COVID-19 pandemic lessons for agri-food systems innovation

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COVID-19 pandemic lessons for agri-food systems innovation

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The COVID-19 pandemic provides both a warning about agri-food systems' (AFS) functioning and an accelerator for AFS innovation. It revealed both the increasing frequency of extreme events and structural shortcomings with respect to access to healthy diets, equitable livelihoods, resilience, and climate and environmental sustainability challenges that pervade AFS worldwide (Barrett *et al* 2020). Return to prior state is both unlikely and undesirable. The central question is how will AFSs transform in response to the pandemic and the conditions it revealed? The pandemic has shifted awareness and incentives in ways that have the capacity—but are not guaranteed—to prompt necessary, transformational AFS adaptation (Kates *et al* 2012, Bassett and Fogelman 2013). Will AFS transformation occur and, if so, who will benefit and who will bear the costs and risks? Drawing on a year-long global expert panel review (Barrett *et al* 2020) we summarize the evidence on AFS impacts of the pandemic and offer seven key lessons to guide adjustments to policies and practices.

Massive AFS disruptions have been commonplace throughout history. Crop failures and livestock disease epidemics have caused agricultural supply shocks, natural disasters and conflict have disrupted local or regional supply chains, and price spikes driven by rapid demand growth—including in related markets, like for petroleum products—or speculative market behavior have been commonplace, even within the past two decades (Barrett 2013, Baldos and Hertel 2015, Lesk *et al* 2016, Davis *et al* 2021, Gomez *et al* 2021). The COVID-19-driven AFS shock is unusual because it originates primarily from a massive collapse and restructuring of food demand, one disproportionately impacting the food service sub-sector (e.g. restaurants, school cafeterias), coupled with shocks to labor availability at multiple agri-food value chain (AVC) entry points (figure 1). There was no major shock to primary production on farm, no infrastructure destruction, and no price spike.

Primary agricultural production proved remarkably robust in 2020 despite modest-to-moderate supply-side disruptions in some countries, mainly due to labor supply and transport disruptions caused by government-imposed movement restrictions meant to slow disease transmission. The Food and Agriculture Organization (FAO) reports record global cereals harvests for 2020 (FAO 2021b). And despite food export bans imposed by at least 21 different national governments—mostly lasting only a few weeks—and massive shutdown of commercial passenger transportation, merchandise freight shipments proved remarkably resilient, especially in multinational firms' global supply chains (Laborde *et al* 2020).

The major AFS disruptions originated chiefly from the demand-side shock of workplace closures that affected 93% of the world's workers as of early January 2021, resulting in historically unprecedented losses equivalent to 255 million full-time jobs, with disproportionately adverse impacts on the food service sector globally (ILO 2021). The combination of disease outbreaks and movement restrictions led to labor shortages at all nodes throughout the value chain (Aday and Aday 2020, Gruère and Brooks 2021). Survey data from >30 000 households in nine low- and middle-income countries (LMICs) reveal 68% reported income losses from the pandemic (Egger *et al* 2021). Income loss combined with a 22.5% increase in the FAO global food price index from the May 2020 low to January 2021—as supply growth was outpaced by demand growth, especially in China and for feedgrains such as maize (FAO 2021b)—together caused 45% of LMIC households to miss or reduce meals (Egger *et al* 2021). Even in high-income countries (HICs), demand for private and public food assistance rose as millions more people struggled to feed their families. Before the pandemic, more than three billion people worldwide could not afford a healthy diet (Bai *et al* 2020, FAO *et al* 2021); the UN estimates that in 2020 the number of people lacking access to adequate food increased by 320 million and the global prevalence of undernourishment increased by 1.5 percentage points (FAO 2021a). The populations most

