frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 18 February 2025
DOI 10.3389/fsufs.2024.1415291

OPEN ACCESS

EDITED BY
Sanzidur Rahman,
University of Reading, United Kingdom

REVIEWED BY
Peter Čajka,
Matej Bel University, Slovakia
Michal Lukáč,
University of St. Cyril and Methodius, Slovakia

*CORRESPONDENCE
Jana Soukupova
✉ soukupova@fzp.czu.cz

RECEIVED 10 April 2024
ACCEPTED 20 June 2024
PUBLISHED 18 February 2025

CITATION
Schilla F, Mumladze G, Soukupova J and Smutka L (2025) Economic analysis of Agaricus bisporus mushrooms production and the perspective of sharing economy. *Front. Sustain. Food Syst.* 8:1415291.
doi: 10.3389/fsufs.2024.1415291

Economic analysis of Agaricus bisporus mushrooms production and the perspective of sharing economy

Filip Schilla[1], Gaga Mumladze[1], Jana Soukupova[2]* and Luboš Smutka[2]

[1]Department of Economics, Czech University of Life Sciences, Prague, Czechia, [2]Department of Trade and Finance, Czech University of Life Sciences, Prague, Czechia

Introduction: Urban agriculture, particularly mushroom cultivation in basements, offers a sustainable solution to climate change, land scarcity, and food security challenges. This article explores the viability of cultivating Agaricus bisporus (white button mushrooms) in basements, while also considering the potential of a sharing economy business model to address these issues.

Methods: We simulate basement and ground-level room conditions, comparing factors such as temperature, humidity, light exposure, and air quality, which are crucial for mushroom growth. Economic calculations are also included to assess costs and profits, allowing for a comparison of feasibility and cost-effectiveness between the two environments.

Results: The basement environment proves more favorable for mushroom cultivation, with stable temperatures and higher humidity reducing energy requirements. Economic analysis shows that basement cultivation has lower initial and operational costs compared to ground-level spaces.

Discussion: Basement cultivation of Agaricus bisporus offers a sustainable solution for urban agriculture, addressing food security and land scarcity. Integrating this practice into a sharing economy model could further enhance its feasibility, contributing to environmental sustainability and economic growth in cities.

KEYWORDS

urban agriculture, sharing economy, climate change, food scarcity, Agaricus bisporus, financial analysis

1 Introduction

There has never been a more pressing need for creative and sustainable alternatives to agricultural operations than in this age of climate change, land scarcity, and food security. Rapid urbanization, coupled with the escalating challenges posed by traditional farming methods, necessitates a paradigm shift in how we cultivate and access food. Urban agriculture has emerged as a promising solution, empowering communities to produce food locally and mitigate the adverse impacts of these global challenges (Langemeyer et al., 2021).

Urban agriculture is one example of an innovative urban development solution that enables a partial relocalization of the food system (Skar et al., 2020). Cities can use urban agriculture to cultivate abandoned land and buildings (Carlet et al., 2017). There are other spaces in cities that can be used for urban agriculture—basement spaces. As spaces of any kind are rare in cities, the basement spaces are no exception. Basement cultivation of mushrooms offers an interesting alternative for using these spaces. Furthermore, if the sharing economy business model is applied, it could be a more efficient way of using them.

According to Certified Urban Agriculturist Grant (2022), the best vegetables to grow inside are lettuce, spinach, radishes, and Swiss chard. Growing vegetables in your basement gives you the ability to experiment with different lighting levels and tones. Because it can be difficult to set up a growing environment indoors for sun-loving veggies, growing mushrooms indoors has even more benefits than growing vegetables (Grant, 2022).

Martin et al. (2022) in the study published on Frontiers.org have studied the Potential of Building Integration and Regional Synergies to Improve the Environmental Performance of Urban Vertical Farming. This study focuses on a prospective assessment of a hypothetical vertical farm located in Hammarby Sjöstad, a city district within Stockholm, Sweden. Within the study of lighting and temperature control, several assumptions were made. Various sensitivity analyses were performed to highlight the potential of developing symbiotic systems for vertical farms through the exploration of building integration and synergies with regional businesses and markets.

