International Journal of Postharvest Technology and Innovation, Volume 8, Issue 2-3, March 2022, pp. 145-157
DOI:10.1504/IJPTI.2022.121791

Scaling-up urban agriculture for a healthy, sustainable and resilient food system: the postharvest benefits, challenges and key research gaps

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ABSTRACT

Sustainably ensuring food security and safety for the urban population is a major challenge. In this perspective, we present the concept of 'rurbanisation' (the ruralisation of urban areas through increased urban agriculture) as a holistic strategy to provide a resilient food system. In particular, we focus on the postharvest benefits of urban agriculture for environmentally sustainable food supply chains, enhanced nutritional content of fresh produce and access to fresh, local and seasonal food. However, upscaling current urban agricultural systems requires improvement in current technologies and local infrastructure as well as the transfer of knowledge and skills to new urban farmers. This perspective summarises the main challenges that urban agriculture is currently facing from a postharvest quality and safety point of view, and highlights the research gaps and opportunities for improvements in that area.

Keywords: urban agriculture; health; sustainability; food system; resilience; postharvest benefits, rurbanisation.

INTRODUCTION

Urbanisation is a major trend worldwide. The global urban population exceeded that of rural areas for the first time in 2007 (Hoornweg and Pope, 2017; Orsini et al., 2013), and by the end of the century, the percentage of people living in urban environments is projected to reach as much as 92% (Jiang and O'Neill, 2017). Feeding this increasing urban population in a healthy, sustainable, and resilient manner is a growing challenge. Strategic expansion of food growing activities in cities –herein rurbanisation (the ruralisation of urban areas through increased urban agriculture) – can be a holistic opportunity to increase the health, sustainability and resilience of our food system (Figure 1). Within the term rurbanisation we consider vertical farming systems, allotments, community gardens, private gardens, rooftops, etc.

For example, rurbanisation offers the possibility of increasing food production without increasing land footprint and the related environmental impacts associated with agriculture to the same extent. Land expansion from urbanisation itself reduces the extent of productive cropland. It is estimated by 2050 that over 50% of future urban expansion will be at the expense of cropland, resulting in an up to 4% decrease in annual food production (Chen et al., 2020).

Rurbanisation may help drive healthier diets by a) increasing availability of fresh fruit and vegetables and b) promoting and supporting healthy behaviours within the general population. Urban agriculture is well-suited to horticultural production – small-scale production of high-value crops. Increasing availability of fresh fruit and vegetables is key to meeting our aspiration for healthy sustainable diets: according to the EAT-Lancet report, fresh fruit and vegetable consumption needs to double to deliver human and planetary health (Willett et al. 2019). Additionally, many studies have suggested that the current urban environments promote poor diets, being described as obesogenic environments (Drewnowski et al., 2020; Lagevin et al., 2007; Townshend and Lake, 2009). A recent review highlights that an increase in green-space exposure is associated with a range of improved health outcomes (van de Bosch and Sang, 2017), and another suggests that urban agriculture more specifically supports dietary health (Audate et al. 2019).

Physical changes to the urban environment presented as scaling-up agriculture in outdoor environments also provide opportunities to enhance a wide range of urban ecosystems and the delivery of ecosystem services (Costanza et al., 1997), such as carbon storage and climate regulation (Edmondson et al., 2014; Kulak et al., 2016; Pouyat et al., 2006), reductions in air pollution and noise (Grote et al., 2016; Van Ryswyk et al., 2019); and increases in biodiversity (Norris, 2008).

The sustainability and resilience of the food system from a supply chain perspective can also be enhanced by rurbanisation. The current global food system is shaped by multinational companies with long-distance supply chains that present a number of risks relating to rising temperatures, water scarcity, or changing trade policies (Hendry and Muellbauer, 2018), all of which might lead to food system stress (e.g., rises in food prices) or shocks, such as flooding, terrorism, or public health crises. For example, food insecurity quadrupled during the Covid-19 pandemic in 2020, worsened by economic vulnerability, self-isolation, and food stock shortages in shops, exposing the vulnerability of our current food supply chains (Loopstra, 2020; Power et al., 2020). A certain level of local sufficiency in food production can help enhance resilience, and thus increases in urban food growing have been a natural response to food shocks in the past such as Dig for Victory during World War 2 and the increase in garden growing in Cuba following the collapse of the Soviet Union (Altieri et al., 1999; Barthel and Isendahl, 2013). A recent global analysis suggested that broad adoption of urban agriculture could produce up to 180 million tonnes of food per annum, approx. equivalent to ~10% of global fruit and vegetable production (Clinton et al., 2018), whereas a city-scale study in Sheffield (UK) showed that the city was already producing enough to provide fresh fruit and vegetables for 15% of the population (Edmondson et al., 2020). These are meaningful proportions of our consumption that could have a role to play in food security. An additional benefit of rurbanisation is to reduce food miles, while logistics and distribution accounts for 18% of carbon emissions in the food system (Poore and Nemecek, 2018).