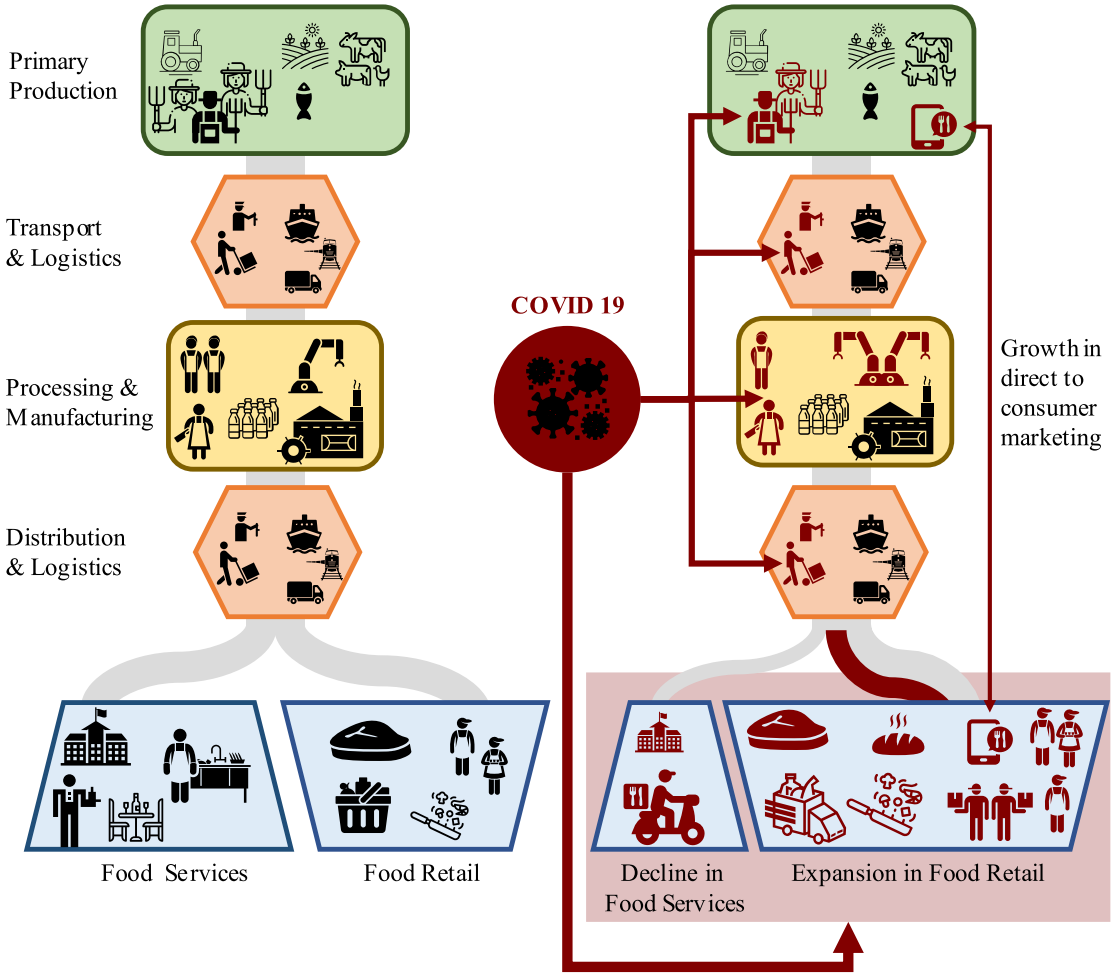

Figure 1. COVID 19 affected virtually all pre-pandemic AVC segments (left panel). Overall primary production and throughput volumes, and resulting prices, largely remained stable. But consumer demand shifted sharply (right panel) from food service (e.g. restaurants, schools) to retail, forcing food service enterprises to prioritize delivery and take-out options, and accelerated primary producer uptake of direct-to-consumer marketing. The shift in food demand, combined with movement restrictions on migrant workers and disease outbreaks that sickened workforces, induced labor reallocation downstream and increased substitution of machines (e.g. robots) for workers throughout AVCs.

vulnerable to COVID-19 infection and death, livelihood loss, and resulting food insecurity have disproportionately been migrants, ethnic and racial minorities, the poor and women (Swinnen and McDermott 2020). Those structural inequities existed long before the pandemic but have been magnified by it.