Urban agriculture is of increasing interest for tackling a range of environmental and social issues of the current food systems. However, many questions remain unanswered regarding upscaling, the balancing of its multipurpose nature, and how it should be embedded into the broader urban system. The realization of the transformative potential of urban agriculture based on industrial ecology and inclusive co-design is discussed in the study by Weidner et al. (2018), which discusses the current knowledge on urban agriculture in productive urban food systems: learnings, gaps, and outlook.

It is important to explore the viability and benefits of basement cultivation of mushrooms as a sustainable solution to climate change, land scarcity, and food security. The growing urban population, climate change, and the scarcity of natural resources are major worldwide challenges. In the coming years, it is needed to ensure that more food is available to feed Earth's growing population (Orsini and D'Ostuni, 2022).

Basement cultivation of mushrooms presents a host of advantages that make it an attractive proposition for urban agriculture. These benefits include efficient use of space, reduced water consumption, minimal reliance on arable land, and the potential for year-round cultivation. Additionally, mushrooms possess a remarkable ability to recycle organic waste and convert it into nutritious food, thus contributing to waste reduction and resource efficiency. Some of the disadvantages related to urban agriculture can be overcome by growing mushrooms because mushrooms are low maintenance, they do not require daylight or artificial light manipulations, and they can be grown all year round.

Like urban agriculture, the sharing economy could also be seen as a pathway to more sustainable consumption and production practices (Martin, 2016). There are already examples of the interconnection of these concepts. The principles of sharing in the form of collaboration among volunteers and the sharing of resources, crops, and knowledge are visibly applied in community gardens (Specht et al., 2021). Alternative food networks are another case where co-ownership and shared access to resources such as land, water, and agricultural equipment (Miralles et al., 2017).

In general, the sharing economy can work as a business model where not only financial motivations play a role, but often non-financial motivations are more important. A very essential element for the functioning of a sharing economy is trust between the actors involved (Hauwers et al., 2020). In addition to financial motivations, urban agriculture can also work on a non-financial basis, such as on the basis of solidarity. An example can be urban community gardens, where people do not work because they must, but because of the pleasure (Rosol and Schweizer, 2012).

In this review, we underline the advantages of urban basement conditions for growing Agaricus bisporus mushrooms. Basement conditions are more cost-effective and environmentally sustainable when compared to ground-level conditions, using different literature, and creating simulated spaces in the basement and ground-level room various calculations were performed using sensitivity analyses.

2 Conceptual framework

Mushrooms are a versatile and nutritious food source that can be grown in a variety of environments. One popular location for mushroom cultivation is the basement of a home or other building. This location offers several advantages, including a consistent temperature and humidity level, as well as protection from external weather conditions. However, not all mushrooms are suitable for growing in a basement environment. In urban environments, mushrooms are unique in their ability to be highly adaptable and able to grow in small spaces, indoors and outdoors. Private storage sheds and basements are ideal for growing an additional protein source such as mushrooms. As fungi develop from fungal spores that thrive in moist, dark environments, they require a growing medium rich in decaying plant matter, and old industrial buildings with dark and moist environments are ideal for growing them. The button mushroom Agaricus bisporus is cultivated almost worldwide. Its cultivation is standardized, and a temperature of 16–19°C is needed during the fruiting period; however, according to Foulongne-Oriol et al. (2014), A. bisporus cultivars can fruit at higher temperatures as well, which represents a promising alternative to reduce energy costs during cultivation in hot weather conditions; within the study tested Agaricus bisporus var. burnettii was able to fruit at 25°C as well. Mushrooms are very low in calories and have a high protein content (Atila et al., 2017) as can be seen in Table 1.

3 Estimated numbers of basement spaces in the big European cities

Urban areas have significant potential for different types of agriculture, especially for growing mushroom. While traditionally associated with rural areas, agriculture is currently being increasingly integrated into urban environments through the concept of urban agriculture. Urban areas offer various advantages for agriculture and mushroom growing.

According to the Office for National Statistics, London had 3.5 million households in 2022 (Office for National Statistics, 2023). If we generalize the number in the 5-floor residential buildings which consist most of the population of this megapolis we can assume that in the case that each block has four addresses on each floor usually, and the total amount of households is 20 in each block, we can divide the number of 3.5 million households on the average number of 20 and total assumed number of residential buildings in London can be calculated as 175,000. According to Seghezzi (2018), the average area of residential buildings in Europe varies significantly from country to country. The study which is called "A Decision Support Framework for Technology related choices in façade retrofit: relevance and impact of morphological factors on retrofit interventions value" gives us Figure 1 provides the average floor areas of

TABLE 1 Agaricus bisporus important nutritional values per 100 g (3.5 oz) of dry raw white.

