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Adoption and desirable characteristics of Information and Communication Technologies for urban small-scale food producers in South Africa

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Small-scale food producers can benefit significantly from the adoption and effective utilization of Information and Communication Technologies (ICTs). For example, ICTs can help improve food production and access to markets, which is particularly valuable in many Sub-Saharan African countries that both urbanize rapidly but whose food systems still rely significantly on small-scale food producers. This study examines the adoption patterns and desirable characteristics of ICTs, as well as the factors influencing them, among small-scale food producers engaged in urban agriculture in South Africa. We administered 85 in-person surveys through referrals from local producers' network in disadvantaged areas of Cape Town (n = 21; Gugulethu, Philippi, Khayelitsha) and Johannesburg (n = 64; Central Business District, Soweto, Orange Farm). A substantial proportion of the respondents articulated the need for food-related mobile applications with functions that facilitate price comparisons, and the sharing of best practices and health advice. User-friendliness, low internet data use, and affordability were perceived as the most important characteristics for such food-related mobile applications. Redundancy analysis (RDA) reveals that the socioeconomic and demographic characteristics of respondents significantly influence the desired functionalities of food apps and their preferred activities among the respondents. Producers that are married and have more children, have higher income and education, and own larger land holdings, show very distinct patterns in terms of desirable functions and uses for food apps. Our research underscores the need for comprehensive approaches to the development and promotion of food-related ICTs when targeting small-scale food producers. The barriers and needs identified here can help ICT developers, development agencies and policy-makers design fit-for-purpose interventions and policies to facilitate ICT adoption among urban small-scale food producers in rapidly urbanizing areas.

KEYWORDS

urban agriculture, smallholders, small-scale farmers, digitalization, sustainable food systems, food security, livelihoods, Sub-Saharan Africa

1 Introduction

1.1 Urban small-scale food production in Sub-Saharan Africa

Small-scale food producers[1] are the backbone of the agricultural sector across Sub-Saharan Africa (Gassner et al., 2019), accounting for most of the food production (Giller et al., 2021). Small-scale food production is essential for the livelihoods and food security of most rural population in the region (Gollin, 2014), as well as many food producers that still operate in urban and peri-urban areas (Vidal Merino et al., 2021). At the same time, Sub-Saharan Africa is the fastest urbanizing region in the world (Githira et al., 2020). Urban food security has been emerging as a major development challenge for the 21st century (Crush and Frayne, 2011), especially as the COVID-19 pandemic clearly showed (Gebeyehu et al., 2022). With urban diets rapidly changing across the region, many urban households increasingly rely on unhealthy, unaffordable and unsustainable diets (Barker et al., 2021). In particular, urban diets increasingly rely on ultra-processed and frozen food, which is imported and accessed through major supermarket chains, ultimately having a negative effect to traditional small-scale food production systems, including those operating within cities (Djurfeldt, 2015; Battersby, 2017; Ahmed et al., 2022).

Urban agriculture[2] sits at this confluence of urbanization and food system transformation. On the one hand it has been a vital source of food in many Sub-Saharan African cities, including for the emerging niche market for locally grown vegetables (D'Alessandro et al., 2018; Ahmed et al., 2022). On the other hand, it is predominately practiced by small-scale producers operating in very diverse spaces such as backyard home gardens, community gardens and open spaces (Tevera, 2022) in inner cities (intra-urban agriculture) and urban peripheries (peri-urban agriculture) (Van Veenhuizen and Danso, 2007). A large portion of these small-scale urban food producers sell their output to low-income consumers in informal markets (Vorley, 2013), while others cater organic products to richer consumers (Coulibaly et al., 2011; Kini et al., 2020). This growing demand of affluent urban consumers on locally-sourced organic vegetables presents new market opportunities for urban small-scale food producers (Orsini, 2020), but the competition with larger producers (especially large international supermarket chains) hinders their market entry (Grebitus, 2021; Ahmed et al., 2022).

Many studies have acknowledged the positive effects of urban agriculture for food security and livelihoods, especially for the urban poor (Zezza and Tasciotti, 2010; Poulsen et al., 2015). For example, urban agriculture can contribute to sustainable and resilient local food systems, especially in the context of growing urban populations and accelerating climate change (Mougeot, 2015; Moustier and Renting, 2015). However, the viability and sustainability of some urban agriculture practices has also been debated (Badami and Ramankutty, 2015; Weidner et al., 2019). As a result, innovative approaches such as vertical farming, rooftop gardens, and community-supported agriculture (CSA) are explored,[3] as they can both improve the performance of urban agriculture systems but also offer several co-benefits (Specht et al., 2014; Orsini, 2020).

Despite their crucial role, small-scale food producers face numerous challenges, including in urban settings. Challenges include limited access to resources/markets/technologies/capital/credit, inability to undertake proper quality control and complex logistics, as well as vulnerability to market volatility (Chagomoka et al., 2017; Ricciardi et al., 2018; Lowder et al., 2021). Other common challenges include reliance on low-quality inputs, declining soil quality, exploitation from suppliers/traders/money lenders, and vulnerability to pests/diseases, weather events and climate change (Makate, 2019; Woodhill et al., 2020). This limited access to resources and these compounding vulnerabilities often marginalize them from decision-making processes (Benedek et al., 2021), and puts them at a disadvantage when competing in the increasingly globalized and distorted food marketplace observed in many Sub-Saharan African cities (Woodhill et al., 2020).

