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Urban agroecology enhances agrobiodiversity and resilient, biocultural food systems. The case of the semi-dryland and medium-sized Querétaro City, Mexico

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Small-scale agroecological practices in the urban areas of Querétaro, México, as in other mid-sized cities, could maintain agrobiodiversity pools and sufficient productivity for a food sovereignty baseline. The application of agroecological principles fosters agrobiodiversity and socio-ecological resilience in urban food production. Emerging urban gardens result from an immediate necessity for food that does not appear in local statistics, nor is there any account of them in any cadastral source or land register of Querétaro City. Based on studies of 28 urban gardens, we survey and analyze farming practices using socio-ecological resilience methodologies and the Diagnostic Survey of Agroecological Practices. We find that the agroecological management of urban gardens results in significantly more species richness than in conventionally managed plots, likely due to the multifunctional purposes associated with biocultural memory. The number of social actors participating in agroecological management is increasing. It represents an urban strategy of resilience that contributes to enhancing the microclimate and nutrient cycling, as well as to improving water management and biodiversity. Results also indicate that gardens of approximately 200 m^2 harbor the highest levels of agrobiodiversity. This area size for home vegetable production appears optimal for user-friendly management practices in urban settings and could represent the minimum benchmark for a family and a goal for urban planning and policy recommendations. Urban gardens contribute to the adaptive capacities of city dwellers to enhance their food security and sovereignty. Therefore, given that 70% of the national population face some level of food insecurity, we argue that, along with the protection of land-use rights, the promotion of a diverse urban landscape could improve long-term socio-ecological and food supply resilience. Additionally, urban gardens promote neighborhood social inclusion and affordable access to food. The empirical results and insights from this study in Querétaro can inform land-use policies for urban agriculture more broadly, especially in Latin American metropolitan areas.

KEYWORDS

urban agroecological practices, urban agrobiodiversity, urban socio-ecological resilience, urban food policy, small-scale food systems, biocultural memory, urban farming, adaptative governance

1 Introduction

1.1 Background of the study

City dwellers, scholars, policymakers, and non-governmental organizations increasingly recognize urban agriculture as an essential contributor to food security, the sustainable use of resources, and biodiversity in urban landscapes (Smit, 1996; Barthel et al., 2013; Clausen, 2015). Community gardens, rooftop gardens, school gardens, guerilla gardens, and other unique forms of urban production enable people to cultivate food and community while conserving agrobiodiversity (Whitney et al., 2017), soil, and water (Colding, 2011; Golden, 2013; Classens, 2014; Tornaghi, 2016). Agrobiodiversity results from interactions between the genetic resources of plant, animal, fungi, and microorganism species (both domesticated and their wild relatives), the environment, and the management systems and practices used by culturally diverse peoples at the intersection of biological and cultural diversity. It includes diversity at the ecosystem, species, and gene levels (FAO, 2004; Jackson et al., 2007 and Casas and Vallejo, 2019) and comprises various foods, fibers, and medicines of natural origin as well as the ways in which they are produced. The collection and cultivation of various species for food and other purposes requires the use of land and water resources. The variety and variability of species are necessary for sustaining key functions of agroecosystems, including both their structure as well as various processes for and in support of food production (FAO, 2004). Indeed, agrobiodiversity is a vital sub-set of overall biodiversity. Many people's food and livelihood security depend on the sustained management of various biological resources that are important for food and agriculture (Schneider and McMichael, 2010). Yet at least 70% of crop genetic diversity has been lost due to climate change, the industrialization of agriculture, and the associated shifts in the socio-economic and cultural dynamics of food and agriculture (FAO, 2020; Njeru et al., 2022).

Parallel to the decline of crop diversity in agricultural landscapes, the current diet of most people is dominated by only three crops – wheat, rice, and corn – which provide over half of the calories consumed globally (Pollan, 2002; UNCSN, 2020). This fact raises concerns about human health as well as the resilience of the global food system, as agrobiodiversity is key to both healthy nutrition and climate change adaptation. This structural lack of diversity in the food system poses immense risks to food security and human well-being, especially for poor and vulnerable populations, for instance in the case of crop failure. These risks are exacerbated by the impacts of financial speculation on food crops ().

The loss of agrobiodiversity[1] also incurs substantial costs. For example, the role of pest control by natural predators is estimated to be worth 100 billion USD, the role of soil biota in increasing soil fertility at least 25 billion, and the value of crops whose production depends on insect pollinators 15 billion (Constanza et al., 2014). According to the more radical views of activists, grassroots movements, and many peasant and indigenous communities, this extraordinary, abundant diversity is sacred, sustaining all forms of life (not least our own), and should not be subject to pricing and offsets in market-driven speculation that causes inflation for those that most need access to affordable food (Hawkes, 2006; FoEI, 2021). In Mexico, as in many other countries where the Green Revolution was institutionalized, agricultural modernization has led not only to the reduction of crop species diversity but to the replacement and erosion of indigenous crop varieties. These varieties are adapted to particular environments and tolerant to adverse climatic conditions and their loss has driven both the reduction of food resilience and a rise in health problems over recent decades. The push of corporate globalized food systems and free trade agreements to replace diverse and rich traditional diets to highly processed, energy-dense, and micronutrient-poor foods and beverages has led to the proliferation of obesity, diabetes, heart disease, and other diet-related chronic (Popkin et al., 2012). For example, most drinks and snacks consumed in Mexico contain high-fructose corn syrup, which has been linked to the epidemic of obesity and Type 2 diabetes (Bello-Chavolla et al., 2017).

The COVID-19 pandemic also had dramatic effects on people's diets. Besides food prices peaking around the world (GRFC, 2020), demand for fresh produce diminished as many people worried about potential supply chain disruptions and shifted towards greater consumption of heavily processed items with longer shelf lives. This trend links to the incidence and severity of diabetes and other diet-related diseases which have been identified as risk factors for COVID-19 mortality (IPES-FOOD, 2020; UNCSN, 2020). Marginalized city dwellers with underlying health conditions such as diabetes, high blood pressure, obesity, and heart disease – mostly belonging to lower-income groups, communities of color, and indigenous groups – are at particular risk of severe illnesses, including hospitalization and death (Popovich et al., 2020). The crisis of the COVID-19 pandemic must provide the impetus to transition from industrial agriculture towards regenerative, diversified, and resilient agroecology-based food systems (Altieri and Nicholls, 2020).

In terms of urban resilience, medium cities have been identified as both the main hosts of urban growth today and the weakest urban-area types in terms of infrastructure, water service, and food provisioning for the future (World Bank, International Monetary Fund, 2013). Medium cities are those with a population between 100 thousand and 1 million inhabitants (Covarrubias, 1985; Padilla, 1998). Urban areas in Latin America are often defined by a population concentration above 1,000 persons per km^2 or more than 10 inhabitants per ha with basic services, such as water, electricity, transportation, and communications. Peri-urban areas, on the other hand, are located within the area of influence of city systems and adjoin neighboring "non-urban" systems (MacGregor-Fors and Ortega-Álvarez, 2013). Landscape stewards in urban and peri-urban areas employ diverse socio-ecological practices. Harnessing the power of these practices can cultivate resilience within urban food systems, enabling them to reorganize to meet human needs in times of crisis (Altieri and Nicholls, 2000; Elmqvist et al., 2003; Folke, 2003; Folke et al., 2011; Colding and Barthel, 2013; Blay-Palmer et al., 2015). Urban resilience has become ever more important in this age of climate change, urbanization, rampant environmental degradation, pandemics, and intensifying social disparities in the food system.

1 Related to agrobiodiversity, the flexibility and variety of production and management technologies and practices of small urban farmers is encompassed by the term agrodiversity, used by Pinedo-Vasquez (2008). Pertaining only to primary production, high agrodiversity is central to any strategy aimed at developing sustainable food-production systems that are resilient to stresses driven by climate change (Brookfield and Stocking, 1999; Njeru et al., 2022). In this article, we use the term agrobiodiversity in order to conform to the definitions of the FAO (2004) and the Mexican Commission for the Knowledge and Use of Biodiversity that operates the National Biodiversity Information System (SNIB, CONABIO, 2023).

Research demonstrates that agroecological perspectives and practices can contribute to food-system adaptation and resilience and, relatedly, to the success and productivity of urban agriculture (Gliessman, 2013; Altieri and Nicholls, 2018). On the field and farm level, this approach aims to foster the optimal recycling of nutrients, organic turnover of soil fertility, closed energy flows, water and soil conservation, and pest regulation. At the same time, management practices that improve crop diversity also significantly contribute to an increase in the supply of critical vitamins and nutrients beyond the production site, particularly when that diversity includes green leafy vegetables (Rajendran et al., 2017). Therefore, agroecology presents a holistic grassroots tool to both improve the ecological impact and the productivity of urban agriculture and benefit surrounding human communities.

Despite the emerging recognition of its advantages, the potential of urban agriculture is scarcely considered in estimates of food production, nor in projections of research priorities. In Mexico, urban farming is not included in agricultural statistics, urban land-use mapping,[2] or accounts of local and national-level food security.[3] The contributions of urban agriculture, in other words, are under-theorized, under-estimated, and under-recognized in both scholarly research and practical policymaking. Given the rapid pace and future trajectory of urbanization around the world – combined with growing concerns over food security, struggles over the resources needed to ensure adequate food access and nutrition, and the ecological implications of industrial food production and long-distance food trade (Schnell, 2013; SEDESOL, 2014) – a strong focus on urban agriculture in scholarship and policy is more urgent than ever.

Our study of urban gardens in the Metropolitan Area of Querétaro, Mexico contributes to the nascent literature on urban agriculture. It provides agrobiodiversity data to inform policy-making processes about the urban circular metabolism and to stimulate political interest in reusing resources in urban ecosystems as much as possible (Bolton and Hildreth, 2013; Mostafavi et al., 2014; Angulo et al., 2015; Lucertini and Musco, 2020; QroCircular, 2023).[4] The study was conducted over a 2-year period and included site visits (28 urban and peri-urban gardens in the Querétaro municipality), personal communication and interviews, species identification, and soil sampling. We posed four questions: (1) What are the main components of agrobiodiversity in urban gardens in Querétaro? (2) Do garden management practices differ across the range of urban garden types? (3) Is agrobiodiversity different between Querétaro's urban and peri-urban landscapes, and if so, how? (4) How does agrobiodiversity in urban agriculture contribute to socio-ecological resilience? The remainder of this introduction situates key contexts and concepts for the study of urban agriculture and resilience and provides the rationale for this case study in Querétaro to inform urban planners, scholars, and food providers elsewhere to consider a similar process.