Energy	Protein	Fat	Fiber	Niacin	Riboflavin	Vitamin C
93 kJ (22 kcal)	3.09 g	0.34 g	1 g	3.61 mg	0.402 mg	2,1 mg

Source: USDA Database (2019).

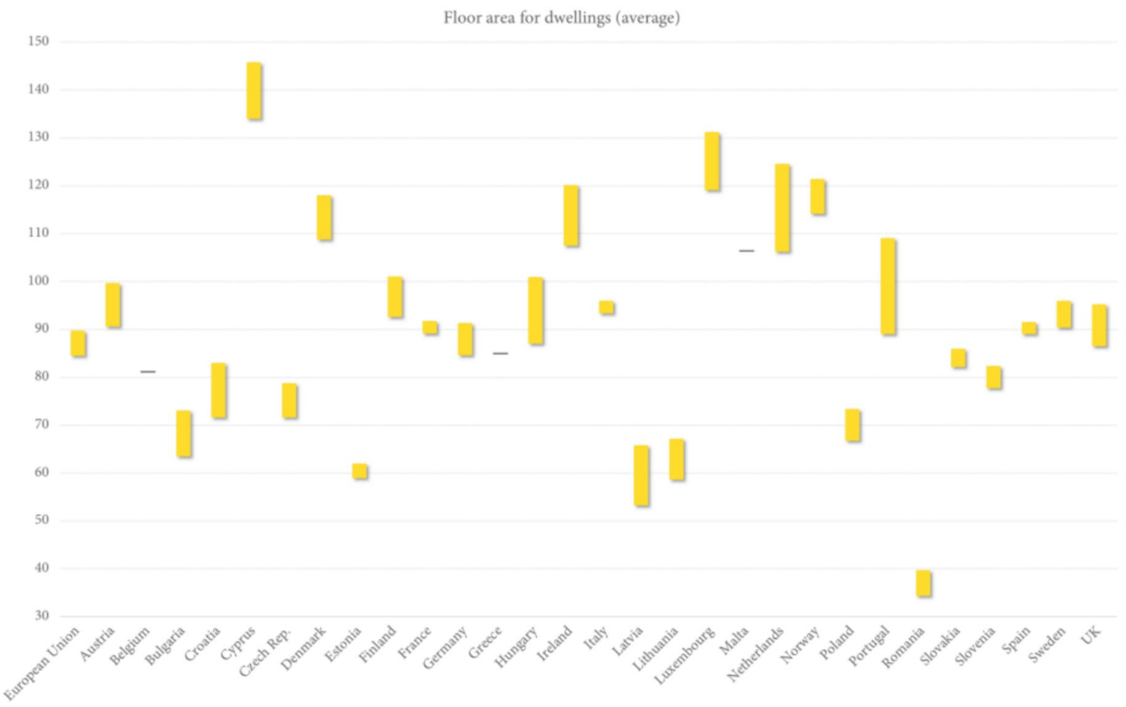

FIGURE 1
Average floor area of residential building stock in Europe. Source: Seghezzi (2018).

residential buildings in various countries. In the UK, the average floor area of residential buildings is approximately 90 m^2.

This gives us the total average number of living area is 175,000 × 90 = 15.75 million square meters. In the case of use of the basement areas with a rate of 10% in London, there is the potential to grow Agaricus bisporus on an area of 1,575 million square meters.

According to the data of the French National Institute of Statistics and Economic Studies Paris had 1.13 million households in 2019 (INSEE, 2023). With a similar method to London, we can calculate the approximate number of residential buildings by dividing the number of 20 households and there are 56,500 residential buildings approximately in Paris. According to Seghezzi (2018), average area of residential buildings in France is approximately 90 m as well. With the numbers, the total average area of residential buildings in Paris is 56,500 × 90 = 5.1 million square meters. With the same potential rate of 10% basement areas 508,500 square meters of basement area can be used for growing Agaricus bisporus in Paris.