Rurbanisation presents many challenges that need tackling in order to be a sustainable and resilient production system, such as energy consumption and urban pollution. Here, we examine the trends and potential for rurbanisation from a postharvest perspective, asking what are the opportunities, challenges, and key research gaps for the multi-disciplinary postharvest community in supporting the growth of a healthy, sustainable, resilient food system through scaled-up urban agriculture.

POSTHARVEST BENEFITS OF RURBANISATION

It is important to clarify that what we term as rurbanisation, includes both technologically advanced growing solutions, such as vertical farms, as well as more traditional ways of growing fruit and vegetables in urban and peri-urban areas, such as small gardens, allotments and community gardens. From a produce quality and safety perspective, these two extremes of the spectrum pose different challenges, but both offer a significant benefit; they have the potential to reduce the distance between the point of production and the point of consumption (Born and Purcell, 2006). Reducing 'food miles' not only contributes to reducing the environmental impact of food production (Coley et al., 2009), but also ensures that fresh produce reaches the consumer at a higher level of quality (freshness and nutritional quality at the point of consumption (Liu, 2018). Physiological quality (i.e. firmness, colour) rapidly decreases after harvest because of the normal behaviour of fresh produce metabolism and decay due to microbial spoilage. Also, health-promoting compounds such as vitamins and phenolics are highly sensitive to environmental changes occurring during food processing and transportation (e.g. temperature, relative humidity, possible mechanical damage and exposure to pathogens).

Shortening the time between harvest and consumption helps reduce the physiological and nutritional quality loss of fresh produce, providing the consumer with a final product of better quality (Coelho et al., 2018). In addition, food grown in cities is more likely to be consumed locally (Goldstein et al., 2016), encouraging the consumer to buy seasonal fresh produce.

Moreover, by reducing the time required after harvest for the produce to reach the consumer, significant reductions in waste could also be observed. According to Porat et al. (2018), these include waste that occurs both in retail (mainly due to inappropriate storage conditions and handling, and exceeding the 'sell by' or 'best before' date) as well as at household levels (mostly caused by poor home-storage management and over-purchasing). Moving food production closer to where the highest demand is by up-scaling urban agriculture could therefore play a significant role in reducing food waste in the pre-consumption stage and contributing to the transformation towards a more environmentally sustainable food system. That would be strongly linked to the UN Sustainable Development Goals (SDGs), especially SDG 2 (on sustainable agriculture and food and nutrition security); SDG 11 (to support positive economic, social and environmental links between urban, peri-urban and rural areas) and SDG 12 (on sustainable production and consumption), especially target SDG12.3 that aims to halve the per capita global food waste at the retail and consumer levels and halve food losses along production and supply chains, including postharvest losses by 2030 (UNHCR, 2017).

CURRENT CHALLENGES AND RESEARCH GAPS

Rurbanisation through increasing small garden, allotment and community growing schemes

Urban agriculture in the form of small-scale gardening and community gardens is often practiced by non-specialists who grow fresh produce mainly for self-consumption. Research has shown that this form of engagement with green spaces and food production could contribute to a healthier lifestyle, including healthier diets, reduced levels of stress and overall well-being (Lin et al., 2017; Sturiale et al., 2020). Therefore, rurbanisation in this form could have an important role to play in improving health and well-being in the increasingly overpopulated urban environments. It is unclear though how feasible it would be to significantly increase urban food production in this way, while maintaining the expected levels of food quality and safety.