The main responses by governments and private charitable organizations have been (a) public health measures to control, reduce the spread, and treat COVID-19, and (b) unprecedented expansion of safety net and social protection programs (Gentilini *et al* 2020). The mechanisms for doing so have varied considerably across and within countries. In the final 9 months of 2020, the governments of at least 215 different countries/territories invested at least $800 billion in more than 1 400 different new or expanded social protection measures in response to pandemic disruptions (Gentilini *et al* 2020). Even so, only 11% of LMIC households report having received non-governmental organization (NGO) or government support (Egger *et al* 2021). Sizable holes remain in social safety nets, especially in the LMICs where they are most needed. The pandemic has made clear the importance of existing, scalable, ever-ready social protection programs to safeguard food access and has sparked innovations in program design and delivery, especially in digital cash and voucher distribution, often targeted using artificial intelligence methods, that make accurate, rapid, scalable delivery easier.

The pandemic has also drawn attention to the importance of the food service sector, which accounts for roughly half of all consumer food expenditures in HICs and a rapidly growing share in LMICs (Barrett *et al* In press). The unprecedentedly rapid closure of food service outlets forced food consumers to redirect most food demand towards retail grocers, including online (Goddard 2020, Richards and Rickard 2020, Varshney *et al* 2020). Manufacturers ran out of warehouse storage space for bulk processed goods packaged for institutional buyers that curtailed purchases. Food manufacturing lines designed for bulk food service needs could not be restructured rapidly,

leaving many farmers and food manufacturers with unsellable perishable products for months as those manufacturing lines slowed or shut (Richards and Rickard 2020, Gruère and Brooks 2021). Many livestock farmers were compelled to euthanize animals and to dump milk and eggs into waste lagoons (Aday and Aday 2020, Marchant-Forde and Boyle 2020). Horticultural producers plowed ripe fruits and vegetables back into their fields. Even fisherfolk who could adjust harvest patterns and thus were not stuck with unmarketable perishables incurred massive income losses due to declining demand, especially if they were tied to food service supply chains (Bennett *et al* 2020, Gruère and Brooks 2021).

The second most important AFS lesson of the pandemic—behind the importance of safety nets to protect food access—has been the need for greater supply chain resilience and redundancy to adapt to channel-specific shocks (Barrett *et al* 2020, Gomez *et al* 2021). For decades AFS actors have focused on reducing (even minimizing) average production costs, but largely failed to account for the costs of rare, extreme events. Attention has focused heavily on how environmental disruptions affect staple foods production, limiting our understanding of—and ability to manage—shocks that impact agri-food supply chains though multiple downstream entry points and propagate both downstream and upstream after entry (Davis *et al* 2021). Poor accounting for catastrophic risk exposure leaves AFS vulnerable to systemic shocks (Gomez *et al* 2021). Leaders manage to what they can measure and have spent relatively little time measuring and managing systemic risk exposure and accounting for it properly in financial, productivity, or other performance metrics.

Despite the massive disruptions, value chain intermediaries adapted quickly to switch among subsector-specific chains and service modes (Richards and Rickard 2020, Varshney *et al* 2020, Lowe *et al* 2021). Those restaurants that survived largely moved to delivery, takeout, and outdoor dining options (Brizek *et al* 2021, Kim *et al* 2021). Processors modified manufacturing processes to expand retail-oriented packaging while reducing wholesale packaging for food service clients (Aday and Aday 2020). Careful price analysis studies find that lockdowns caused at most a temporary surge in retail food prices—mainly of perishables—that peaked in the first month or so before returning to pre-pandemic trends after 2 to 4 months, with many markets exhibiting no discernible price adjustments (Varshney *et al* 2020, Lowe *et al* 2021, Mahajan and Tomar 2021, Ruan *et al* 2021).

The pandemic disruptions sparked technological and organizational innovations that will likely prove permanent. Crop and dairy farms, meatpackers, and other processors have sharply increased investment in robots invulnerable to infectious disease transmission and worker movement restrictions (Di Vaio *et al* 2020). Farmers and processors have adopted creative approaches to improve worker safety and firm resilience, such as the Nigerian chicken processors who organized dedicated bus transport for workers and more sparsely staffed shifts at factories (Swinnen and McDermott 2020). Farmers around the world eagerly joined an expanding ecosystem of (largely digital) direct-to-consumer marketing schemes, just as consumers have sharply expanded use of online grocery purchases, food delivery, and home gardens (Guo *et al* 2020). Communities have revived gleaning—the informal collection of unharvested crops that farmers left behind—to reduce food loss and improve poor consumers' access to healthy fresh foods. Already-growing demand for plant-based meat substitutes has accelerated sharply as consumers grew more concerned about the sustainability of production systems (Siegrist and Hartmann 2019) and the potential for food contamination in long value chains (Jalil *et al* 2020, Van Loo *et al* 2020). Many of these changes are welcome advances unlikely to reverse once the pandemic eases.