Madrid has a household number of approximately 2.64 million (INE, 2022). With the same method of calculation, we have already used for the previous two cities the number of residential buildings in Madrid is 132,000. According to Seghezzi (2018), Madrid has an average 90 m average area of residential buildings. The total average area of residential buildings and basements will be calculated as 132,000 × 90 = 11.88 million square meters and the 10% potential for growing Agaricus bisporus will be 1,188 million square meters in Madrid.

4 Urban agriculture and environmental impacts

Urban agriculture has the potential to mitigate the environmental impacts of the food system (Benis and Ferrão, 2017), but it also has some environmental impacts of its own (Dorr et al., 2021). The authors selected various types of urban agriculture and evaluated their environmental impacts. Among the evaluated types of urban agriculture are community gardens, rooftop gardens, urban beekeeping, green walls, balcony gardens, and basement cultivation. The effects assessed are the impacts on the landscape character, water pollution, water consumption, energy consumption, air pollution, degradation of soil, and biodiversity. The effects are rated as neutral (0), negative (1), or positive (2). Table 3 shows that all selected types of urban agriculture have mostly positive or neutral environmental impacts. An exception may be community gardens, where certain agricultural practices (such as improper use of pesticides) may result in water pollution or degradation of soil. On the other hand, outdoor urban agriculture such as community gardens or rooftop gardens can contribute to the improvement of urban environmental factors in a different way than indoor urban agriculture (Milestad et al., 2020), among other things they transform the "gray urban landscape" into green and help promote biodiversity. Due to the technologies used (sophisticated irrigation systems, etc.), basement cultivation (like almost all other types of urban agriculture) has positive impacts on water and energy consumption and has neutral impacts on water pollution or air pollution.

Basement cultivation (and other indoor types of urban agriculture) does not have the risks associated with urban pollution. Urban gardening has such risks, for example, due to exposure to contaminated soil (Kim et al., 2014). Urban beekeeping is also problematic from this point of view. Studies suggest that there is a risk for honeybees in cities. Due to pollution, the ability of honeybees to recognize a floral blend is reduced (Langford et al., 2023).

5 Basement cultivation of mushrooms and sharing economy

Basement cultivation of mushrooms in cellars could work as a part of a sharing economy business model. Basements in apartment buildings are often owned by the community of unit owners of the apartment building, and the individual owners have the exclusive right to use them. Often, cellars are only used to store old, unused items. The cultivation of mushrooms offers a more efficient use of these scarce spaces (especially in cities). If there were an electronic P2P platform that would allow individual owners (or communities of owners) to offer their (previously little used or unused) cellar for mushroom cultivation, with low transaction costs, cellars could function in a similar way to apartments/houses in the case of the Airbnb platform. Sharing/selling the harvest of the mushrooms grown in the cellars is another way of engaging the sharing economy. Indeed, the harvest could also be offered via a digital sharing economy platform with the possibility of using result-oriented (RO) business models (Ritter and Schanz, 2019).

A closer look at the individual actors in this sharing economy case shows what the potential benefits could be. As mentioned earlier, the individual owners/communities of unit owners ("providers") can offer their cellars which are currently unused and where only expenses are paid (e.g., for electricity). If someone is interested in the cultivation of mushrooms in their cellars, they can generate (at least some) revenues. Mushroom growers could have these additional basement spaces for their activities and can generate higher revenues. The P2P platform for transactions between providers and mushroom growers could have revenues from these transactions (in the form of fees). Due to the positive externalities (such as shortening the transport distance of the mushrooms) there are other benefits for the whole community in the city (waste reduction, less pollution from traffic, etc.).

On the other hand, there are also negative externalities. Greater expansion of the basement cultivation of mushrooms due to the P2P platform may cause some difficulties for owners of neighboring cellars or neighboring apartments, for example, because of a smell from the cultivation. However, as people do not usually spend much time in cellars and cellars are usually well separated from living spaces (apartments), the impact of this type of negative externality is minimal.

6 Methodology

To compare the conditions of two different spaces for growing Agaricus bisporus, we have used a simulation of spaces and used different data connected to the basement conditions or ground-level conditions. Freely available data were collected to determine yearly basement average temperatures from the town of Turku, Finland. Data were collected from Åbo Akademi University meteorological station (Åbo Akademi University, 2024). Every month's average temperature was compared to the standardized Agaricus bisporus growing temperatures, which is 16–19°C according to Foulongne-Oriol et al. (2014). Differences between the desired temperature and real average temperature were calculated, and to calculate energy spent, a British thermal unit calculator was used. BTU Calculator (Calculator.net, 2024) is the tool that determines energy spent per square meter per 1-h period, by knowing the simulated area of 20 square meters and the amount of desired temperature growth/decreases multiplied by the amount of hours per month and the total amount was determined for 1-year period (Figure 2).