There are several factors that contribute to not only the levels of yields obtained, but also the quality of fresh fruit and vegetables produced in urban gardens. Amateur growers often lack the level of specialist knowledge required to optimise crop production for a robust postharvest life (Lin et al., 2015). Since in many cases certain agricultural practises have an effect on the postharvest quality of the produce, it is important to understand the effect of pre-harvest practises on shelf and storage life.

The impact of weather conditions, pests, soil and water quality can strongly affect the attributes of fresh produce and therefore, their potential shelf-life (Koukounaras et al., 2020; Falagán and Terry, 2018). The urban environment creates micro-climates that add a further challenge to the outdoor urban grower compared to agriculture in rural settings, as does the relative paucity of understanding of urban soil types and conditions. Developing understanding of urban agronomic suitability and providing useful information on the growing environment to urban farmers is a key gap.

The choice of crops can have an impact on both yields and quality. What is grown in these settings is more likely to be influenced by the availability of seeds collected from previous seasons, varieties/seeds shared by other gardeners, growing feasibility in urban environments, and seeds bought from non-specialist retailers. There are definite benefits to this approach, including diversification of agri-ecosystems and diets. But from a postharvest perspective, these varieties are not chosen with a robust postharvest life in mind, making spoilage more likely, and potentially leading to food waste.

Seasons also plays a role in urban agriculture. The access to high tech indoor farms such as vertical farming facilities can help to provide year-round fresh produce. In these types of facilities temperature, relative humidity and light cycles are controlled and avoid the exposure of urban grown crops to the 'heating island' effect of cities, especially in tropical countries (Orsini et al., 2013). However, when grown in community and private gardens, allotments and rooftops the production in warm seasons is much higher and varied than in cold seasons.

The extent of air pollution in urban areas is a concern, and fresh produce grown in open-air locations is often exposed to high levels of heavy metals and other atmospheric pollutants. The literature is scarce on the health risks of consuming such crops, but it is clear that the levels of pollutants detected on the fruit and vegetables are tightly linked to the specific locations and the distance from the main source of atmospheric pollution such as motorways, factories, and airports (Agrawal et al., 2003; Dumat et al., 2019). The increased safety risk of urban grown produce is not limited to air pollutants though, as the soil used in certain locations could also pose a risk of heavy metal contamination, especially in urban areas with a long history of industrial use (Nabulo et al., 2012). The safety of soil-based outdoors-grown urban fresh produce, can therefore be of a particular concern, to the extent that it is often likely to deter people from consuming it, resulting in food waste.

Food losses and waste in this type of settings often occurs as a result of bad agricultural practise (e.g. inappropriate control of pests and diseases), as well as due to the lack of appropriate postharvest management and specialists in the field (Alamar et al., 2017; Porat et al., 2018). Lack of access to equipment, technology and specialised skills to determine harvest maturity, can lead to overripe fresh produce with limited postharvest life and quality and questionable safety due to microbial loads and agrochemical residues. In addition, limited or non-existent cold-storage facilities do not allow the appropriate temperature management for each crop, leading to rapid deterioration due to fungal and bacterial rots, but also to significant nutritional losses from harvest to consumption.

If urban food production was to be upscaled through small gardens, allotments and community growing schemes, further consideration would need to be given to ensure the postharvest quality and safety of the fresh produce. Also, it is key to design optimal business models for an enhanced postharvest value chain in urban agriculture. So far, urban agriculture is praised for its positive impact on society and the environment but little research has been developed at a business level (Liu, 2015). Therefore, appropriate infrastructure and distribution channels for this agricultural system are needed to turn rurbanisation into a fundamental player in food supply chains, avoiding waste and reducing nutritional losses.

Rurbanisation through up-scaling commercial food production in urban and peri-urban areas

On the opposite end of the spectrum, rurbanisation could also be achieved by increasing indoor commercial food production in urban and peri-urban areas utilising advanced engineering solutions, as some farmers already do in order to diversify their business. In recent years there has been a surge in the establishment of urban vertical farms, using innovative light technologies, internet of things and a range of growing systems, such as hydroponics, aeroponics and aquaponics (Orsini et al., 2013). Although this form of rurbanisation has a great potential at contributing to the self-sufficiency and resilience of local food systems, there are still important limitations and challenges to consider and there are research gaps that need to be addressed in order to be able to use the full potential of these new technologies for producing high quality fresh produce.