1.2 Urban farming, biocultural food systems, and resilience

Urban agriculture (UA) includes the production, distribution, and consumption of food within the limits of a metropolitan area (Companioni et al., 1997; Altieri, 1999; Smit et al., 2001; Cole et al., 2008). While the boundary between cities and the countryside is ambiguous and shifting, for urban agriculture, the "metropolitan area" typically includes both urban and peri-urban spaces.[5] In this study, we examine urban and peri-urban gardens which, following Esteva (2013), we refer to as *urbicultura*.[6]

Urbicultura comprises strategies and mutual-support networks for growing food in the city. It has experienced a significant boom in Mexico in recent decades (Esteva, 2013). Such "alternative" food networks have the potential both to increase resilience in the face of ongoing food insecurity due to political strife, economic recession, and climate change and to minimize risks for farmers (Blay-Palmer et al., 2015). An agroecological base in the production system may reduce the dependence on external inputs, promote the consumption of local and healthy food in the population, and generate various alternatives for food access and distribution within the metropolitan area. It also can allow urban dwellers, who are socially isolated from farmers and their policy issues, to connect with each other in ways that can both build and heal communities (Simmel, 1903; Nabhan, 2001; Altieri and Nicholls, 2009; Ostrom, 2009; De Zeeuw et al., 2010; Peretto and Valente, 2015). As such, agroecological *urban farming* can be an important component of efforts toward food sovereignty,

2 Cadastral municipal land descriptions of legal ownership, land-use, and location within the Querétaro's Municipal Registration.

3 The National Census, which is conducted every 10years, does not include urban agriculture metrics, nor does the most recent biennial Household Intercensus Survey (ENIGH, 2022). The SAGARPA-Mexico without Hunger National Program only collects information on small-scale farmers and producers in rural areas (SIAP, 2017). Urban agriculture is also not included in the biannual multidimensional poverty evaluation in Mexico (CONEVAL, 2019). As a result, there is no estimate of the number or contributions of urban farming operations in Mexico.

4 Querétaro City is widely used as a representation of a prosperous expansive urban model by mainstream institutions, such as (UN-Habitat, 2017), but in reality, its rapid expansion is repeating the complexity of structural problems of many other mid-sized Latin American cities, like Caracas and Lima and Santiago de Chile. In February 2021, Standard & Poor's awarded Querétaro a national credit rating of MxAA+. This rating came after the state had been recognized as the second most competitive in the country by the Mexican Institute of Competitiveness (IMCO). However, the growing real estate speculation of 56% accounted for only an 18.9% increase in investment in public transportation and 4.4% in water distribution according to the Builders National Survey (ENEC, 2023). Prior to the COVID pandemic, Querétaro registered a growth of 1.4 million dwellers and after it, became one of the most popular cities for remote workers. In 2022, a total of 118 individuals were reported to daily inmigrate into the City of Querétaro (González, 2022).

5 In their study of urban agriculture and food security in the Global North, Opitz et al. (2016) argue that urban and peri-urban areas are categorically different from each other, and should be studied as such. For our purposes, and in the context of Querétaro, we approach urban and peri-urban agriculture as spatially overlapping categories.

6 We used the term Urbicultura in italics and Spanish (with potential translation) since it represents the cultural appropriation of an emerging practice in Mexico. We use this language in an explicit attempt to decolonize research, to preempt viable criticism, and provoke thought about the coloniality of knowledge production.

defined in the Nyéléni (2007) Declaration as, "the right of peoples to healthy culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems." Achieving food sovereignty entails gaining bottom-up control over agrifood production, processing, and consumption. It will necessitate strengthening the socio-ecological resilience of food and farming systems within and between rural and urban areas, which includes protections for biodiversity and land rights. It also will require the adoption of knowledge-intensive farming practices linked to the biocultural memory of ingredients, processes, and uses of different varieties of crops. Biocultural memory can be defined as the knowledge, practices, and the basis of identity and beliefs transmitted from generation to generation of peoples (FAO, 2020). The term "biocultural food systems" thus refers to the diversity of food crops and the associated knowledge.

Emerging research indicates that urban farming and its practitioners, often referred to as *urbicultores* in Spanish (which translates as *urbicultivators* in English), have the potential to enhance food security, climate adaptation, and community-level resilience in cities (Colding and Barthel, 2013). Resilience is the capacity of a system to withstand disturbance and to reorganize to retain its function, structure, identity, and feedback (Holling, 1973; Gunderson and Holling, 2002; Walker et al., 2004; FAO, 2010/6; MacGregor-Fors, 2011). For example, *urbicultura*, whether considered as identity-based knowledge of food, culturally-appropriated ingredients, products, and processes or as a biocultural food system (Esteva, 2013), can reduce negative impacts within households during periods of food scarcity. This role is especially relevant when food prices experience substantial spikes, as witnessed during the 2007/2008 global food-price crisis and more recently, amid the COVID-19 pandemic and the war in Ukraine. This is particularly important for poor and marginalized people who are most affected by food price spikes and for whom gardens can be a buffer in the short term. Rather than representing momentary shocks to otherwise well-functioning systems, *disturbances* reveal deeper structural problems in the food system. Indeed, recent food price hikes have pushed the number of hungry in the world to its highest level in human history. At the same time, leading transnational agribusiness corporations recorded record profits during the crisis and the productivist approaches to food security that they champion have gained more traction in policy and business circles (McMichael and Schneider, 2011; Bloomberg, 2021). In the longer term, the food crisis disturbance demonstrates that rather than a lack of food availability, it is social exclusion and economic disparity that systemically limit people's access to food (De Schutter, 2014; Piketty, 2014).

The high proportion of people on the planet who are hungry, food insecure, and/or deficient in micronutrients co-exists with a growing proportion of people who suffer diet-related diseases and maladies from "over-consumption." This trend is related to the replacement of more locally-based and whole foods with calorically dense but nutritionally empty industrial foodstuffs (Muñoz de Chávez et al., 2002; Drewnowski and Specter, 2004; Patel, 2008; Scrinis, 2008; Carolan, 2012; Tilg and Moschen, 2015; FAO, 2016).

FAO (2010/6) urges that the solution to the structural causes of food crises lies in establishing local markets, promoting urban gardens, improving natural-resource sustainability and land distribution, and supporting grassroots organizations. More than simply a matter of official, top-down policy, maintaining and enhancing urban food production for resilience also involves civil society. Walker et al. (2004) refer to collective action to empower agency in local food systems and manage resilience as governance *adaptability* (Walker et al., 2004). Urban gardens often serve as an important example of such community-based adaptability led by civil society. However, city dwellers also require a supportive policy environment to ensure land-use rights and safeguard against dislocations.

Urban farming is particularly powerful as a form of resilience when based on the agroecological model, the main objective of which is the prioritization and design of ecological-regulatory functions (Smit, 1996; Golden, 2013; Nicholls et al., 2015a,b). For instance, agroecological practices facilitate functional redundancy through high levels of crop diversity and peripheral plot complexity in urban farming practices (Whitney et al., 2017). Redundancy provides a broader adaptive capacity to respond to disturbances (Altieri, 1999). Agroecological urban farming promotes biological activity in the soil, conserves soil organic matter, and relies on interactions and positive synergies between agroecosystem components, further enhancing the system's resilience. Therefore, agrobiodiversity creates functional insurance and supports the reorganization and renewal efforts of disturbed systems (Elmqvist et al., 2003; Colding, 2007). While greater ecological complexity is essential for a city's resilience, the activation of cultural diversity through conducive governance practices and organization is key for the capacity of cultural practices and the landscape to co-evolve, i.e., for the development of land use and management (Rindos, 1980; Barthel et al., 2005; Colding and Barthel, 2013). As this empirical study shows, this activation depends more on diversification and the knowledge-intensive biocultural memory of its practitioners than on its capital intensity or the productivity of a single crop. Therefore, activating the biocultural memory of city dwellers becomes strategic. The food selection and preparation processes transmitted through history are key for alternative futures. Agroecology has the potential to restore the importance and recognition of agricultural practices that have been present in the territories for several generations and that are kept vital through biocultural memory (Zeeza and Tasciotti, 2008; FAO, 2020). Because of the relatively small scale of production, UA can be highly decentralized. As many crops in UA have been carried to metropolitan areas by migrants, these systems tend to be highly diverse in terms of crop mixtures and production practices. Urban gardens are less dependent on external inputs, such as fossil fuels and fossil fuel-based inputs. Instead, they rely on recycling soil and water and using plant and animal waste for fertility. As such, UA has the potential to close energy cycles in cities (Altieri and Nicholls, 2007). Finally, in addition to improving food access, UA projects are a form of financial saving and community development for urban farmers, and they provide learning opportunities, youth development, and community integration (Colding, 2011).

Urban farming does not inherently embody agroecological principles, nor does it solely rely on biocultural memory. Realizing the full potential of urban agriculture in enhancing resilience often requires an *agroecological transition*. This transition involves the comprehensive transformation of a production system, encompassing technical, productive, ecological, and socio-cultural aspects, in a multilinear process of change (FAO, 1996; Smit, 1996; Freire, 2000; Caporal and Costabeber, 2004; Rogé et al., 2014).

The transition of urban farming in this direction depends on the adaptive capacity of social and ecological conditions. Key social factors, including local governance, the presence of biocultural memory among practitioners, community organization, property rights, and institutional alliances, must be addressed. On the ecological front, it is imperative to enhance biodiversity through functional groups like organisms that perform vital roles such as pollination, seed dispersion, grazing, predation, nitrogen fixation, decomposition, soil fertility enhancement, and water flow modification. To ensure their livelihoods, urban farmers also must re-learn how to maintain ecological functions, such as nutrient cycling and organic matter optimization for soil fertility, system diversification, pest prevention (e.g., by stimulating the presence of natural enemies as a biodiversity management strategy), and sustainable water management over time (Altieri, 2002; Altieri and Toledo, 2011).