7 Results

Average temperatures and the desired growing temperatures for Agaricus bisporus were collected, along with the heating and cooling requirements for each space. These data, along with key economic factors such as energy consumption and financial expenses, were summarized in a single table comparing basement and ground-level room conditions.

As close to the desired temperatures the natural condition of each space is a more economical place for growing Agaricus bisporus it gets, this trend can be seen in Figure 3. After the simulation of the ground-level room (with heating), total energy of 4,180kwh was spent for a 20 square meter area room, while in the basement condition, total energy spent was 437,6kWh for a 1-year period.

According to the European Commission Statistical Office, the price of electricity for industrial use in Finland in 2022 was 0.19 USD cents per kWh. In the ground-level room conditions with an area of 20 square meters, total spent for a year was calculated as 810USD and in the same size basement conditions 84.8USD for creating desired temperatures of Agaricus bisporus growing in Turku, Finland. Within the same source, the price of electricity in France is 0.22USD and total spending for growing Agaricus bisporus on a 20-square-meter

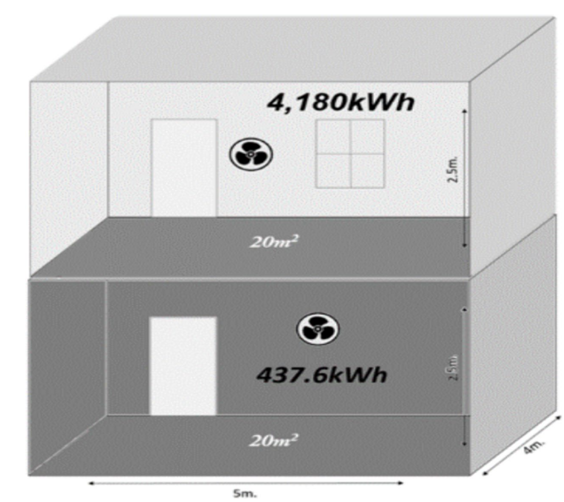

FIGURE 2
Simulated comparison of the Basement level room conditions and Ground level conditions 205 in the spending of electricity for one year.

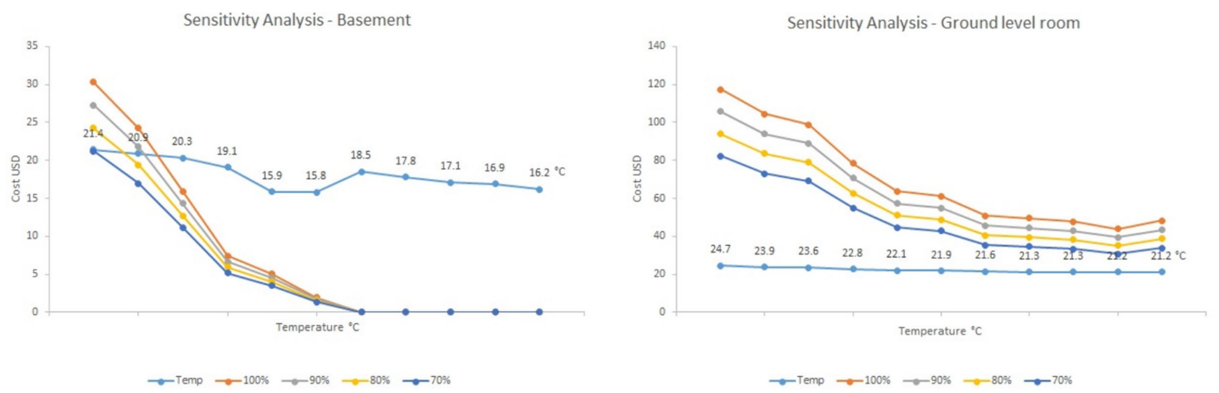

FIGURE 3
Simulated sensitivity analyses, where costs, and energy spent are dependent on temperature according to the data of Åbo Akademi University data in Turku, Finland (Åbo Akademi University, 2024).

