of silkworm strains most suited for the job. By injecting silkworms with recombinant baculoviruses containing a genetic sequence for the SARS-CoV-2 spike protein, the scientists could reprogram silkworm tissues to generate spike proteins necessary for vaccines.[10]

Baculoviruses specifically replicate in insect hosts, and the baculovirus technology used by laboratories such as at KAICO stems from the legacy of managing silkworm-infecting pests during the nineteenth century. Scientists, then aided with but a simple microscope, had noticed crystalline protein matrices in the tissue of diseased silkworms. These are now understood as the calling card of nucleopolyhedrovirus (NPV) infection.[11] NPVs, which belong to the Baculoviridae family of viruses, have throughout the twentieth century been used to microbially control unwanted pests such as *Lymantria dispar*—gypsy moths.[12] Pest management objectives helped lead scientists to use the cells of pests to cultivate useful molecules from them. The alfalfa looper moth and fall armyworm (*Spodoptera frugiperda*) have also had reputations as pests, especially in the agricultural context. During the 1980s, US scientists Max Summers and Gale E. Smith (now a Novavax executive) developed a 'Baculovirus Expression Vector System' (BEVS), which involved developing recombinant baculoviruses and introducing them to these cultured moth cells.[13] Such cells could

10 Nishiyama Akihiko, 'Kaiko ga korona no kyūseishu? Taberu wakuchin kaihatsu he' [Silkworm as savior from coronavirus? Toward an edible vaccine], *Nihon Keizai Shimbun*, 4 August 2020; Ryosuke Fujita et al., 'Efficient Production of Recombinant SARS-CoV-2 Spike Protein Using the Baculovirus-Silkworm System', *Biochemical and Biophysical Research Communications* 529, no. 2 (2020): 257–62, doi.org/10.1016/j.bbrc.2020.06.020. Japanese names appear as they do in Japan, with the family name preceding the given name unless they appear otherwise in a publication. The history of silkworms as genetic resources in Kyushu, Japan, is discussed in the author's *Cocoon Cultures* (forthcoming).

11 Emilio Cornalia, *Monographia del bombice del gelso* (Memorie dell'I.R. Istitutio Lombardo di Scienze. Lettere ed Arti, 6) (Milano: Bernardoni di Gio, 1856), 348–51; Angelo Maestri, 'Del giallume', in *Frammenti Anatomici, Fisiologici e Patologici sul baco da seta* (Pavia: Fusi, 1856), 117–20.

12 Dave Goulson, 'Wipfelkrankheit: modification of host behaviour during baculoviral infection', *Oecologia* (1997) 109: 219–28, doi.org/10.1007/s004420050076.

13 Max D. Summers and Gale E. Smith, *A manual of methods for baculovirus vectors and insect cell culture procedures* (College Station, TX: Texas Agricultural Experiment Station, 1987); US Patent No. 4,745,051: Method for Producing a Recombinant baculovirus Expression Vector; Granted 17 May 1988 (Gale E. Smith, Max D. Summers).

handle the synthesis of larger proteins more readily than could bacterial systems.[14] In the context of developing Covid-19 vaccines, insect cell expression systems are gaining wider appreciation among biotechnology companies worldwide. Their economic efficacy has helped make baculovirus-based protein expression platforms appealing, especially in consideration of prioritising safety combined with mass production.[15]

Interest in rapidly developing vaccines and antibody tests for emergent infectious diseases had been instigated already by the time of the SARS crisis, which has pointed companies in Asia toward insect systems over the last two decades. The need for efficiency crucially pressured researchers to deploy accurate diagnostic test kits and effective vaccines in fast-moving outbreaks where they were needed quickly.[16] Yet enhanced deployment speed has usually entailed greater costs. The fact that research reagents used in Japan largely came from overseas also motivated KAICO's investors, who saw potential in the domestic reagent market.[17] Efforts to develop rapid test kits and vaccines during the novel coronavirus pandemic made even more visible the logistical infrastructure of making and transporting reagents, antibodies and proteins for research, development, testing and production. Thus, for Covid-19, Kusakabe has explained to the press, their goal was not merely to speed up the process of producing vaccines. By lowering reagent production costs, he stressed the important possibility of stably producing inexpensive vaccines in Japan that could be administered to people in developing countries and elsewhere.[18] The development of vaccines using silkworms in this vision would ideally address the logistical shortcomings that unevenly distribute vaccines in the Global South.

14 Donald L. Jarvis, 'Baculovirus–Insect Cell Expression Systems', in *Methods in Enzymology*, ed. Richard R. Burgess and Murray P. Deutscher (San Diego, CA: Academic Press, 2009), 191–222, doi.org/10.1016/S0076-6879(09)63014-7.