1.3 Urban farming: the case of urbanization in Querétaro City

Urban food insecurity and diet-related diseases and illnesses vary across social classes, resulting in corresponding disparities in access to food (Harvey, 2006; McClintock et al., 2016; FAO and OECD, 2020). As is the case in many Latin American metropolitan areas, the underlying root cause of the food-related problems in Querétaro, especially people's inability to access nutritious food, is the structural social crisis of exclusion and economic inequality (FAO, 2012; De Schutter, 2014). Although millions of tons and varieties of food and food products arrive in urban markets every day, they are unevenly distributed throughout the city. Shorter and more equitable food supply chains also exist, but the ongoing industrialization and capitalization of the world's agrifood systems marginalize players in these localized chains (Nabhan, 2001; Clapp and Fuchs, 2009; McMichael, 2009). The farmers (especially smallholders), who might otherwise operate and benefit from their production directly receive only 5 to 17% of their food's retail value (Nabhan, 2001; Baker, 2013; Schneider, 2014).

Historical increases in food prices have limited access to food in Mexico (FAO, 2001, 2009; ENSANUT, 2013; CONEVAL, 2014a,b), particularly following the surge in processed-food consumption associated with NAFTA (Grain Report, 2015). Between 1993 and 2001 the sale of processed food grew 10.5%. This trend, along with food financial speculation (Isakson, 2014), has intensified the country's dependence on food imports, which rose 300% from 5,000 million tons of imports of corn in year 2000 to 18 million tons in 2021 (Enciso, 2021). In Querétaro, as in Mexico more broadly, food access is limited by food availability and price increases. In 2015, almost 22% of the national population lacked access to sufficient amounts of food, and only 30% were considered food secure[7] (CONEVAL, 2015; GRAIN with ENSANUT). According to CONEVAL (2015), 17.5% of the population (>300,000 people) lack regular access to food in Querétaro alone, and 40% are considered food insecure. In October 2017, the minimum cost of a monthly basic food "basket" in Querétaro's urban areas was 2,924.94 Mexican pesos (146.98 USD), while it was 1,891.51 Mexican pesos (95.05 USD) in rural areas. In January 2023, the value of the "extreme income poverty line" defined with the price of the urban food basket went from 1,930.38 USD (January 2022) to 2,143.72 USD (January 2023), increasing by 11.1%. Similarly, the value of the rural food basket increased by 11% (from 1,481.10 USD in January 2022 to 1,644.23 USD in January 2023; CONEVAL, 2023).

On its multidimensional poverty measurement ENIGH (2016, 2018, 2020), CONEVAL (2020) reported an increase from 4.9% of the population (99,423 persons) in 2016 to 6.9% in 2020 (164,201 persons) experiencing severe food insecurity in Querétaro, and an increase from 48,798 in 2016 to 66,471 persons having limitations in food access and consumption during pandemic[8] (CONEVAL, 2020). The consumption limitation of households refers to when household members have a poor or borderline diet. This assessment takes into account the frequency of food consumption and dietary diversity of 12 food groups, the variety of foods across 12 food groups, serving as an approximation of nutrient adequacy. The situation in Querétaro illustrates the broader problem of urban food access, which is becoming a high-priority issue in Mexico and Latin American medium-sized cities (MDGs Goal 2: Zero Hunger Challenge of the United Nations, Envision 2030, Agenda 21, GEO, MDG, UN-Habitat, 2004).

Anemia, i.e., a deficiency in red blood cells or hemoglobin, is also widespread in the Mexican population. Data showed that 11.6% of non-pregnant and 17.9% of pregnant women had anemia in 2012. Since then, this figure has increased to over 20% of pregnant women. This deficiency affects infant growth within the first months of life. In Querétaro, anemia stands at 23.5% in data for pre-scholar toddlers, contrasting with 10.1% of those of school-going age (IC95% 17.9–30.0). Rural children present a smaller index of anemia (22.0%) than urban children (24.4%) (CONEVAL, 2020). This situation within the most critical ages of development creates a public health challenge. The largest portion of the Mexican population is 25–35 years old, meaning that in the coming years, this population will increase demand for public health services due to food-related illnesses.

In Querétaro, like elsewhere,[9] urbanization is accompanied by both deepening social inequalities and intensifying environmental problems (Jordán and Simioni, 1998; IPCC, 2007; Kunzmann, 2009). With the population having grown around 30% in the last 6 years (from 1,091,025 to 1,530,820 inhabitants in 2022; CONAPO, 2022), the population of Querétaro City[10] is booming. It makes up 64.4% of the entire state's population (INEGI, 2015; COESPO, 2021).

The city has seen state-promoted industrialization, rapid population growth, and national immigration due to the mechanical and aeronautic investment of private capital. This growth has attracted a middle class with resource-intensive lifestyles to Querétaro (Arvizu-García, 2006), even while urban poverty and food insecurity are on

7 42% were ranked as mildly food insecure, 18% as moderately food insecure, and 10% as severely food insecure.

8 Mexican Food Security Scale (EMSA), as well as the limitation of food consumption according to the World Food Program (WFP) of the United Nations.

9 Rural–urban food disparities are intensifying in the context of rampant global urbanization. Today almost half of the world's population lives in urban areas, and this level is expected to reach 70% by 2050 (FAO, 2016).

10 Querétaro City Metropolitan area that includes four municipalities: Querétaro, Corregidora, El Marqués and Huimilpan.

the rise. Simultaneously, there has been a notable trend in the real estate sector, characterized by the proliferation of vacant newly built homes (Bayona, 2016).

Furthermore, urban sprawl itself contributes to social inequality as it often encroaches upon agricultural land, including prime farming areas, to accommodate urban and suburban development.

What is more, urban sprawl itself contributes to social inequality: the physical growth of cities oftenprevents land from being used for farming (Olson and Lyson, 1998).

Querétaro City is sprawling on semi-arid lands previously occupied by agriculture, pasture, and native vegetation (INEGI, 2015). Located in the hydrologic region of Lerma -Santiago, Laja River Basin, and Apaseo River sub-basin, the city has a semi-dry temperate climate (BS1k) according to the Köppen classification. It has warm summers and an average annual precipitation of 550 mm. While El Marqués and Querétaro municipalities have mainly rain-fed agriculture, urban expansion has fragmented the remaining natural vegetation areas, especially those in highly vulnerable locations that serve as regeneration zones for aquifers, such as vegetation on steep cliffs, in the foothills, on stream banks, or sites into canyons (Bayona, 2016). For this reason, the urban and peri-urban areas of Querétaro have the highest risk levels for both flooding and drought in the state. Between 2001 and 2010, out of nearly 1.5 million inhabitants, more than 60,000 people (4% of the population) were affected by floods (Suzán-Azpiri et al., 2014). These disasters have the strongest impacts in neighborhoods characterized by the lack of employment options, housing, services, income, health security, education, and food provision (IPCC, 2014).

The city's water supply faces significant vulnerability. Scarce groundwater has been under pressure for decades (the deficit according to data from CNA is −105.9 Mm3), and the PNUMA GEO Querétaro 2008 reported that wells were sinking at a rate of 4–6 meters per year, heightening concerns about potential aquifer depletion. The city has virtually no surface water, and sewage is discharged directly into the Querétaro River. The river's treatment is partial and urban drainage infrastructure is insufficient. The Acueducto II Project for water distribution in the city intends to bring water from the Panuco Watershed as far as the Infiernillo spring, located in the Moctezuma River. As many civil protests and human rights violations have happened in 2023 to Cadereyta, Querétaro inhabitants, the current administration is looking to source water from Querétaro semidesert dam in Tzibanzá with a new megaproject for the "following 50 years" called Acueducto III.[11] Although the project should partially overcome the dependence on the local aquifer for the next 30 years (PNUMA GEO Ciudad de Querétaro, 2008; Kirkland, 2020; Granados-Muñoz, 2022), there is some skepticism about the medium-term viability of the project among some insiders in the State Water Commission (personal communication CEA Agency, 2022). Furthermore, the watershed course within the city and the presence of vertisols, which tend to limit the drainage velocity, increase flood vulnerability. The aquifer issue has recently been made public by civil organizations reporting on the critical problem of water availability in Querétaro City (Bajo Tierra Museo, 2022). Additionally, the Metropolitan Zone of Querétaro (MZQ) is decreasing its aquifer water infiltration area due to the conversion of agricultural lands and land of high ecological value into industrial, commercial, or new housing lands (Soria et al., 2020).

Land use and vegetation juxtaposed layers in Figure 1 show the remaining irrigated and rain-fed agriculture, demonstrating that sources of locally available food have been displaced by urban sprawl. Reduced wild biodiversity and agrobiodiversity around Querétaro make the city increasingly vulnerable to natural and human-induced changes. About 60% of natural forested areas (scrubland) in Querétaro have been removed,[12] including profound losses of mesquite wood (99% reduction), tropical deciduous forest (90% reduction), and oak forest, (85% reduction) (PNUMA GEO Ciudad de Querétaro, 2008). At the microclimate level in dryland urban gardens, the loss of soil organic matter by higher air temperatures caused by the urban heat-island effect can accelerate the decomposition of the remaining organic matter, increasing the salt and sodium contents, affecting soil fertility while suggesting that green vegetation and food production may also reduce urban heat island effects (Colunga et al., 2015). At the same time, longer growing seasons may allow insect pests to complete a greater number of generations per year and spread plant diseases, resulting in crop losses.

Increased cultural diversity is perhaps the bright side of urbanization. Urban farming can benefit from this silver living. Like many cities in Latin America, Querétaro attracts migrants from rural areas and other regions within the country. The immigration rate has grown by 2.6% [La Voz de Querétaro, 2017 with data from COESPO (2017)] and almost doubled during the COVID-19 pandemic (Expansión Obras, 2021). Migrants from rural areas often bring with them agricultural knowledge that can be useful for farming in the city. In referring to biocultural memory, scholars, such as Toledo and Barrera-Bassols (2009), suggest that it can be recovered in the public space of urban agriculture. As such, it can be harnessed to enhance the responsive capacity to, and resilience in the face of, multiple threats, such as those described above. The biocultural memories carried with migrants to Querétaro might be reflected and used in its urban food and farming system. This possibility becomes especially important as the social and environmental impacts of capitalist, industrial food and farming emerge.