Transformation is essential because the pandemic is a trial-run not just for inevitable, future infectious disease outbreaks, but also for growing shocks arising from climate change, which has even longer-lasting implications for humanity and the AFSs that support us than does COVID-19 (Herrero and Thornton 2020). Such transformation depends fundamentally on adequate, sustained funding of scientific research and mechanisms to permit rapid diffusion of discoveries (Herrero *et al* 2020). The fastest vaccine development and delivery in history was made possible both by decades' prior investment in fundamental scientific research—e.g. on genetics, virology and immunology, leading to new RNA-based technologies—and unprecedented mobilization of finance for basic and applied science to develop vaccines and treatments (Barrett *et al* 2020). Pre-existing intellectual property (IP) has not significantly impeded R&D progress due to a shared sense of urgency. The Open-COVID Pledge, launched in April 2020 and covering more than 250 000 patents worldwide within 3 months (Contreras *et al* 2020), enables biomedical researchers to freely share their IP following a model like that of open-source software. The COVID-19 experience clearly demonstrates that massive amounts of financing, scientific talent, international cooperation can and must be mobilized quickly with adequate political will and a shared sense of urgency, which are equally needed for broader AFS transformation (Herrero *et al* 2020, Gruère and Brooks 2021). At the same time, it also reveals stark inequalities in access to key innovations, both between and within countries, with innovation reinforcing pre-existing advantages if no concerted effort is made to correct for systemic inequities.

Mainly, the pandemic has been a wake-up call to prepare and build AFS back better. The pandemic

will not be the last major systemic shock of our lifetimes. We must prepare for more severe, frequent, compound, and cascading shocks. The pandemic creates an opportunity to address systemic needs arising from other pressures (e.g. climate change) to which the world has, to date, been insufficiently responsive. This can be a moment of transformative adaptation, innovating so as to navigate to healthier, more equitable, resilient and sustainable AFSs. Alternatively, the innovations born of COVID-19 necessity could further aggravate the burdens of those least able to afford healthy diets, and most burdened by climate change and hazardous work in agri-food supply chains.

Based on a global expert panel's year-long deliberations—with process and supporting information detailed in Barrett *et al* (2020)—seven key lessons stand out from the COVID-19 pandemic experience for AFS transformation.

(a) **Build ever-ready social safety nets.** The pandemic's pain has aggravated underlying inequalities. Reliable, scalable social protection programs sensitive to patterns of systemic discrimination based on race, gender, ethnicity, etc are essential but cannot be built on the fly. Pre-existing safety nets in countries such as Bolivia and Ethiopia sharply reduced or eliminated adverse food security impacts of the pandemic (Abay *et al* 2021, Bottan *et al* 2021). Weak or incomplete social protection mechanisms undermine solidarity and cooperation within society, too often laying the foundation for socio-political instability (Barrett 2013).

(b) **Strengthen supply chain resilience through increased diversity, flexibility, modularity and redundancy.** With more reliable social safety nets to ensure access to healthy diets governments and private businesses can afford the increased, true costs of greater safeguards against catastrophic systemic risk (Rockefeller Foundation 2021). Greater diversification, flexibility, modularity and redundancy in AFS production, sourcing, processing, and distribution patterns may sacrifice some efficiency yet add net value (Gomez *et al* 2021). Just as auto, health and home insurance are wise investments against catastrophic loss for individuals and we should not stop paying for insurance just because we have not suffered recently, so must we willingly incur some modest costs in AFS to insure against massive future disruptions (Barrett *et al* 2020).