Light conditions, including specific wavelengths, light intensity and photoperiod, can have a great impact not only on crop yields, but also on the postharvest quality of the produce. Shelf-life, taste and nutritional content of leafy greens and tomatoes have all been shown to be affected by specific light parameters (Gruda, 2005; Nicole et al., 2019; Ntakgas et al., 2019; Pennisi et al., 2019). There is, therefore, a great potential in manipulating indoor growth conditions in order to improve the postharvest quality and nutritional content of urban-grown produce. The limitation is that these effects are not only crop-specific, but often cultivar/variety-specific too (Cocetta, 2017; Shimizu, 2016), so more research is required in order to optimise growth parameters for each crop setting. The same could be argued for the nutrient composition of growth solutions in such systems. Although established 'recipes' exist for key crops, their optimisation for specific settings could have a substantial impact on the postharvest quality of the fresh produce (Ding et al., 2018; Kalantari, 2018).

In general, indoor soilless cultivation systems tend to produce high quality crops with low levels of microbial loads and agrochemical residues compared to conventional outdoors soil-based systems (Selma et al., 2012). However, concerns regarding the safety of produce still exist in some cases, especially in systems that have not yet been widely adopted and therefore still under improvement. For example, leafy greens grown in aquaponic systems were shown to accumulate high levels of nitrates (Pérez-Urrestarazu et al., 2019). Leafy vegetables are particularly good nitrate accumulators and research has demonstrated that agricultural practices such as levels and timing of irrigation and fertilization, and environmental factors such as light levels and temperature can have an impact on the quantity of nitrates accumulated (Du et al., 2007). This fact highlights even more the need for optimisation of these new cultivation systems as well as the upskilling of the workforce involved in urban growing. High levels of nitrates in the plant can increase their susceptibility to pathogens, but also have a negative impact on the nutritional quality of the crop (Santamaría, 2006).

If we were to upscale urban food production through commercial indoors crop production, utilising unused spaces (e.g. underground stations, warehouses, basements) and growing vertically, the biggest challenge we would have to face is the currently limited range of crops that can be grown in such systems. At present, production in vertical hydroponic or aeroponic systems is limited mainly to salads, leafy greens and herbs (Bemke and Tomkins, 2017). This is mainly due to the short life cycle and high value of these crops that make it economically feasible to produce in those settings. Although these are very nutritious and an essential part of a healthy diet, expanding to a diverse range of more calorie-dense crops would have a bigger impact on the resilience of local food systems. Besides, leafy greens and herbs are also some of the most perishable crops, with a relatively short shelf life and therefore more prone to waste at the retail and household levels. Although at present comparable data for waste generated in these crops in different farming systems does not exist, it would be interesting to evaluate the true potential of urban agriculture in reducing food waste in the years to come.

CONCLUSIONS

Rurbanisation has the potential to transform our food system for health, sustainability and resilience. From a postharvest quality and safety perspective, moving part of the food production system closer to consumers where the demand is high can have a positive impact on the nutritional and overall quality of the fresh produce at the point of consumption, due to the shorter supply chains. Several challenges exist though depending on the type of urban growing and many research questions are still to be answered. We identify the seven following key priorities for the postharvest research community:

1) **Understanding and avoiding food losses and waste in urban agriculture supply chains.** It is crucial to ensure that rurbanisation will not further increase the current

levels of food waste, but will instead be able to assist in reducing them, contributing to the global efforts of meeting the SDG challenges.

2) **Continued optimisation of the indoor growing environment**, tailoring lighting, nutrient inputs and other conditions to the range of crops currently grown to support postharvest outcomes.
3) **Diversifying indoor and soilless crop production,** in order to increase the availability of fresh fruit and vegetables grown in this urban system and provide more calorie-dense options.
4) **Facilitating knowledge and skills transfer of outdoor and indoor growers,** alike in order to support the challenges raised above.
5) **Supporting the production of high yields and quality through development and provision of urban agronomic advice.** For example, through the development and provision of better soil mapped products, urban farming forecasts, training and urban specific agricultural extension services, including specific support on postharvest management.
6) **Address safety concerns of urban food production in both indoor and outdoor growing environments**, including air pollution, soil contamination, and microbial loads.
7) **Establishing postharvest infrastructures and distribution channels specific to urban agriculture,** in order to support the development of alternative business models for a resilient and sustainable food supply chain.