In Querétaro, there is a growing recognition of the lack of fresh, safe, and local food. For example, a recent study found that 70% of people between the ages of 18 and 23 in Querétaro expressed concerns about the availability of nutritious food (Félix, 2017). With rising awareness of the harmful impacts of agrochemicals, desire, especially among young people, for non-industrial and "local" foods, and the biocultural memories and "traditional" knowledge carried by migrants, urban agriculture in Querétaro may have a role to play in transitioning towards more agroecologically and socially resilient food

11 The emblematic icon of Queretaro City is a patrimonial UNESCO World Heritage Site shows that from the beginning of the second half of the 17th century, the city has experienced water shortages and struggled to supply the valuable liquid. The aqueduct has been designated as an International Historic Civil Engineering Landmark by the American Society of Civil Engineers.

12 It should be noted that some vegetative regeneration has occurred with the abandonment of farming plots in peri-urban areas; however, this also makes those regenerative spaces vulnerable to interests of speculative capital to convert land into private urban developments.

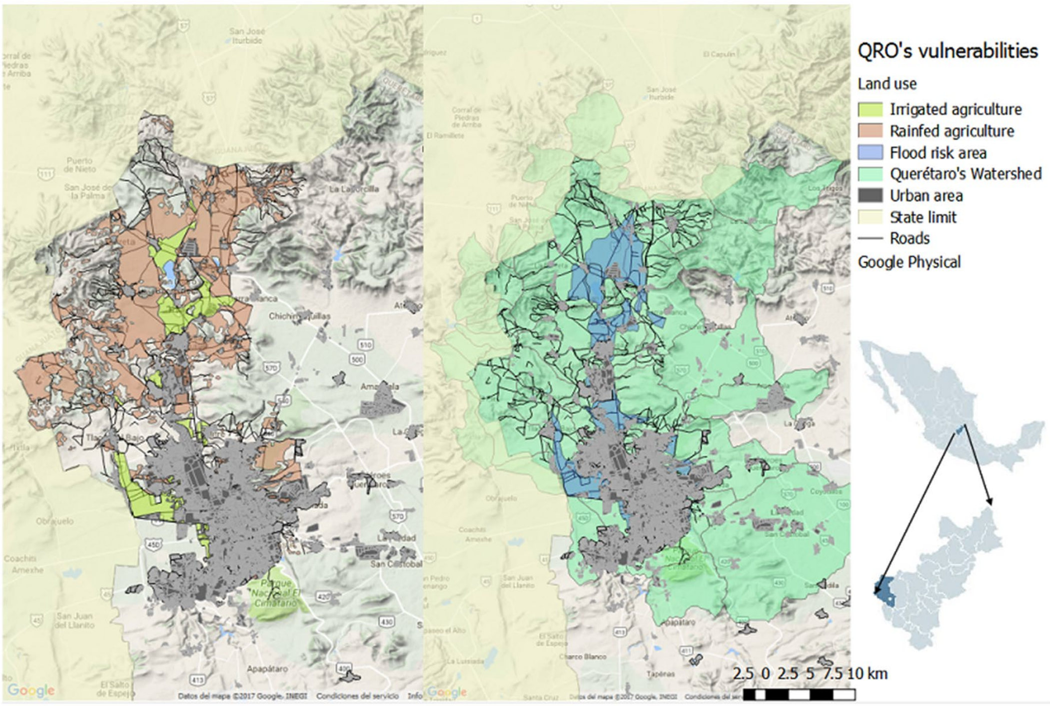

FIGURE 1
Vulnerable areas of city sprawl over rain-fed agriculture and flood risk across Apaseo River watershed, Querétaro City, Mexico.

and farming systems. To this end, this study aimed to identify the practices of urban farmer*s* in Querétaro and analyze their impacts on agrobiodiversity and socio-ecological resilience in the city.

2 Methods

2.1 Sampling and data collection

The present study is an attempt to initiate primary data collection on urban farming in Querétaro City. As there are currently no data on the number or distribution of urban gardens in the city, we used a convenience sample using snowball sampling. Sampling started with five gardens from a list of friends and acquaintances of the authors, whom we visited and whose urban farmers were invited to participate in the study. In the initial phase, key informants provided further contacts, resulting in a contact list of 17 urban farmers which we started visiting. Those garden owners provided us with the names of other gardeners, and so on. We also contacted Facebook groups and online networks (Sembradores Urbanos-Colectivo Tlalli, NaYax, CIASPE), as well as emerging networks and independent horticultural enthusiasts involved in urban gardens (Zona Viva, Transición Querétaro). From these contacts, the sample snowballed to 31 gardens, from which 28 gardens were suitable for the study, due mainly to their food production, hosting availability, and consent to participate in the study. Garden sizes ranged from 12 m^2 to 0.6 ha, with 25 to 60 m^2 as the most common range. During the two-season study period from 2015 to 2017, each of the 28 gardens was visited at least three times in person to administer surveys, conduct interviews, and document agrobiodiversity and management practices. The location of each garden was recorded with GPS to plot data in Quantum GIS Version 2.18.2 with GRASS 7.0.5 and Google Earth Pro.

Using the principles of agroecological methodology (Altieri, 1995; Henao, 2014; Nicholls et al., 2017), we characterized agrobiodiversity in the 28 urban gardens by evaluating each garden's (1) horticultural composition, (2) agricultural productivity, and (3) water and soil management. The first round of data collection to identify garden management practices was based on Altieri et al.'s (2014) Diagnostic Survey of Agroecological Practices. It consisted of a 24-item questionnaire of agroecological indicators, including nine main indicators: nutrient cycles, nutrient loss prevention, soil water and humidity retention, diversification, soil quality, organizational support, land tenure aspects, and pest control practices. The lead author implemented the survey and interviewed every urban farmer or the person who spent the most time in the garden, assigning a score of 0 to 3 for each item in the questionnaire. To differentiate between "conventional" and "agroecological" gardens, management practices were rated on a scale of 24 points. Sites rated above 12 points were identified as agroecological due to their higher complexity (see Figure 2).

Additionally, a quantitative closed-question survey was administered to record the gardeners' demographic profile (age, occupation, formal education, and gender). The species richness (S), defined as the number of species within a plot, was obtained through sampling or via a census of individual frequencies and recorded (Moore, 2013). Once the agrobiodiversity of the urban gardens was plotted, we used an extrapolation tool to describe and report its evidence across the city. The Inverse Distance Weighting (IDW) algorithm was used to interpolate and report the highly variable data, assuming that the weight of distant inverses has a local influence that

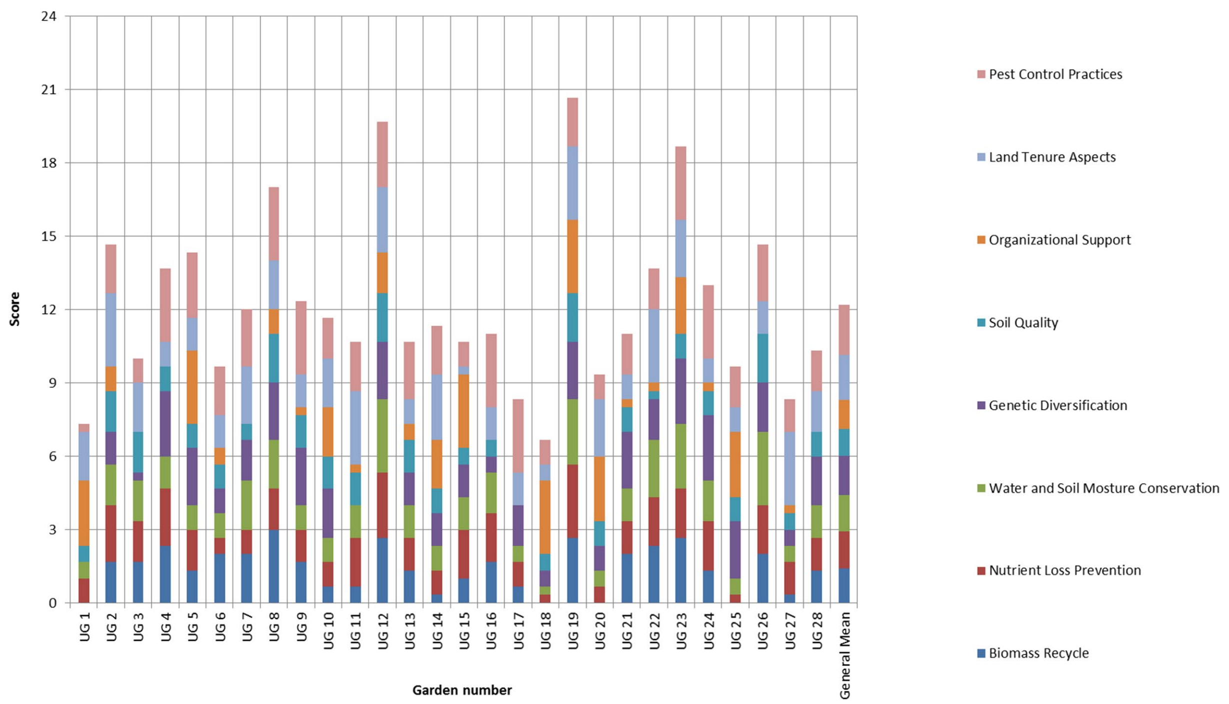

FIGURE 2
Cumulative agriculture management score for all 28 sites based on the diagnostic survey of agroecological practices. The threshold between the two management types was 12 points.

diminishes with distance (Childs, 2004). Weighting was assigned to sample points through the use of a weighting coefficient that controls how the weighting influence will drop off as the distance from the new point increases.