(c) **Beware excessive de-globalization.** Building on the prior point, enhanced supply chain resilience to systemic shocks requires optimizing the portfolio of global, regional and local sourcing with an eye to both costs and risks. As emergent technologies make more localized food production (e.g. 'de-agrarianized' controlled environment agriculture, or cultured or plant-based meat substitutes) economically viable, localization grows more attractive and feasible (Barrett *et al* 2020, Barrett 2021). Combined with the temporary imposition of export bans by some governments (Laborde *et al* 2020), advocates for trade barriers have been emboldened. But excessive de-globalization carries significant prospective risks. It can harm the poor by making healthy diets more expensive (Falkendal *et al* 2021), undermine sustainability because *how* a product is produced, processed, and distributed matters far more to its footprint than *how geographically promixate to the consumer* it was made (Sala *et al* 2017, Poore and Nemecek 2018), leave AFS and their markets more vulnerable to climate shocks (Baldos and Hertel 2015), and undercut global cooperation and coordination, the importance of which the pandemic has underscored.

(d) **Fund and build trust in first-rate science.** Technical skill is essential preparation. Innovation and post-crisis adaptation require adequate pre-crisis investments in scientific and engineering capacity (Herrero *et al* 2020). Moreover, misrepresentation and denialism of science can massively obstruct the impacts of even well-funded science. Rapid, accurate science communication is increasingly important, and increasingly challenging, with online social media. Science communication needs to take full advantage of behavioral science lessons on combating misinformation and denialism, coupled with more effective governance of social media channels (Schmid and Betsch 2019, Lorenz-Spreen *et al* 2020, Lunn *et al* 2020, Van Bavel *et al* 2020).

(e) **Confront behavioral and political barriers to progress.** Although the science on COVID-19 has progressed at unprecedented speed, behavioral adjustments have proved far slower and more uneven across communities. Culture and policy change is key but hard. It requires convincing social influencers and thought leaders to adapt individual and collective behaviors in response to scientific discovery, shocks, and other drivers, as well as convincing researchers to engage more effectively in science communication. The billions of independent people and firms exercising agency throughout AFSs makes market incentives and social norms the key policy instruments, more so than top-down directives. One challenge of building market incentives and social norms is lack of cooperation and coordination among and within governments, leading to mixed messages, confusion, and resistance (Herrero *et al* 2020).

(f) **Treat underlying causes, not just symptoms.** Pandemics are the long-predicted consequence of excessive human disturbance of natural

ecosystems (partly due to expanding land use in agriculture) that increases exposure to zoonoses, of inconsistent and non-transparent food safety regulations, and of insufficient integration between food, environmental and health systems, including underlying environmental safety and health drivers (Rohr *et al* 2019, Gibb *et al* 2020, Di Marco *et al* 2020, Rulli *et al* 2021). Root cause analysis is key to identify each limiting factor (Rushton *et al* 2021).

(g) **Emphasize high-frequency monitoring.** Systemic shocks require predictive and near-real-time monitoring of fast-changing conditions. Innovations in remote sensing, data science, digital records, monitoring biomarkers for disease in human and animal waste streams, and crowd-sourcing open up new opportunities to improve the timeliness and cost-effectiveness of community-driven as well as external responses to systemic shocks.

Crises inevitably spark innovation. The crucial questions are what AFS changes the COVID-19 pandemic will induce and how to shift the odds in favor of beneficial transformation? The adaptations that AVC businesses, governments, and NGOs make now to their policies and practices in response to the pandemic—in institutions and policies, as much as in technologies—will have lasting effects. We have less confidence that key AFS organizations and their leaders will make those adaptations than we have that such changes are increasingly, undeniably necessary. If leaders can learn these seven key AFS lessons of this pandemic, however, it will maximize the odds of innovation that ushers in healthier, more equitable, resilient and sustainable AFS.

Data availability statement

No new data were created or analysed in this study.