15 Linda A. Johnson, 'Novavax: Large Study Finds COVID-19 Shot about 90% Effective', *Associated Press*, 14 June 2021, apnews.com/article/coronavirus-pandemic-science-business-health-02b977b3ed5cfa59643bef1baabde4f7, accessed 25 October 2021; Richard Hitchman, Robert Possee and Linda King, 'Baculovirus Expression Systems for Recombinant Protein Production in Insect Cells', *Recent Patents on Biotechnology* 3, no. 1 (2009): 46–54, doi.org/10.2174/187220809787172669; Takara Bio USA, 'Insect expression overview', www.takarabio.com/learning-centers/protein-research/expression-systems/insect-expression-overview, accessed 25 October 2021; Life Technologies Corporation, 'Bac-to-Bac® Baculovirus Expression System: An Efficient Site-Specific Transposition System to Generate Baculovirus for High-Level Expression of Recombinant Proteins' (user guide) (Carlsbad, CA: Life Technologies Corporation, 2015).

16 Tony Greenway, 'Why the insect cell system is a boost for vaccine development', *Health Awareness*, 4 March 2020, www.healthawareness.co.uk/vaccines/why-the-insect-cell-system-is-a-boost-for-vaccine-development, accessed 25 October 2021; Alice Street and Ann H. Kelly, 'Counting coronavirus: Delivering diagnostic certainty in a global emergency', *Somatosphere* (blog), 6 March 2020, somatosphere.net/forumpost/counting-coronavirus-diagnostic-certainty-global-emergency, accessed 25 October 2021.

17 'Kyūdaihatsu no kaiko, kenkyūsha wo zōin 19nendo ni beishinshutsu' [Kyushu University's silkworm project to expand into the United States in 2019 with more researchers], *Nihon Keizai Shimbun,* 9 November 2018.

18 Takenouchi Takahiro, 'Kaiko kara wakuchin kōhobu'shitsu Kyūdai, rainendo ni mo rinshōkenkyū shinsei korona' [Vaccine candidate from silkworm: Kyushu University to conduct clinical research on novel coronavirus next year], *Asahi Shimbun*, 27 June 2020, 34.

Agricultural animal systems, values and vaccine manufacture

Disruptions to food supply chains are expected in disasters, but in pandemics, these issues refract in discomfiting ways that exceed food security concerns and fall into the arena of biosecurity.[19] Fragilities in global supply chains underscore how the work of producing vaccines has often relied upon animal systems to produce serums, antigens and other medically valuable substances. Such systems reliant upon animals like cows and chickens are equally vulnerable to infectious diseases.[20] For example, although eggs are used to manufacture influenza vaccines, disruptions from avian influenza pose the risk of also blocking their production.[21] Furthermore, the prospect of co-administering Covid-19 and influenza vaccines risks being impacted even if eggs cannot technically be used for Covid-19 vaccines.[22] In the way personal protective equipment shortages during early 2020 shed light upon the tenuous relationship between materials and the logistical provisioning of manufactured supplies, Covid-19 vaccine research illustrates both the strength and fragility of interconnectedness.

The difficulties of relying upon shipping and logistics to protect global health in the face of the outbreak had particularly encouraged ventures that focused primarily upon vaccines and therapeutics for animals to diversify their product range to humans.[23] For instance, KAICO's vaccine program had originally worked on producing different kinds of proteins used in diagnostic reagents and vaccines for coronaviruses that infect chickens and pigs. As they expanded to proteins key for protecting human health, the uses of insects have come to even more clearly exceed their known confines of binary categories such as pests or economically productive bodies. The work of making effective vaccines with insect cells and

19 Vasco M. Carvalho et al., 'Supply Chain Disruptions: Evidence from the Great East Japan Earthquake', Social Science Research Network, Rochester, NY (23 August 2020); Philip Garnett, Bob Doherty and Tony Heron, 'Vulnerability of the United Kingdom's food supply chains exposed by COVID-19', *Nature Food* 1, no. 6 (June 2020): 315–18, doi.org/10.1038/s43016-020-0097-7; Kanika Mahajan and Shekhar Tomar, 'COVID-19 and Supply Chain Disruption: Evidence from Food Markets in India', *American Journal of Agricultural Economics* 103, no. 1 (2021): 35–52, doi.org/10.1111/ajae.12158; David Laborde et al., 'COVID-19 Risks to Global Food Security', *Science* 369, no. 6503 (31 July 2020): 500–2, doi.org/10.1126/science.abc4765.