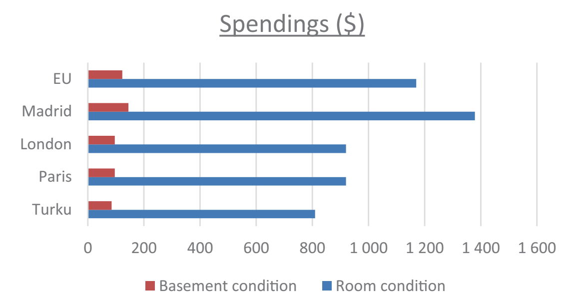

FIGURE 4
Financial spending for both conditions in the EU and simulated cities in USD.

basement area will be 96,2USD for a year. United Kingdom has the same price for electricity (Department for Energy Security and Net Zero, 2024), and spending will be the same. In Spain, electricity is more expensive and has a cost of 0.33USD per kWh, the total spending for the year in Madrid basement of 20 square meters area will be 144.4USD. European Union's average price of electricity is 0.28USD per kWh and the average energy for the basement conditions in the EU will be 122,5USD per year and 1,170.4USD in the room conditions (Figure 4).

8 Discussion

Mushrooms have gained popularity in recent years due to their versatility and use in various cuisines. The growing interest in healthy and sustainable food options has contributed to the increased demand for mushrooms. The fact that mushrooms are a healthy food is mentioned in many publications (Feeney et al., 2014; Beelman et al., 2019; Rizzo et al., 2021; Bell et al., 2022; El-Ramady et al., 2022). Growing mushrooms in urban basement conditions can be environmentally friendly and economical at the same time. Similar studies on cultivating other vegetables and fruits have been conducted on various occasions (Conti et al., 2016; Milestad et al., 2020). The best vegetables to grow inside are lettuce, spinach, radishes, and Swiss chard. Growing vegetables in your basement gives you the ability to experiment with different lighting levels and tones. Because it can be difficult to set up a growing environment indoors for sun-loving veggies, growing mushrooms indoors has even more benefits than growing vegetables (Grant, 2022). Mushroom cultivation requires less land and water than traditional crops.

Most of the types of mushrooms have a lower carbon footprint than many other crops. The process of growing Agaricus bisporus is relatively quick, taking a few weeks rather than months, which reduces the energy and resource inputs required for cultivation. Martin et al. (2022) in their study simulating lighting and temperature control, which is connected usually with high costs. According to iFarm (2021) which is a famous international company that develops software and hardware for vertical farming and hydroponics vertical farms are more expensive to build than greenhouses — sometimes it can be up to 10 times more costly. According to their source, vertical farming costs $ 2,200 to $ 2,600 per square meter of cultivation bed space, while high-tech greenhouses cost $ 250 to $ 350 per square meter of cultivation space. Same-time mushroom growing does not require specific and expensive equipment or materials, recycling organic matter can be used as a growing base, and light control is not needed.

As the study shows basement conditions can be used to grow Agaricus bisporus mushrooms. The main reason for it is the temperatures in the basement, which is very close to the desired Agaricus bisporus growing temperatures of 16–19°C. Half of the year the artificial manipulation of temperatures is not needed in the basement when in the ground-level room all the time is the need for warming/cooling. Sensitivity analyses show that as close the natural conditions were to the desired temperature line less energy was needed to be spent. Basements provide a controlled environment that can be optimized for Agaricus bisporus growth. If we take the number of the basement areas in the simulated cities, we can conclude that the growing Agaricus bisporus in the basement conditions has great potential. With the price calculations, we can assume that growing Agaricus bisporus in basement conditions can be significantly cheaper than in all studied areas of Finland, France, the UK, and Spain. Moreover, the potential of growing Agaricus bisporus in cellar conditions could be even greater if the sharing economy business model is applied.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

FS: Writing – original draft, Writing – review & editing. GM: Writing – original draft, Writing – review & editing. JS: Writing – original draft, Writing – review & editing. LS: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This article was supported by the Czech University of Life Sciences.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

Åbo Akademi University (2024) Basement temperatures and humidity. Available at: https://users.abo.fi/jskata/HogWeather/basement/ (Accessed March 23, 2024)