2.2 Data categorization and analysis

To gage locational variability in practices and agrobiodiversity, and to test the null hypothesis that no differences exist between management and location that affect species richness and productivity among urban gardens across the city, we differentiated peri-urban and urban gardens. There are many approaches to defining peri-urban spaces (see, for instance, Maestre et al., 2012; MacGregor-Fors and Ortega-Álvarez, 2013). For this study, sites with paved roads were the main attribute used to distinguish peri-urban and urban gardens. As a result, 20 gardens were located within the city of Querétaro (adjacent to an asphalt paved road) and eight were peri-urban (no paved road).

We categorized gardens as: (a) home-consumption gardens, for families sharing a private backyard, (b) community gardens, (c) didactic school gardens, and (d) commercial market gardens (Figure 3).

Botanical records for each garden were created through a combination of site visits and photography. Because gardeners typically do not keep a complete botanical record of their gardens, photographs were taken at each site, species were identified, and the resulting database was compared with botanical keys of plants of the World Online databases of Kew Royal Botanic Gardens (2017) and the Missouri Botanical Garden. Additionally, garden owners were asked to tour their site together and name every possible species by their common name to later contrast them with botanical keys and databases. In order to review the accepted name and its synonyms, The Plant List (2013) Version 1.1 was consulted to work down the taxonomic hierarchy. Key species in the gardens were determined using the highest Importance Value Index IVI as the measure of the spatial value of one particular species, which is the sum of the relative coverage by species (RC), relative density by species (RD), and the relative frequency by species (RF).

$$IVI = RC + RD + RF^{*}\,100.$$

Relative coverage (RC) was registered by taking the average of two canopy diameters of every species. RD was calculated by accounting for its density across gardens, and RF was the global discrete frequency across gardens. Data was organized by management practices, location, productivity, species richness, and IVI-value for ecological importance. Data about the number and profile of people involved in the garden, land dimensions, and productivity were kept updated in the dataset as the research progressed over a period of three years. Statistical analysis of variance was carried out using R Studio. A two-factor ANOVA (Location * Management) was performed to analyze differences in species richness and productivity. Some analyses required logarithmic or square root transformations to meet assumptions. Significant differences between combinations of factors were subsequently determined by a *post hoc* Tukey's HSD test (Quinn and Keough, 2002). Across the study, horticultural varieties were used as species for richness calculation. Richness and management practices were both indicators of agrobiodiversity.

FIGURE 3
Urban and peri-urban gardens in Querétaro City, Mexico categorized by **(A)** family or private backyard gardens, **(B)** community gardens, **(C)** didactic school gardens and **(D)** commercial market gardens. Photos by *G. Villavicencio*.

3 Results

3.1 Agrobiodiversity results

3.1.1 Species richness and productivity

In terms of species richness, the most diverse gardens cultivated up to 86 plant varieties and achieved between 5 to 7.5 kg/m^2 of overall production (Figure 4).

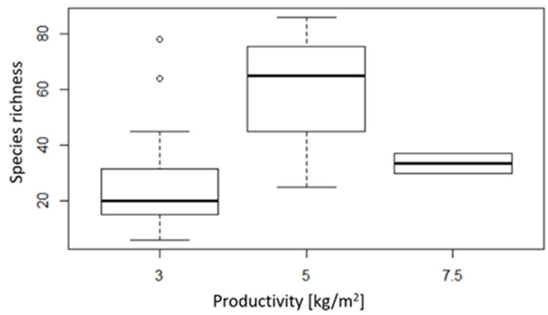

FIGURE 4
Species richness vs. productivity (3, 5, and 7.5 kg average per square meters) in Querétaro City, Mexico.

Location and management were the most important factors in species richness, with urban gardens having higher and significant richness differences (W = 0.86377, value of p = 0.007404) than peri-urban gardens (W = 92,503, value of p = 0.5094). This was mostly due to the non-commercial focus of the urban garden and the cultural adaptations depending on their food preferences and origins. More specifically, urban sites managed with agroecological practices were shown to enhance the species richness (ANOVA value of p 1.71e-05*** *post-hoc* Tukey test HSD; Kruskall-Wallis of group differences chi-squared = 15.558, df = 3, p = 0.001397 and a Pairwise comparison using Dunn's test for multiple comparisons of independent samples value of p of 0.0009) as compared to conventional management (Figure 5). Overall, gardens with approximately 200 m^2 registered the highest biodiversity richness and rated considerably high in productivity.

Species richness was higher in the medium-sized gardens (200 m^2) of middle-class gardeners than in high-income or large commercial gardeners. Of special relevance is the fact that urban gardens with the highest productivity were not the most agrobiodiverse. Production showed a stronger relationship with location (higher productivity in peri-urban areas) than with management (Figure 6).

The total productivity of the urban gardens in the study, which covered a total of 6,984 m^2, was approximately 36,000 kg wet mass per season. We conservatively estimate that this is the equivalent nutritional intake of 6,050 kg of proteins (168.51 proteins per gram), 161,487.19 Kcal of energy (4,498 Kcal of Energy per gram), 34, 957.41 kg of carbohydrates (973.69 per gram), and 5,428.382 kg of fats (151.2 fats per gram).

FIGURE 5
Species richness per Location (left), Richness per Management (middle), and Richness vs. Location and Management (right) where P denotes Peri-urban; U, Urban; A, Agroecological; and C, Conventional.

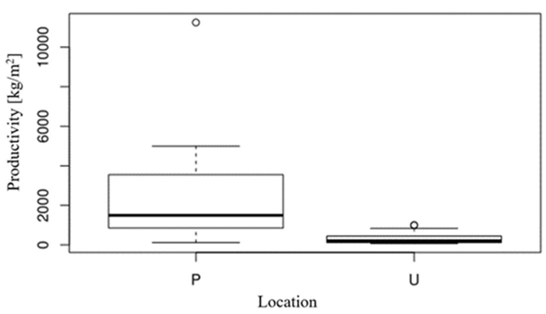

FIGURE 6
Productivity vs. Location (P, Peri-urban; U, Urban) and Management (A, Agroecological; C, Conventional) showing significant differences per location in Querétaro City, Mexico.

3.1.2 Agrobiodiversity composition

Using the Importance Value Index (IVI) described above, of the 142 horticultural varieties identified in the study, the key horticultural varieties were: *Capsicum annuum L.* (Chili 7.6/300%), *Aloe* sp. (*Aloe vera* 6.9/300%) and *Beta vulgaris* var. *cicla* (Chard 6.1/300%). The most common plant families where Solanaceae, Laminaceae, and Asteraceae, followed by Apiaceae, Rutaceae, and Rosaceae. We separated IVI values for trees, shrubs, and herbs. Even though the production of mushrooms was reported, they were not included in the list.

For herbs, vegetables, and annual crops, the most relevant IVI value indexes were *Aloe* sp. (*Aloe vera* 6.9/300%), *Beta vulgaris var. cicla* (Chard 6.1/300%), *Lactuca sativa L.* (Lettuce 24.1/300%), and *Coriandrum sativum* (Coriander 8/300%) (Figure 7).

The highest IVI value indexes for shrubs (Figure 8) were *Opuntia ficus-indica* (Prickly pear 43.1%/300), *Capsicum annuum L.* (Chilli pepper 30.4%/300), and *Rosmarinus officinalis* (Rosemary 21.2%/300).

The most relevant IVI value indexes for trees (Figure 9) were *Carica papaya* (Papaya 24.5/300%), *Persea Americana* (Avocado 23/300%), and *Prosopis laevigata* (Mesquite 18/300%).

Biocultural Food Systems, as reported in Nabhan (2020), restore the broad diversity of wild and cultivated plants once found in ancestral diets, such as prickly pear species that dominate the extensively managed *nopaleras* in Arid America, in the fluctuating border of Mesoamerica and Arid America. The present study shows that in the arid landscape of Querétaro City, *Salvia, Aloe,* and *Opuntia* and genra reported the highest IVI Values. The CAM succulents *Aloe* and *Opuntias*, which exhibited the highest IVI values, are drought-tolerant species that have evolved from ancestral diets. This suggests that these food plants could serve as a foundation for climate-resilient food security when cultivated in perennial-dominated polycultures. This approach can contribute to the restoration of land health, particularly in terms of enhancing the soil moisture retention capacity of *Prosopis laevigata* and drought-tolerant or polyphenolic shrubs. Additionally, it can reduce the overall water consumption of crops and provide stability in yields, even in the face of climatic uncertainties (Nabhan et al., 2020).

3.1.3 Agroecological management survey results

Using the Diagnostic Survey of Agroecological Practices (Table 1), we classified 83% of the gardens as agroecological, and 17% as conventional.

Figure 10 illustrates survey results by garden, using an example of three gardens for the agroecological group and three gardens for the conventional group. Nutrient-loss prevention and water and soil conservation were the most important variables differentiating the two groups (Figure 10).

Most agroecologically managed sites practiced composting for soil conservation. Some did contour planting (only in some peri-urban areas), increased vegetation, mulching, integration of flowers and borders to promote pollination and beneficial insects, intercropping, crop associations, and efficient use of water such as using Tlaloque water treatment systems[13] or collecting it from kitchen areas as gray watering. The use and availability of appropriate technologies for efficient recycling and collection of biomass and water were greater in commercial gardens. Limiting factors most often mentioned by urban gardens were the lack of compost, management skills, and seeds and local varieties, followed by lack of space, insecure land tenure, water costs, and pest presence.

In the community garden *El Huerto del Buen Comer* located in Menchaca III, the economically most disadvantaged garden in the present study, no water irrigation reached the area by the time of the study. The neighbors used to buy waterpipes on communal basis of

13 Tlaloque is an ingenious rainwater harvesting system developed by a non-profit that is helping the most marginalized communities in Mexico City and nearby cities to have access to clean water.