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References

Abay K A, Berhane G, Hoddinott J F and Tafere K 2021 COVID-19 and food security in Ethiopia: do social protection programs protect? *Econ. Develop. Cultural Change* in press (https://doi.org/10.1086/715831)
Aday S and Aday M S 2020 Impact of COVID-19 on the food supply chain *Food Qual. Saf.* **4** 167–80
Bai Y *et al* 2020 Cost and affordability of nutritious diets at retail prices: evidence from 177 countries *Food Policy* **99** 101983
Baldos U and Hertel T 2015 The role of international trade in managing food security risks from climate change *Food Secur.* **7** 275–90
Barrett C B (ed) 2013 *Food Security and Sociopolitical Stability* (Oxford: Oxford University Press)
Barrett C B *et al* 2020 *Socio-technical Innovation Bundles for Agri-food Systems Transformation* (Ithaca and London: Cornell and Nature)
Barrett C B 2021 Overcoming global food security challenges through science and solidarity *Am. J. Agric. Econ.* **103** 422–47
Barrett C B, Reardon T, Swinnen J and Zilberman D (In press) Agri-food value chain revolutions in low- and middle-income countries *J. Econ. Lit.*
Bassett T J and Fogelman C 2013 Déjà vu or something new? The adaptation concept in the climate change literature *Geoforum* **48** 42–53
Bennett N J, Finkbeiner E M, Ban N C, Belhabib D, Jupiter S D, Kittinger J N, Mangubhai S, Scholtens J, Gill D and Christie P 2020 The COVID-19 pandemic, small-scale fisheries and coastal fishing communities *Coast. Manage.* **48** 336–47
Bottan N, Hoffmann B and Vera-Cossio D A 2021 Stepping up during a crisis: the unintended effects of a noncontributory pension program during the Covid-19 pandemic *J. Dev. Econ.* **150** 102635
Brizek M G, Frash R E, McLeod B M and Patience M O 2021 Independent restaurant operator perspectives in the wake of the COVID-19 pandemic *Int. J. Hosp. Manage.* **93** 102766
Contreras J L, Eisen M, Ganz A, Lemley M, Molloy J, Peters D M and Tietze F 2020 Pledging intellectual property for COVID-19 *Nat. Biotechnol.* **38** 1146–9
Davis K F, Downs S and Gephart J A 2021 Towards food supply chain resilience to environmental shocks *Nature Food* **2** 54–65
Di Marco M *et al* 2020 Opinion: sustainable development must account for pandemic risk *Proc. Natl Acad. Sci.* **117** 3888–92
Di Vaio A, Boccia F, Landriani L and Palladino R 2020 Artificial intelligence in the agri-food system: rethinking sustainable business models in the COVID-19 scenario *Sustainability* **12** 4851
Egger D *et al* 2021 Falling living standards during the COVID-19 crisis: quantitative evidence from nine developing countries *Sci. Adv.* **7** eabe0997
Falkendal T, Otto C, Schewe J, Jägermeyr J, Konar M, Kummu M, Watkins B and Puma M J 2021 Grain export restrictions during COVID-19 risk food insecurity in many low- and middle-income countries *Nat. Food* **2** 11–14
FAO 2021b *World Food Situation* (available at: www.fao.org/worldfoodsituation/csdb/en/) (accessed 4 February 2021)
FAO, IFAD, UNICEF, WFP and WHO 2021a *The State of Food Security and Nutrition in the World 2021. Transforming Food Systems for Food Security, Improved Nutrition and Affordable Healthy Diets for All* (Rome: FAO)
Gentilini U, Almenfi M and Dale P 2020 *Social Protection and Jobs Responses to COVID-19: A Real-Time Review of Country Measures* version 14 (Washington, DC: World Bank)
Gibb R, Redding D W, Chin K Q, Donnelly C A, Blackburn T M, Newbold T and Jones K E 2020 Zoonotic host diversity increases in human-dominated ecosystems *Nature* **584** 398–402
Goddard E 2020 The impact of COVID-19 on food retail and food service in Canada: preliminary assessment *Can. J. Agric. Econ.* **68** 157–61
Gomez M, Mejia A, Ruddell B L and Rushforth R R 2021 Supply chain diversity buffers cities against food shocks *Nature* **595** 250–4
Gruère G and Brooks J 2021 Characterising early agricultural and food policy responses to the outbreak of COVID-19 *Food Policy* **100** 102017
Guo H, Liu Y, Shi X and Chen K Z 2020 The role of e-commerce in the urban food system under COVID-19: lessons from China *China Agric. Econ. Rev.* **13** 436–55