Atila, F., Nadhim Owaid, M., and Ali Shariati, M. (2017). The nutritional and medical benefits of Agaricus Bisporus: a review. *J. Microbiol. Biotechnol. Food Sci.* 7, 281–286. doi: 10.15414/jmbfs.2017/18.7.3.281-286

Beelman, R. B., Kalaras, M. D., and Richie, J. P. J. (2019). Micronutrients and bioactive compounds in mushrooms: a recipe for healthy aging? *Nutr. Today* 54:16. doi: 10.1097/NT.0000000000000315

Bell, V., Silva, C. R. P. G., Guina, J., and Fernandes, T. H. (2022). Mushrooms as future generation healthy foods. *Front. Nutr.* 9:1050099. doi: 10.3389/fnut.2022.1050099

Benis, K., and Ferrão, P. (2017). Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – a life cycle assessment approach. *J. Clean. Prod.* 140, 784–795. doi: 10.1016/j.jclepro.2016.05.176

Calculator.net. (2024) BTU Calculator. Available at: https://www.calculator.net/btu-calculator.html (Accessed March 24, 2024)

Carlet, F., Schilling, J., and Heckert, M. (2017). Greening US legacy cities: urban agriculture as a strategy for reclaiming vacant land. *Agroecol. Sustain. Food Syst.* 41, 887–906. doi: 10.1080/21683565.2017.1311288

Conti, L., Barbari, M., and Monti, M. (2016). Design of Sustainable Agricultural Buildings. A case study of a wine cellar in Tuscany, Italy. *Buildings* 6:17. doi: 10.3390/buildings6020017

Department for Energy Security and Net Zero. (2024) Available at: https://www.gov.uk/government/collections/quarterly-energy-prices

Dorr, E., Goldstein, B., Horvath, A., Aubry, C., and Gabrielle, B. (2021). Environmental impacts and resource use of urban agriculture: a systematic review and meta-analysis. *Environ. Res. Lett.* 16:093002. doi: 10.1088/1748-9326/ac1a39

El-Ramady, H., Abdalla, N., Badgar, K., Llanaj, X., Törős, G., Hajdú, P., et al. (2022). Edible mushrooms for sustainable and healthy human food: nutritional and medicinal attributes. *Sustain. For.* 14:4941. doi: 10.3390/su14094941

Feeney, M. J., Dwyer, J., Hasler-Lewis, C. M., Milner, J. A., Noakes, M., Rowe, S., et al. (2014). Mushrooms and health summit proceedings. *J. Nutr.* 144, 1128S–1136S. doi: 10.3945/jn.114.190728

Foulongne-Oriol, M., Navarro, P., Spataro, C., Ferrer, N., and Savoie, J. M. (2014). Deciphering the ability of Agaricus bisporus var. burnettii to produce mushrooms at high temperature (25 °C). *Fungal Genet. Biol.* 73, 1–11. doi: 10.1016/j.fgb.2014.08.013

Grant, L. B. (2022) Growing a basement garden: can you grow vegetables in your basement, gardeningknowhow. Available online at: https://www.gardeningknowhow.com/special/containers/growing-vegetables-in-basement.htm (Accessed March 24, 2024)

Hauwers, D., Bank, J., and Montakhabi, M. (2020). Trust, transparency and security in the sharing economy: what is the role of the government? *Tech. Innov. Manag. Rev.* 10, 5–17. doi: 10.22215/timreview/1352

iFarm (2021) Vertical farms vs greenhouses – the first consideration: location. Available online at: https://ifarm.fi/blog/vertical-farms-vs-greenhouses (Accessed March 24, 2024)

INE (2022) Household projections 2022-2037. Available online at: https://www.ine.es/en/prensa/ph_2022_2037_en.pdf (Accessed April 5, 2024)

INSEE (2023) Couples – family – households in 2020 — municipality of Paris (75056). Available online at: https://www.insee.fr/en/statistiques/7634038?geo=COM-75056 (Accessed March 25, 2024)

Kim, B. F., Poulsen, M. N., Margulies, J. D., Dix, K. L., Palmer, A. M., and Nachman, K. E. (2014). Urban community gardeners' knowledge and perceptions of soil contaminant risks. *PLoS One* 9:e87913. doi: 10.1371/journal.pone.0087913