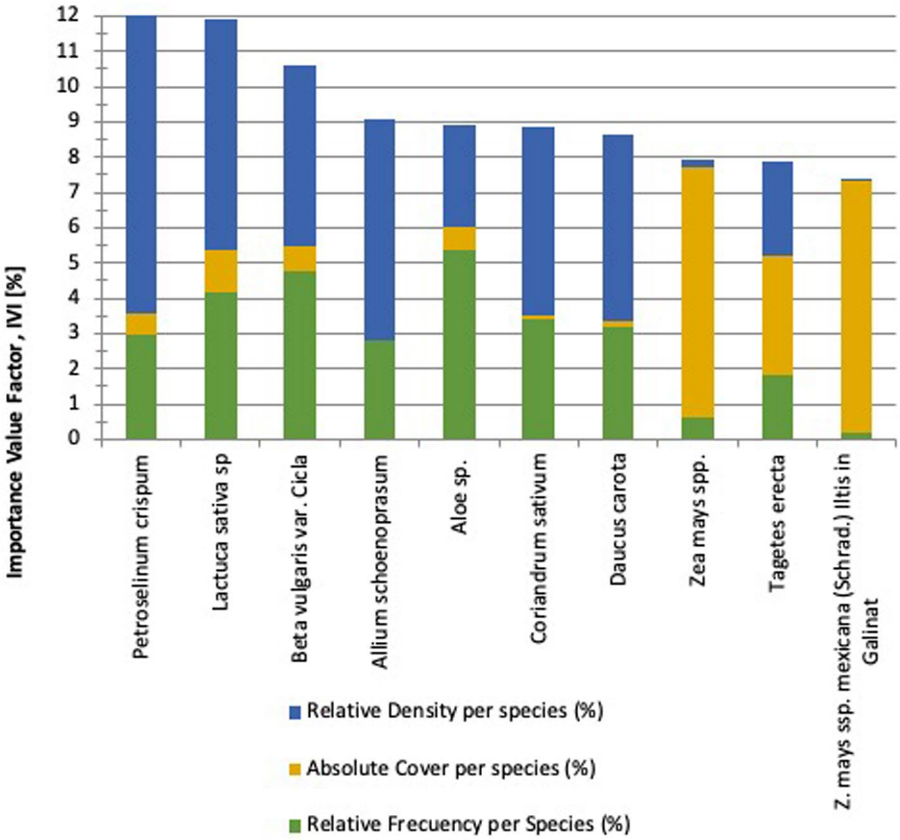

FIGURE 7
Highest IVI value indexes reported for the main variety of herbs, vegetables, and annual crops.

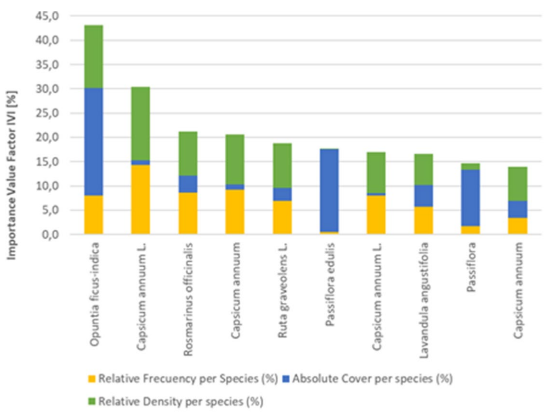

FIGURE 8
Highest IVI value indexes reported for the main varieties of shrubs.

cooperation. The water was stored using low-cost practices as much as possible, such as using PET bottles to cover sprouts to reduce water evapotranspiration and enhance soil moisture.

3.2 Demographics of urban farmers

In our study of 28 urban gardens, 18 urban farmers were women and 10 were men. The preliminary results were shared and validated on 8 March 2017 over a dinner organized and called *De urbicultor a urbicultor* (from urban farmer to urban farmer). Of the 34 attending gardeners, 29 were asked to bring something they harvested from their garden. We collected the harvested vegetables on a previous afternoon and they were cooked by a local chef interested in ancestral cuisine. The dinner took place in the home garden of a local wheat-producing peri-urban farmer and social leader. The age of respondents ranged from 20 to 69, with a mean of 45 for women and 35 for men. Urban farmers were more educated than the state's schooling average of 10.5 years, which is equivalent to a little more than the first year of high school (INEGI, 2020) with 67% of the female respondents and 60% of the male respondents having a bachelor's degree. The idea of food access was particularly relevant for Menchaca's garden, which was the only one under a community-based organization and which has been replaced by a police station. Of the women sampled, 20% held a graduate degree, which is a high-level degree in terms of formal education. Furthermore, 90% of the male gardeners were employed outside the home. For women, an equal number (39%) were employed outside the home, and inside the home, with jobs ranging from flexible, independent jobs and projects to informal jobs done while parenting. Overall, nearly 61% of *urban growers* were women between the ages of 40 and 49, with more than 15 years of formal education. Despite high levels of formal education, only nine gardeners indicated that they felt comfortable with, and knowledgeable about, horticulture.

3.3 Socioeconomic characterization of urban gardens

The main difficulty during sampling was to develop trust with the garden owners for them to allow us to enter their houses. In Mexico there are few front yards, so we needed to cross the whole house to have access to the plots. We visited mostly owned or leased backyards, with the exception of Menchaca's community garden in a vacant lot that has since been taken over by the municipality in order to build a Police Control Station, to reduce the neighborhood insecurity, on top of rich soil.

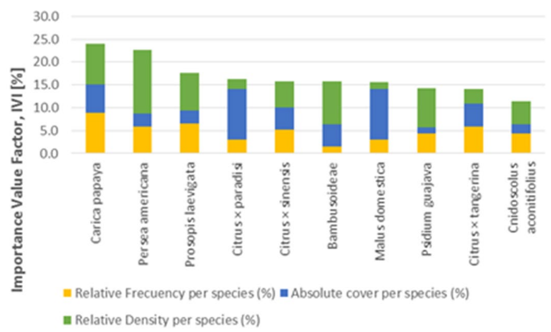

FIGURE 9
Highest IVI value indexes reported for the main varieties of trees.

For descriptive purposes, we categorized the 28 urban and peri-urban gardens (UPA) based on Orsini's adaptation Orsini et al. (2013) of Moustier and Danso's (2006) socio-economic typology. In total, 18 gardens were categorized as *small-scale agriculture*. They were urban, less than 100 m^2, and operated with self-consumption as the main objective. Of these, 90% were operated by women. Two gardens were categorized as small-*scale commercial agriculture*, located in urban and peri-urban areas on less than 1,000 m^2, and operated by both men and women for small-scale income generation. Four sites, operated by men in peri-urban areas on more than 2,000 m^2 for income generation, were classified as *agriculture businesses*. Four peri-urban gardens of more than 5,000 m^2 were categorized as *non-specialized agriculture* (Table 1).

The 28 urban and peri-urban gardens analyzed in our study were highly complex and heterogeneous systems. Food production practices consisted of raised beds, biointensive beds, double digging beds, vertical gardens, planting directly in soil, in pots, on green roofs, in backyard gardens, on street sidewalks, in vacant lots, and in municipal parks. Half of the urban gardens (14 of 28) were primarily

TABLE 1 General typology of socio-economic profiles of urban and peri-urban gardens of Querétaro City.

Socioeconomic profiles of urban farmers, based on Orsini et al. (2013)				
	Small-scalle agriculture	Small-scale commercial agriculture	Agriculture business	Non-specialized agriculture
Number of identified gardens	18	2	4	4
Location	Urban	Urban and peri-urban	Peri-urban	Peri-urban
Product's destiny	Self-consumption	Urban markets	Urban and export markets	Self-consumption and urban markets
Main objective	Self-consumption	Small-income generation	Main income or part-time	Self-consumption and small-income generation.
Classification by objective	Family gardens, communitarian, commercial and school gardens.	Commercial and communitarian gardens	Commercial urban gardens	Family gardens
Adaptations by allocations	Directly on the ground, biointensive double digging, raised beds, vertical, green roofs, public roads, vacant lots, municipal parks, pots and reused containers.	Municipal vacant lots, roads, city parks, biointensive double digging, shaded plots.	Raised beds, on the ground growing, greenhouses.	Directly on the ground.
Size	<100 m^2	<1,000 m^2	>2,000 m^2	>5,000 m^2
Products	Vegetables, flowers, fruits and chickens.	Vegetables, prickly pear, flowers, chickens, rabbits, sheep and milk.	Vegetables and flowers, chickens, turkeys, pigs, sheep, horses and aquaculture.	Corn, beans, fruits, flowers, legumes, tubers, pumpkins and prickly pears.
Technology appropriation level	Low	Low to middle	Middle to high	Very low
Gender	Women	Both	Men	Both
Limiting factors	Lack of compost and seeds, pest control (aphids, molluscs, gastrophods and grubs) land size and access.	Land size, land access, insumes, lack of agroecological intensive knowledge, local market prices, fluctuations.	Technological knowledge, market prices fluctuations.	Lack of agroecological intensive knowledge and strategies for water and soil regeneration.

Categorized based on Orsini's adaptation Orsini et al. (2013) of Moustier and Danso (2006).

