editorial

Innovation in fruit and vegetable supply chains

Global fruit and vegetable systems are challenged by food loss and waste, food miles and climate change. Technological and political innovations are needed to improve supply and to ensure that the world's population has access to 5-a-day.

Few would argue against the benefits of fruits and vegetables for human and planetary health. With high inherent chemical diversity, fruits and vegetables are nutrient-rich, and the World Health Organization's recommendation to consume at least 400 g per day is based on evidence for risk reduction of cardiovascular disease and some cancers. The environmental footprints of food systems are also seen to be reduced by shifts towards plant-based diets, and EAT–*Lancet* advocates the consumption of 500 g of fruits and vegetables per day for planetary health. Two opportunities here for health promoters — messaging to consume more, rather than less, of a food group, and messaging on which the science seems unambiguous.

Over two billion tonnes of fruits and vegetables are produced annually[1], sufficient for the world's population to meet these recommendations. Yet, almost half of fruits and vegetables are lost or wasted (22% lost in the supply chain post-harvest to distribution)[1], and availability actually falls short of global requirements for healthy, sustainable diets for all. And so, while the dietary messaging is confident, the ability to deliver the goods is far less certain. Research in this issue of *Nature Food* elaborates on a number of the challenges of the global production and supply of fruits and vegetables — food loss and latent waste due to packaging and transport, food-miles emissions and climate change.

"Frequently better travelled and more worldly than its eater"[2], fruits and vegetables shipped through today's globalized trade networks require well-tuned handling and hygrothermal conditions to reduce immediate and latent deterioration in quality. Sustainable packaging solutions that protect food safety and quality are a priority in mitigating supply-side food loss. In research by Huibin Chang from Harvard University and colleagues, published in this issue, an antimicrobial fibrous packaging material has been developed in a high-throughput system using a polysaccharide called pullulan. Applied directly to avocados, the study represents a proof of concept for a low-cost, biodegradable and effective technology to protect fruit and vegetable safety and quality. Digital twin technology also has

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the potential to enhance supply-chain decision-making in terms of hygrothermal environment as it uses real-time sensing and in silico models to predict food quality and marketability metrics in shipped food. By upcycling standard sensor data from a real-world commercial setting, in this issue of *Nature Food*, Chandrima Shrivastava from the University of Bern and colleagues report how they employ digital twins to characterize hygrothermal conditions to maintain quality, eradicate fruit fly larvae and avoid chilling injury in trans-continental maritime export of citrus fruit. Importantly, the metrics developed in the research enable trade-off decisions to be made about shipment conditions, and enable the prediction of remaining post-harvest life — with implications for reducing food waste downstream in retail, food service and household settings.

The domestic and international transport networks that support global food security and healthy diets also incur greenhouse gas emissions from food miles. According to a global multi-region accounting framework developed by Mengyu Li from the University of Sydney and colleagues, and presented in this issue of *Nature Food*, 27% of greenhouse gas emissions from total freight miles are related to food miles. Among the many findings of this study, fruits and vegetables — transported at high tonnage and requiring temperature-control — contribute more than a third of global food-mile emissions. For nearly all global regions, emissions related to food miles of fruits and vegetables were greater from domestic transport than from international transport.

Global assessment studies of the impact of climate change on food production have primarily been conducted for major commodity crops, and to a lesser extent for nutrient-rich and economically important fruits and vegetables such as the tomato (which is a fruit or vegetable, depending on your discipline). Research published by Davide Cammarano from Aarhus University and colleagues in this issue models the impact climate change will have on processing-tomato production (used in ketchup, tomato sauce, tomato puree and other tomato-derived products) in three major growing regions: the United States, Italy and China. By 2050, they find that global yields will decrease by 6%. Thereafter to 2100, analysis of shared socioeconomic pathways indicates global yield reductions and temporal variability that demands a rethink of how and where processing tomatoes — and indeed, other fruits and vegetables — are grown in the future.

Achieving 5-a-day or more is a challenge. The Prospective Urban Rural Epidemiology study, as one of many examples, showed that the mean consumption of fruits and vegetables was about two servings daily in low-income countries, three in lower-middle-income countries, four in upper-middle-income countries and five in high-income countries[3]. About two-thirds of adults and four-fifths of children in England do not meet the dietary recommendations for fruits and vegetables[4]. Affordability is a key determinant here[3,4], and achieving the shift to plant-based diets for human and planetary health, including 400 g to 500 g of fruits and vegetables per day is further challenged by food price rises.

With uncertain availability of these recommendations for a growing global population facing the constraints of increasing climate change, technological and political innovations must be applied to efficiencies in the entire fruit and vegetable supply chains. An inventory of technological innovations — across digital agriculture, gene technology, vertical farming, additive manufacturing — offers a suite of options with the potential to transform supply chains[5]. There are, however, limits to technological fixes[6]; a policy environment must be ripe for consensus among the multitude of stakeholders in the entire supply chain. Policy measures could be adopted to invest in energy-efficient infrastructure to reduce food loss, improve the access of smallholders to that infrastructure, incentivize nutrition-sensitivity of supply chains and disincentivize food loss. Advanced global accounting frameworks that unveil the health and environmental trade-offs of trade could be utilized here to make true-cost sense of decision-making.

At present, however, even in the face of insufficient availability of fruits and vegetables for a growing world population and climate change, the loss and waste of about half of fruits and vegetables produced in globalized food systems is seen as inevitable and acceptable. That mindset needs to change. ❐

Published online: 23 June 2022c
https://doi.org/10.1038/s43016-022-00548-1

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