20 D. A. Espeseth and H. Lasher, 'History of Regulatory Requirements for Poultry Biologics in the United States, 1970s to 1990s', *Avian Diseases* 57, no. 2 (2013), 167–71, doi.org/10.1637/10372-091312-Hist.1.

21 *Avian influenza. USDA has taken actions to reduce risks but needs a plan to evaluate its efforts: Report to Congressional requesters* (Washington, DC: US Government Accountability Office, 2017).

22 This potential is discussed in a preprint article: Seth Toback et al., 'Safety, Immunogenicity, and Efficacy of a COVID-19 Vaccine (NVX-CoV2373) Co-Administered with Seasonal Influenza Vaccines', *MedRxiv*, 13 June 2021, 2021.06.09.21258556, doi.org/10.1101/2021.06.09.21258556.

23 Ryosuke Fujita et al., 'Efficient production of recombinant SARS-CoV-2 spike protein using the baculovirus–silkworm system', *Biochemical and Biophysical Research Communications* 529, no. 2 (August 2020): 257–62, doi.org/10.1016/j.bbrc.2020.06.020.

bodies reassigns how we value them.[24] We need to appreciate how static categories of value are becoming complicated in order to gain a fuller sense of the dynamic relationship between entomological and human life. Intriguingly, an awareness that agro-industrial production yields the mammalian and avian surplus vital matter that has and still fuels many biomedical advances emerges from examining the growing use of insects in the context of valuing human health. Cognisance of this facet of biotechnology connects to the scientific rationale to seek, with insect life, more efficient and safer methods in the global effort to produce proteins for vaccines meant for humans. In addition to cost- and market-driven rationales, entomological alternatives illuminate how biological matter is exploited and the different reasons why animal lives are cared for in relation to human health.

Efforts to produce therapies with silkworms have been maturing over the last decade and a half in Asia. For example, in 2015, a team of scientists in Japan announced that they had successfully mass-produced influenza virus-like particles in silkworm larvae for vaccine use.[25] BEVS-derived vaccines, from vaccines for swine flu, the human papilloma virus, or influenza, seem to be steadily developing and being commercially licensed around the world. Proponents of the baculovirus systems that generate these aforementioned vaccines especially stress they are safe because they do not involve live pathogens.[26] These safety concerns also relate back to the link between vaccine production and agricultural systems. The team of Kyushu University scientists who used the baculovirus–silkworm system to synthesise and purify spike proteins have made a point of rendering their system free of foetal bovine serum. BEVS often use foetal bovine serum to encourage the productivity of infected insect cells, but Fujita Ryosuke et al. decided to avoid the serum for Covid-19 vaccine development in order to remove the potential contamination of prions or other virus-like organisms.[27] As a result, this trajectory of generalising baculovirus–silkworm protein expression systems seems to promise a way to avoid the use of serums from unborn calves

24 Catherine Waldby, *The Visible Human Project* (London: Routledge, 2000). As Waldby puts it, such biovalue arises as new biological technologies, intended to promote human health, are generated from vital matter, which create new economic value as these things are exchanged.

25 Tatsuya Kato et al., 'Silkworm expression system as a platform technology in life science', *Applied Microbiology and Biotechnology* 85, no. 3 (2010): 459–70, doi.org/10.1007/s00253-009-2267-2; Hao Feng et al., 'Canine ParvovirusVP2 Protein Expressed in Silkworm Pupae Self-Assembles into Virus-Like Particles with High Immunogenicity', *PLoS One* 9, no. 1 (2014), doi.org/10.1371/journal.pone.0079575; Akitsu Masuda et al., 'Purification and characterization of immunogenic recombinant virus-like particles of porcine circovirus type 2 expressed in silkworm pupae', *Journal of General Virology* 99, no. 7 (2018), 917–26, doi.org/10.1099/jgv.0.001087; Kuniaki Nerome et al., 'The Large-Scale Production of an Artificial Influenza Virus-like Particle Vaccine in Silkworm Pupae', *Vaccine* 33, no. 1 (January 2015): 117–25, doi.org/10.1016/j.vaccine.2014.11.009.

26 Rachael S. Felberbaum, 'The Baculovirus Expression Vector System: A Commercial Manufacturing Platform for Viral Vaccines and Gene Therapy Vectors', *Biotechnology Journal* 10, no. 5 (2015): 702–14, doi.org/10.1002/biot.201400438.