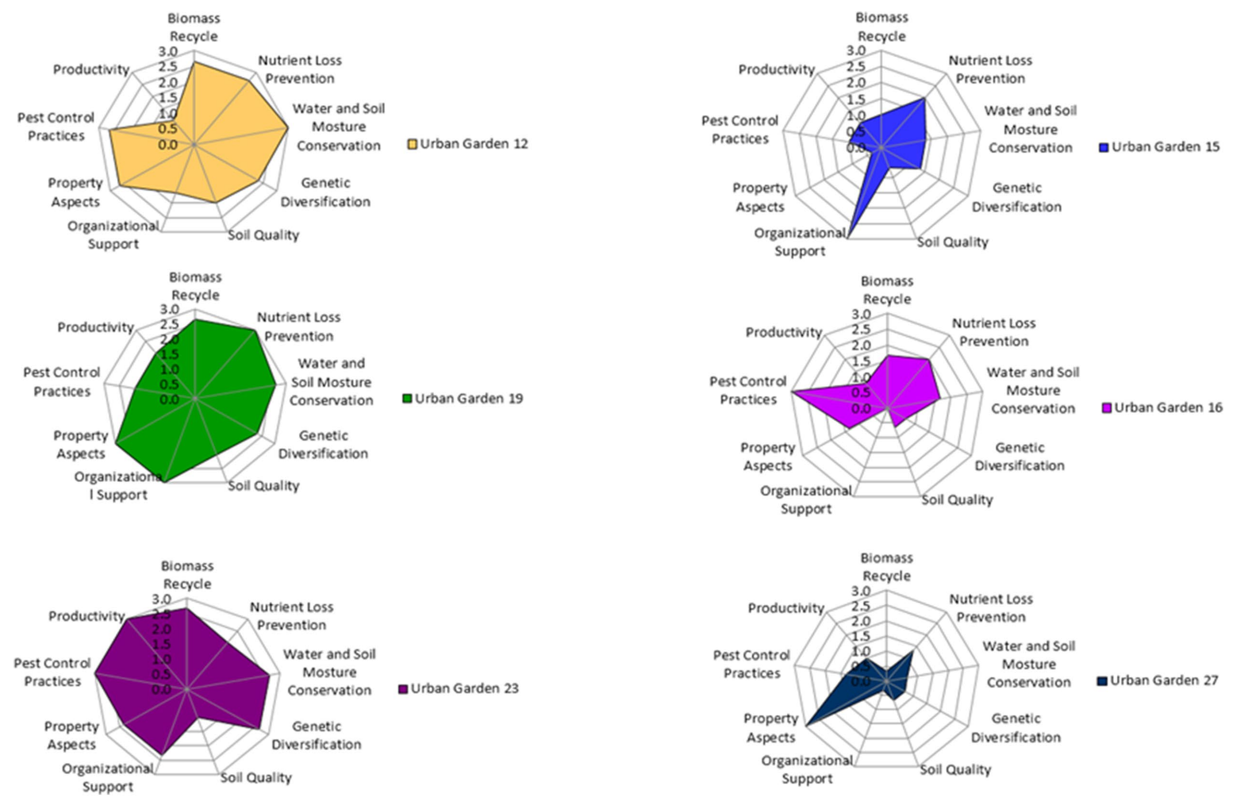

FIGURE 10
Management survey results by example gardens, where cumulative >12/24 points was considered agroecological management (Left group) and < =12/24 points conventional management (Right group).

used for self-consumption or household-level food self-sufficiency. Other uses were commercial (7), didactic/learning (4), and recreational (3) (Figure 11).

While most of the self-consumption plots were founded in high-income areas, Menchaca's "*Huerto del Buen Comer*" was located in a low-income, high-risk, and marginal area (Metropoli, 2013). Commercial gardens were generally located in peri-urban areas except for "*Bioleta Café*," located in an urban residential area. All commercial gardens were able to pay employees. It is important to note that, even though most urban farmers were women, most urban farmers with the "economically active population" status were men. This is due to the preponderance of commercial sites in peri-urban locations that were managed by men. Nearly 86% of the gardens in the study were community-based, meaning that they were financed and operated by their members with no additional state programs or funding provided. Only four of the 28 cases, or 14%, depended on civil-association funds or governmental support. One result of this is that secure land access and tenure were a major concern for respondents, as community-based gardens were informal and at risk of displacement or dispossession due to urban development. In addition to insecure land tenure, urban gardeners mentioned other limiting factors, including the lack of compost, management skills, seeds, and local varieties, followed by a lack of space, high costs for water, and the presence of pests.

Our GPS investigation indicated that rainfed fields appear to be atrophying or disappearing due to the recent urban sprawl and water scarcity. Our findings also show that hotspots of agrobiodiversity (Figure 12) coincided with high socioeconomic development (levels B and C+) and describe a hierarchical structure in the capacity to access certain goods and lifestyles (AMAI, 2008).

Considering that most of the urban gardens in this study are not located in low-income areas, it is important to highlight the key distinctions of gardens located in low-income areas. These distinctions encompass factors like land tenure and the vulnerability of leases, both in gentrified areas and in cases of State expropriation, as exemplified by the case of *El Huerto del Buen Comer.* Ensuring food security is not a main objective of most of the cases represented in this study due to the fact that the participants are more likely to already have diverse diets through purchasing food and being more socio-ecologically resilient due to their ownership of larger green spaces and potentially higher literacy profiles. Nevertheless, these *urbicultoras* are more engaged in cultural processes of biocultural recognition, native farming or renewed domestication, foraging cacti revival, learning to process local food options, and improving the diversity of their dooryard gardens to value the cultural use of foods and beverages.

4 Discussion

4.1 Urban agroecological practices provide agrobiodiversity

Agricultural management significantly impacts the ecological composition of agrobiodiversity across urban locations. In our study,

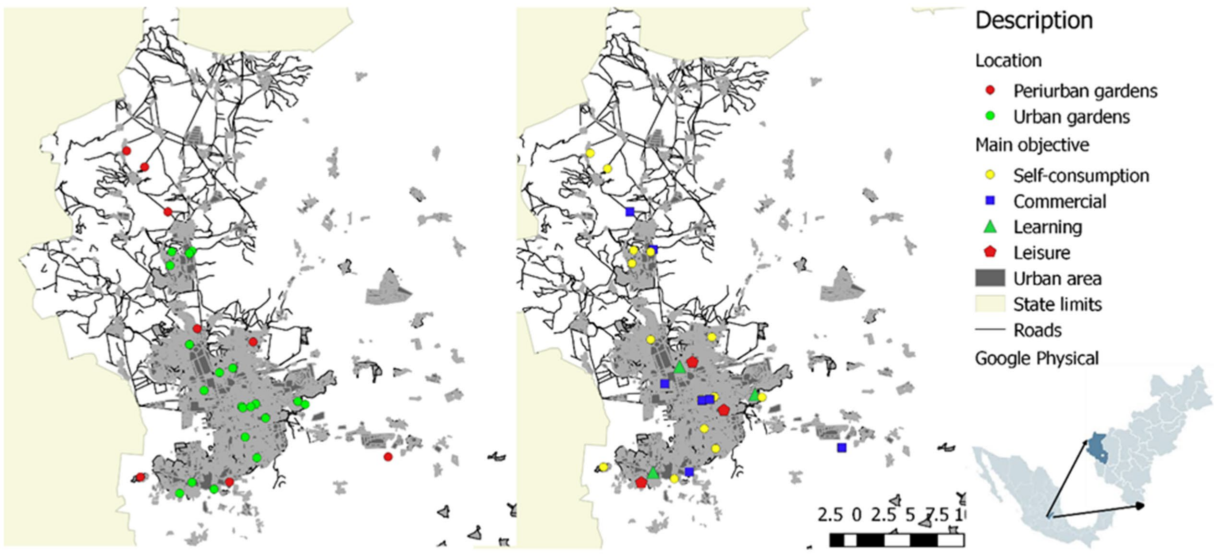

FIGURE 11
Distribution of gardens per location (urban = red circle or peri-urban types = green circle; Left side) and main purpose (self-consumption = yellow circle, commercial = blue square, learning = green triangle, and leisure = red pentagon; Right side) in Querétaro City, Mexico.

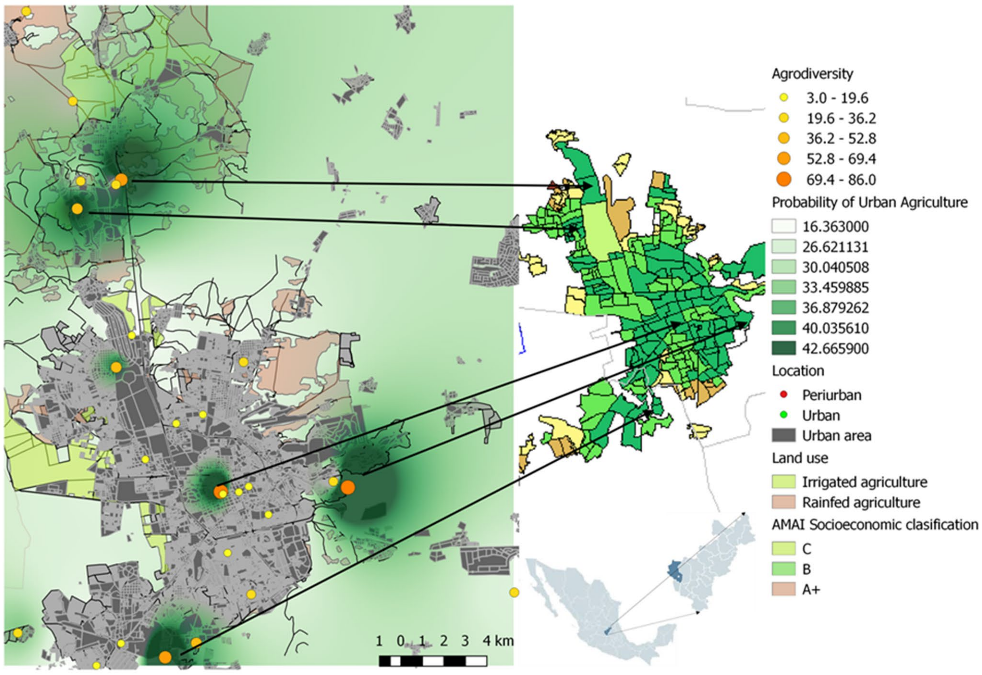

FIGURE 12
Agrobiodiversity (hotspots) interpolation of species richness within the 28 urban gardens per socioeconomic units in the Metropolitan (A+ High-income class, C Middle class and D+ Low middle class and D Low class and E Lowest class) Area of Querétaro City, Mexico. AMAI Data source per AGEB, INEGI (2022).

urban sites managed with agroecological practices demonstrated enhanced species richness, which is essential for building resilience in food and farming systems. Productivity, however, was significantly higher in peri-urban locations, where species richness was lower. In Querétaro, average production in urban gardens ranged between 5 and 7.5 kg/m^2. In Cuba, in contrast, the range is 10–20 kg/m^2 (Companioni et al., 2001; Ortiz et al., 2001; Hernández et al., 2005; Vázquez-Moreno, 2007). This difference might be related to both precipitation (Querétaro is a dryland area, while Cuba is not), and to the *organopónico* agroecological management of the Cuban case. *Organopónico* refers to community-led low-input systems in which producers plant in beds, plots, or covered areas. Most often this takes place in vacant lots or spaces where there are no urban buildings, patios, or gardens, and is usually of small scale up to 100 m^2 (Nicholls et al., 2002). The main difference is that *organopónico* systems were the result of a historical process led by the Cuban state's political will and policies and its *Campesino a campesino* methodology to guarantee food production in the cities (Ortiz et al., 2001; Machín, 2010).