Herrero M *et al* 2020 Innovation can accelerate the transition towards a sustainable food system *Nat. Food* **1** 266–72
Herrero M and Thornton P 2020 What can COVID-19 teach us about responding to climate change? *Lancet Planet. Health* **4** e174
International Labour Organization (ILO) 2021 *ILO Monitor: COVID-19 and the World of Work* 7th edn
Jalil A, Tasoff J and Bustamante A 2020 Eating to save the planet: evidence from a randomized controlled trial using individual-level food purchase data *Food Policy* **95** 101950
Kates R W, Travis W R and Wilbanks T J 2012 Transformational adaptation when incremental adaptations to climate change are insufficient *Proc. Natl Acad. Sci.* **109** 7156–61
Kim J, Kim J and Wang Y 2021 Uncertainty risks and strategic reaction of restaurant firms amid COVID-19: evidence from China *Int. J. Hosp. Manage.* **92** 102752
Laborde D, Martin W, Swinnen J and Vos R 2020 COVID-19 risks to global food security *Science* **369** 500–2
Lesk C, Rowhani P and Ramankutty N 2016 Influence of extreme weather disasters on global crop production *Nature* **529** 84–87
Lorenz-Spreen P, Lewandowsky S, Sunstein C R and Hertwig R 2020 How behavioural sciences can promote truth, autonomy and democratic discourse online *Nat. Hum. Behav.* **4** 1102–9
Lowe M, Nadhanael G V and Roth B N 2021 India's food supply chain during the pandemic *Food Policy* **105** in press
Lunn P D, Belton C A, Lavin C, McGowan F P, Timmons S and Robertson D A 2020 Using behavioral science to help fight the coronavirus *J. Behav. Public Adm.* **3** 1–15
Mahajan K and Tomar S 2021 COVID-19 and supply chain disruption: evidence from food markets in India *Am. J. Agric. Econ.* **103** 35–52
Marchant-Forde J N and Boyle L A 2020 COVID-19 effects on livestock production: a one welfare issue *Front. Vet. Sci.* **7** 585787
Poore J and Nemecek T 2018 Reducing food's environmental impacts through producers and consumers *Science* **360** 987–92
Richards T J and Rickard B 2020 COVID-19 impact on fruit and vegetable markets *Can. J. Agric. Econ.* **68** 189–94
Rockefeller Foundation 2021 *True Cost of Food: Measuring What Matters to Transform the U.S. Food System* (New York: Rockefeller Foundation)
Rohr J R *et al* 2019 Emerging human infectious diseases and the links to global food production *Nat. Sustain.* **2** 445–56
Ruan J, Cai Q and Jin S 2021 Impact of COVID-19 and nationwide lockdowns on vegetable prices: evidence from wholesale markets in China *Am. J. Agric. Econ.* **103** 1574–94
Rulli M C, D'Odorico P, Galli N and Hayman D T S 2021 Land-use change and the livestock revolution increase the risk of zoonotic coronavirus transmission from rhinolophid bats *Nat. Food* **2** 409–16
Rushton J *et al* 2021 Roll-out of the Global Burden of Animal Diseases programme The *Lancet* **397** 1045–6
Sala S, Anton A, McLaren S J, Notarnicola B, Saouter E and Sonesson U 2017 In quest of reducing the environmental impacts of food production and consumption *J. Clean. Prod.* **140** 387–98
Schmid P and Betsch C 2019 Effective strategies for rebutting science denialism in public discussions *Nat. Hum. Behav.* **3** 931–9
Siegrist M and Hartmann C 2019 Impact of sustainability perception on consumption of organic meat and meat substitutes *Appetite* **132** 196–202
Swinnen J and McDermott J 2020 *COVID-19 and Global Food Security* (Washington, DC: IFPRI)
Van Bavel J J *et al* 2020 Using social and behavioural science to support COVID-19 pandemic response *Nat. Hum. Behav.* **4** 460–71
Van Loo E J, Caputo V and Lusk J L 2020 Consumer preferences for farm-raised meat, lab-grown meat, and plant-based meat alternatives: does information or brand matter? *Food Policy* **95** 101931
Varshney D, Roy D and Meenakshi J V 2020 Impact of COVID-19 on agricultural markets: assessing the roles of commodity characteristics, disease caseload and market reforms *Indian Econ. Rev.* **55** 83–103