Langemeyer, J., Madrid-Lopez, C., Mendoza Beltran, A., and Villalba Mendez, G. (2021). Urban agriculture — a necessary pathway towards urban resilience and global sustainability? *Landsc. Urban Plan.* 210:104055. doi: 10.1016/j.landurbplan.2021.104055

Langford, B., Ryalls, J. M. W., Mullinger, N. J., Hayden, P., Nemitz, E., Pfrang, C., et al. (2023). Mapping the effects of ozone pollution and mixing on floral odour plumes and their impact on plant-pollinator interactions. *Environ. Pollut.* 336:122336. doi: 10.1016/j.envpol.2023.122336

Martin, C. J. (2016). The sharing economy: a pathway to sustainability or a nightmarish form of neoliberal capitalism? *Ecol. Econ.* 121, 149–159. doi: 10.1016/j.ecolecon.2015.11.027

Martin, M., Weidner, T., and Gullström, C. (2022). Estimating the potential of building integration and regional synergies to improve the environmental performance of urban vertical farming. *Front. Sustain. Food Syst.* 6:849304. doi: 10.3389/fsufs.2022.849304

Milestad, R., Carlsson-Kanyama, A., and Schaffer, C. (2020). The Högdalen urban farm: a real case assessment of sustainability attributes. *Food Secur.* 12, 1461–1475. doi: 10.1007/s12571-020-01045-8

Miralles, I., Dentoni, D., and Pascucci, S. (2017). Understanding the organization of sharing economy in Agri-food systems: evidence from alternative food networks in Valencia. *Agric. Hum. Values* 34, 833–854. doi: 10.1007/s10460-017-9778-8

Office for National Statistics (2023) Households by household size, regions of England and GB constituent countries – Office for National Statistics. Available online at: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/datasets/householdsbyhouseholdsizeregionsofenglandandgbconstituentcountries (Accessed March 24, 2024)

Orsini, F., and D'Ostuni, M. (2022). The important roles of urban agriculture. *Front. Young Minds.* doi: 10.3389/frym.2022.701688

Ritter, M., and Schanz, H. (2019). The sharing economy: a comprehensive business model framework. *J. Clean. Prod.* 213, 320–331. doi: 10.1016/j.jclepro.2018.12.154

Rizzo, G., Goggi, S., Giampieri, F., and Baroni, L. (2021). A review of mushrooms in human nutrition and health. *Trends Food Sci. Technol.* 117, 60–73. doi: 10.1016/j.tifs.2020.12.025

Rosol, M., and Schweizer, P. (2012). Ortoloco Zurich: urban agriculture as an economy of solidarity. *City* 16, 713–724. doi: 10.1080/13604813.2012.709370

Seghezzi, E. (2018) A decision support framework for technology related choices in façade retrofit: relevance and impact of morphological factors on retrofit interventions value. [dissertation/master's thesis]. Politecnico di Milano. Available online at: https://

www.researchgate.net/profile/Elena-Seghezzi/publication/330798616_A_Decision_Support_Framework_for_technology_related_choices_in_facade_retrofit_relevance_and_impact_of_morphological_factors_on_retrofit_interventions_value/links/5ecf825445851529451854b1/A-Decision-Support-Framework-for-technology-related-choices-in-facade-retrofit-relevance-and-impact-of-morphological-factors-on-retrofit-interventions-value.pdf (Accessed March 24, 2024)

Skar, S. L. G., Pineda-Martos, R., Timpe, A., Pölling, B., Bohn, K., Külvik, M., et al. (2020). Urban agriculture as a keystone contribution towards securing sustainable and healthy development for cities in the future. *Blue-Green Syst.* 2, 1–27. doi: 10.2166/bgs.2019.931

Specht, K., Schimichowski, J., and Fox-Kämper, R. (2021). Multifunctional urban landscapes: the potential role of urban agriculture as an element of sustainable land management. Berlin: Springer Science and Business Media LLC, 291–303.

USDA Database (2019) FoodData central. Available online at: https://fdc.nal.usda.gov/fdc-app.html#/food-details/169251/nutrients (Accessed April 4, 2024)

Weidner, T., Yang, A., and Hamm, M. (2018). Consolidating the current knowledge on urban agriculture in productive urban food systems: learnings, gaps and outlook. *J. Clean. Prod.* 209, 1637–1655. doi: 10.1016/j.jclepro.2018.11.004