The present study provides explorative data on urban farming and agrobiodiversity in Querétaro, undertaken in part to inform further research and policymaking on urban agriculture and socio-ecological resilience. Based on surveys and interviews with urban farmers, the study also reveals some of the vulnerabilities of urban and peri-urban farming. Several respondents mentioned land tenure as a major concern for the permanence of garden sites. Indeed, the rising cost of land leases and land speculation are often neglected aspects of urban agriculture even though they can fuel gentrification and marginalize the space for food production, especially for lower-income people (Mougeot, 2000; Schupp and Sharp, 2012; McClintock et al., 2016).

In our study, gardens of 200 m^2 registered the highest species richness and rated considerably high for productivity. These traits contribute both to providing diversified diets and promoting complexity and redundancy (the latter being among the principles of agroecological resilience) in the urban ecosystem. Moreover, the urban gardens rated higher in richness than peri-urban gardens, mostly due to their non-commercial focus which enabled the *urban farmers* to plant a variety of crops. Often these were more associated with crops related to their subjective life stories or to biocultural memory than with yield or market-led productivity. Current leasing costs in Querétaro might limit the further spread and scaling-up of agroecology to only middle- and upper-class citizens within the city. The two exceptions in our study of urban agriculture in downtown Querétaro were only possible because the leasers could still afford a low, almost-frozen rent for large properties with enough space to cultivate. Other marginalized gardens in Menchaca III, the most insecure zone in the city (due to gangs according to interviewed cab-drivers; El Universal de Querétaro, 2013, 2017), did not experience the same luck. This was the case of "El Huerto del Buen Comer," the only community garden found in the study that was initiated by a centralized municipality of Querétaro, and progressively self-governed using an organizational culture inspired by Liberation Theology Pedagogy in the 1970s. Not long before the publishing of this study, the municipality dismantled this community garden, which had been creating and co-evolving the biocultural memory in a variety of food collective-cooking activities and restoring the social fabric. The municipality did so with the aim of gaining more control and security of the neighborhood by building a Police Station on top of long-managed fertile soil and a safe public oasis for sociocultural restoration. These kinds of displacements – whether by private or state forces – disempower the idea that people may actively and cooperatively protect their local ecosystems and strengthen the fragile communities as the base of their livelihoods (DeLind, 2001; Martínez Alier and Roca, 2013).

The urban garden represents a heterotopian place that delineates social space where the potential for "something different" exists (Harvey, 1979, 2013; Lefebvre, 2014). In the context of urban farming, this "something different" signifies that through food production, consumption, preserving and practicing biocultural traditions, and ensuring municipal support, the transition to community-based food systems can be promoted, concurrently fostering socio-ecological resilience. Because of its highly complex and heterogeneous nature, urban agriculture can help to improve food access, enhance agrobiodiversity, conserve energy in the rural–urban relationship, create purposeful jobs, and contribute to overall urban community health and wellness. To bring about a transition to agroecological *urbicultural* systems, it is necessary to identify agroecological principles that allow for biodiverse, resilient, energy-efficient, socially just urban projects and a bottom-up strategy for locally based food and energy production (Altieri, 1995; Gliessman et al., 1998; Mougeot, 1999; Holt-Giménez and Patel, 2012; Marasas, 2012). However, this potential to change the "everyday life of the city" is only attainable when the people who build and maintain that everyday life are able to exercise their rights to live in that city (Harvey, 2013). For instance, urban land tenure as a common good could incentivize the emergence of more community garden initiatives (Federici, 2013). We must be careful that these heterotopian places are not absorbed by dominant practices, such as gentrification driven by real estate development. In the case of Querétaro, and in cities more broadly, urban agriculture depends on affordable and secure land tenure, i.e., the main factor that can foster resilience through time. Looking forward, further cultural drivers should be considered to understand the dynamics of urban agrobiodiversity in Querétaro's metropolitan city.

4.2 Resilient, biocultural-systems based, and affordable access to food in the Latin-American, semi-dryland, and medium-sized city of Querétaro, Mexico

Our study shows that urban and peri-urban agroecological practices enhance agrobiodiversity in a semi-dryland city. Enhanced agrobiodiversity is a baseline requirement for creating more resilient food systems. Furthermore, the appearance of highly heterogeneous and complex urban gardens within the urban system has the potential to reactivate the ecological interaction of a diversified genetic pool of plant species which is intrinsically linked to human management. This interaction over centuries has been described as domestication, made possible through socialization and axiological priorities such as exchanging seeds and the continuation of common codes of biocultural memory. Independent of public policies, the marginal and heterogeneous design of urban farming in Quéretaro is creating a baseline ecosystem function for resilience. This is vital to sustain the landscape matrix of the food and farming systems we depend on. Compared to the 209 species reported by Whitney et al. (2017) in the drier peripheral semi-evergreen Guineo-Congolean rainforest, and the 340 species of edible plants – higher in urban than in rural areas – documented in Tucson, Arizona, a UNESCO City of Gastronomy (Nabhan et al., 2017), we documented the agroecological management of up to 86 crop varieties in plots of approximately 200 m^2 and a total of 142 species in Querétaro, a semi-arid city that is experiencing both extensive urban sprawl and water conflicts.

This article suggests that emerging urban farming practices need to be further characterized. An action-research agenda should consider the following. (1) Urban agroecological management practices in Querétaro city have been shown to enhance agrobiodiversity. (2) Gardens of approximately 200 m^2 showed the highest agrobiodiversity, representing a reasonable size for city planners, landscape designers, and policymakers to address food sufficiency. (3) Diversified gardens promote complexity in the urban ecosystem by harboring a biodiversity richness of up to 86 different crops per site. They produce on average between 5 to 7.5 kg/m^2 of horticultural crops. (4) The three key and most frequent species resulting from 142 total landraces were chili, *aloe vera*, and chard. In the interviewed sample, nearly two-thirds of the urban farmers were formally educated women between 40 and 49 years old, and over 85% had no municipal support. (5) Urban gardens with the highest productivity were more significantly associated with location (higher productivity in peri-urban than in urban areas) than with management, demonstrating that private family or backyard gardens (Orsini et al., 2013) were the most agrobiodiverse due to the biocultural memory associated with the urban farmers.

This case study aims to inform policymaking regarding adaptative governance through urban agroecology. The crop richness found in Querétaro's semi-dry garden ecosystems confirms that endogenous solutions may be available thorough sharing local knowledge and practices, while activities such as the *De urbicultor a urbicultor dinners* should be further stimulated and engage both practitioners and scientists. These ideas enable a practice of deliberative democracy that is needed to change daily practices and build the capacities to produce strategies for public affairs (Habermas, 1989; Niemeyer, 2022). At the producer level, agrobiodiversity may not be related to income and social status but rather to a deeper network of significance between culinary traditions and biocultural memory. Due to the fact that higher agrobiodiversity was present in medium-sized and middle-class or high-income gardeners with culinary traditions, further research will require in-depth patterns of biocultural heritage, local network interconnectedness, and land tenure.

Across much of Latin America, temperature thresholds and drought are beginning to limit the production of most maize and bean varieties (Stiller et al., 2021), and the extremely high summer temperatures are causing the abortion of flowers and fruits (Nabhan, 2013). As most of Mexico's population now dwells in hot, dry climates and the arid food-producing landscapes dominate 60% of the national territory (Pontifes et al., 2018), clearly, food production and diets in the "new climatic normal" will have to employ a set of food crops different from and far more diverse than those currently employed in conventional agriculture (Nabhan, 2020). Besides this, the use of biocultural food systems based on native farming practices reinforces cultural identity.

Identifying key players for an agroecological transition and local efforts that are already underway in the city – along with key challenges, such as land access and tenure – is critical to understanding the impacts, scope, and qualities of current and emerging processes (Right to Food-UN, MDG 1 and 7, 2016). Furthermore, collecting and reporting primary data on the occurrence and contributions of urban agriculture to food sovereignty and urban biodiversity are urgently needed. While the urban poor, especially those coming originally from rural areas, have practiced horticulture as a survival strategy, the sector remains largely informal and usually precarious in Querétaro. Besides citizens' emerging self-organized efforts, municipalities need to realize the possibilities of nurturing small urban farming cultures and local ecological knowledge while becoming drivers of social inclusion and violence reduction. To do this, securing long-term access to land is essential. Recognizing the environmental and social justice initiatives already taking place in the urban context – whether they are formal participants in food sovereignty movements or informally operating in line with agroecological principles like the participants of this study – and listening to their voices and needs, could inform a cultural shift that diminishes violence, builds an alternative future of social inclusion and community cohesiveness, improves public health and well-being, and promotes landscape urban resilience.

5 Conclusion

From our study, it follows that further ecological analysis of crop diversity across a wider range of urban gardens is necessary. Due to the lack of geographic information regarding urban gardens of food growers, we relied on a sampling method that biases low-income areas, where crop diversity and cultural appropriation might be underrepresented by the scope of the present study. There is potential sampling bias towards middle- and higher-income areas, and therefore there is a need to further research low-income areas to better understand patterns of biocultural food systems appropriation, as well as the revival, continuity, and change of diets. As a recommendation for decision-makers, further peer dialog should be promoted by municipal programs and policies directed at urban agriculture. We think that it is important to cross-pollinate agricultural practices through interaction between people with different socio-economic backgrounds. In order for the social fabric to be restored, biocultural food systems need the interaction and exchange of advice between *urbicultores*, especially regarding water and soil management, integrated pest management control, and crop diversification.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Comité de Bioética, Facultad de Ciencias Naturales, Universidad Autónoma de Querétaro. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

GV-V contributed to the formal study and survey design, data analysis, writing of the paper, and design of graphics, and conducted field implementation of the survey with primary advising from HS-A. GV-V and JJ both authors contributed to the research article and approved the submitted version. MS contributed with formal analysis. MA contributed to the conceptualization. All authors contributed to the article and approved the submitted version.

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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.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1066428/full#supplementary-material

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