27 Ryosuke Fujita et al., 'Efficient Production of Recombinant SARS-CoV-2 Spike Protein Using the Baculovirus-Silkworm System', *Biochemical and Biophysical Research Communications* 529, no. 2 (August 2020): 257–62, doi.org/10.1016/j.bbrc.2020.06.020.

from cows headed for slaughter, and therefore mammalian systems altogether.[28] Although the idea of serum-free culture media has been gaining scientific attention for decades, these developments must be considered as more than mere biomedical issues.[29] The potential to shift vaccine manufacturing's reliance on the by-products of the meat and poultry industries helps us consider how insect–baculovirus systems relate to environmental and economical sustainability efforts. It also hints at the affective ties that humans have with mammals and birds that relate to the moral issues of using agricultural animal by-products that could make insect alternatives appear more socially 'acceptable'. Beyond making vaccines, their administration to humans can also be rethought alongside other shifts in animal protein consumption as marked by the possibility of consuming the pupae of metamorphosing insects as a means of taking in the vaccine.[30] In addition to biomedicine and food, the use of insects in the business of prolonging human and other animal life needs to be analysed in the context of the human consumption patterns that give the pandemic its relentlessly global character.[31] Now, in addition to producing capital through the international commercial trade of its proteinaceous silk fibre, the silkworms selected for biomedicine carry therapeutic value and potential for securing human and animal health, while posing implications for sustainability, and creating a generative space for discussing questions about insects and pandemics that departs from the language of infestation.

Conclusion

To understand our efforts today to curb the spread of coronavirus infections worldwide, future historians will need to be willing to embrace a multifaceted understanding of animals as simultaneous sources of inspiration and anxiety that generate economic and social value, change and healing for (or protection against) various kinds of harm, medical or environmental. Emergent crises like the current pandemic will continually require greater openness to new ideas and different perspectives if public health crises are to become less energy-dependent or more environmentally and ethically sound. Here, an appreciative attention to

28 Carlo E. A. Jochems et al., 'The Use of Fetal Bovine Serum: Ethical or Scientific Problem?', *Alternatives to Laboratory Animals: ATLA* 30, no. 2 (April 2002): 219–27, doi.org/10.1177/026119290203000208.

29 D. Barnes and G. Sato, 'Methods for growth of cultured cells in serum-free medium', *Analytical Biochemistry* 102, no. 2 (1980): 255–70, doi.org/10.1016/0003-2697(80)90151-7.

30 F. S. Bodenheimer, 'History of Entomophagy', in *Insects as Human Food: A Chapter of the Ecology of Man*, ed. F. S. Bodenheimer (Dordrecht: Springer Netherlands, 1951), 39–69, doi.org/10.1007/978-94-017-6159-8_2; Noguchi Kenichi, *Konchūshoku Senshinkoku Nippon* [Leading nation in entomophagy Japan] ([Tokyo: Aki Shobō], 2008). Insects have been well-regarded as a valuable source of complete proteins in many parts of the world for centuries.

31 The commercial prospect of creating sustainable cultured meat has additionally contributed to growing interests in sustaining cell lines without traditional serum-based media. For example, A. M. Kolkmann et al., 'Serum-free media for the growth of primary bovine myoblasts', *Cytotechnology* 72, no. 1 (2020), 111–20, doi.org/10.1007/s10616-019-00361-y.

insect bodies can play a role. Insects have often occupied a lesser stature in the eyes of humans than charismatic megafauna. Examples from the twentieth century, such as the introduction of the Japanese beetle and San Jose scale (*Aspidiotus perniciosus*) to California, have demonstrated how the connections drawn between the invasiveness of some insect species, their damage to plants, and the double bind faced by Japanese-American gardeners who sprayed food crops with insecticides that sickened consumers, have made it very easy for both public and government to criminalise Asian immigrants and parallel them with pestilence—entomological threats to native ecologies that deserve to be eradicated.[32] If the pandemic's related hate-based name-calling directed at East Asians in the twenty-first century is any indication, our negatively associated memories of insects as invasive, dangerous or economically damaging species, for instance, have lasting effects upon society.[33] Perhaps, by attending to new historical contexts connected to the use of animals in the formation of diagnostic tools and vaccines for Covid-19, insects as a whole can gain new kinds of appreciation. And, perhaps, that is one six-legged step of many more that can make a difference.

32 Shinozuka, 'Deadly Perils: Japanese Beetles and the Pestilential Immigrant, 1920s–1930s', 883.

33 I. M. Nick, 'In the Name of Hate: An Editorial Note on the Role Geographically Marked Names for COVID-19 Have Played in the Pandemic of Anti-Asian Violence', *Names* 69, no. 2 (2021): 1–10, doi.org/10.5195/names.2021.2276; Aggie J. Yellow Horse, 'Anti-Asian Racism, Xenophobia and Asian American Health during COVID-19', in *The COVID-19 Crisis: Social Perspectives*, ed. Deborah Lupton and Karen Willis (Abingdon and New York: Routledge, 2021), doi.org/10.4324/9781003111344-21.

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