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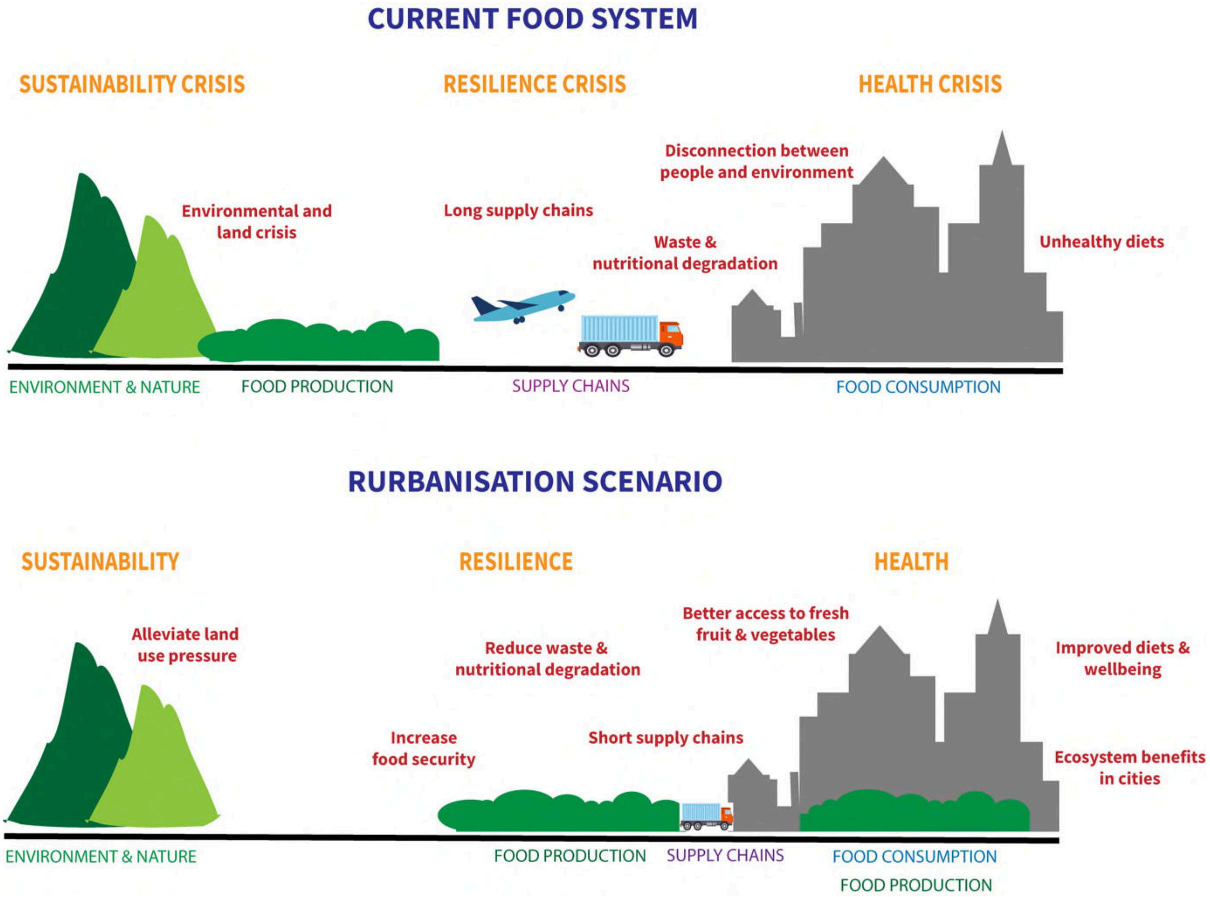

Figure 1. The potential of rurbanisation to transform our current food system for sustainability, resilience and health.

Scaling-up urban agriculture for a healthy, sustainable and resilient food system: the postharvest benefits, challenges and key research gaps

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2022-03-29

Kourmpetli S, Falagán N, Hardman CA, et al., (2022) Scaling-up urban agriculture for a healthy, sustainable and resilient food system: the postharvest benefits, challenges and key research gaps. International Journal of Postharvest Technology and Innovation, Volume 8, Issue 2-3, pp. 145-157
https://doi.org/10.1504/IJPTI.2022.121791