Various technological, economic and policy responses have been proposed to address such challenges facing small-scale producers in Sub-Saharan Africa, including in urban food systems. Examples include new technologies for food production and marketing, improved access to credit and financial services, extension services and training, the promotion of sustainable agricultural practices, and the enhancement of market linkages (Tambo and Mockshell, 2018; Bizikova et al., 2020; Mizik, 2021; Sarr et al., 2021; Wadumestrige Dona et al., 2021). Participatory approaches that engage small-scale food producers in the design and implementation of such responses can be very effective in achieving such positive outcomes (Pamuk et al., 2015; Sergaki and Michailidis, 2020; Sachet et al., 2021; Doherty et al., 2023).

1 According to FAO (2018a) small-scale food producers can be defined as those whose cultivated land size, number of livestock and/or annual economic revenue from agricultural activities fall in the bottom 40% of the respective cumulative distribution at national level. UNEP (n.d.) characterizes small-scale food production as relying on low asset base, operating in small plots (<2ha), experiencing structural constraints (e.g., low access to resources, technology, and markets), struggling to be competitive, and having limited resource endowment compared to other farmers in the sector. Khalil et al. (2017) use the terms "smallholder" and "small-scale farmer" synonymously, stating that although "smallholder" refers more to tenure and "small-scale producer" refers more directly to production levels, the two refer to very similar entities. Acknowledging this slight difference, for the remainder of the paper we use the term "small-scale food producer."

2 Van Veenhuizen and Danso (2007) define urban agriculture as "the growing of plants and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, processing and marketing of products." Acknowledging similarities and slight differences with other terms such as "urban farming," for the remainder of the paper we use consistently the term "urban agriculture."

3 Vertical farming involves crop production in vertically stacked layers or on inclined surfaces (often indoors), achieving very high levels of productivity and low resource use. Rooftop gardens are unused rooftop spaces converted into green areas for food production, and the provision of benefits for urban biodiversity, air quality, and human wellbeing. CSA entails partnerships between local food producers and local food consumers, where subscribers (consumers) receive a portion of the harvest from the producers.

1.2 Information and Communication Technologies for food systems transformation

Information and Communication Technologies (ICTs) are a particularly promising technological option to improve small-scale food systems in Sub-Saharan Africa (Onyeneke et al., 2023). Collectively ICTs refer to any method of electronically sharing or storing data, including telephones, mobile broadband, the Internet, broadcasting, sensor networks, and data storage and analytics (FAO, 2018b). ICTs can improve information search capabilities and augment both the quality and quantity of accessible data, thereby reducing ambiguity and improving productive activities and market engagement (Bertolini, 2005).

On the production side, ICTs have facilitated access to agricultural advice, climate information, and extension services (Hlophe-Ginindza and Mpandeli, 2021). In particular, smartphone technology has afforded new ways of communicating information in interactive and multimedia formats (Harris and Achora, 2018), helping small-scale food producers make suitable decisions by accessing better market information (Hoang, 2020). Moreover, ICTs can facilitate the adoption of sustainable agricultural practices, such as precision farming and climate-smart agriculture, by providing farmers with access to information, decision support tools, and monitoring systems (Antle et al., 2017; Klerkx and Rose, 2020).

On the marketing side, ICTs can empower small-scale food producers to better participate in modern food value chains and markets (Aleke et al., 2011; Krone and Dannenberg, 2018). For example, access to real-time market information helps small-scale food producers make informed decisions about what to produce, when to sell, and at what price (Courtois and Subervie, 2015). Furthermore, ICTs can enable small-scale food producers to connect directly with buyers, reducing transaction costs and improving their bargaining power (Nakasone et al., 2014). For example, digital platforms, such as e-commerce and mobile money services, can enhance market access and financial inclusion for small-scale food producers (Agyekumhene et al., 2018). Additionally, ICTs can support the development of innovative business models, such as farmer cooperatives and agri-food e-commerce, which can help small-scale food producers overcome challenges related to economies of scale and market access (Berti and Mulligan, 2016; Alam et al., 2023), income diversification (Leng et al., 2020), increase farm productivity (Chandra and Collis, 2021), and enhance food security (Ayim et al., 2022).

However, many of the introduced ICT solutions targeting small-scale food producers in Sub-Saharan Africa have failed to achieve sustained positive impact. For instance, most such ICT solutions have relied on basic messaging services, which have a limited ability to boost commercialization as they simply broadcast standard market pricing information (Fafchamps and Minten, 2012). Conversely, many of the more promising advanced ICTs have tended to focus on large-scale food producers, often overlooking the unique constraints of small-scale food producers (Klerkx et al., 2019). Other complementary ICT solutions, such as helplines and advisory services, have frequently struggled with high maintenance expenses and continuous upgrading requirements to address evolving threats (e.g., pests, climate change) and user feedback (Baumüller, 2018).

Studies have identified three main reasons behind such failures. First, is the techno-centric design assumptions of many ICTs that overestimate user digital literacy, resources, and access to smartphones and reliable internet, which is generally not the case for small-scale food producers. Second, is the lack of long-term viability and credible pathways to scale beyond scattered pilot trials (Baumüller, 2018; Chandra and Collis, 2021), sometimes due to their limited geographic coverage that cannot account for the diversity of contexts facing small-scale food producers across regions (Trendov et al., 2019). Third, is the insufficient institutional backing (Aker et al., 2016; FAO, 2018c).

Arguably, at the heart of this situation lie the persistent digital inequalities between large- and small-scale food producers (Mushi et al., 2022; Revenko and Revenko, 2022). This raises concerns on whether increased digitalization will be inclusive for small-scale food producers (Lajoie-O'Malley et al., 2020), considering their multiple constraints to ICTs adoption such as the high costs for using mobile phones, mobile network problems, and limited ICT skills (Hoang, 2020). Such constraints might force low-income users (a) opt out of services requiring additional payment for accessing information, (b) decide not to invest additional funds in services that do not clearly convey the benefits, or (c) require intermediaries to mediate trust and enable successful credit transactions through digital platforms (Agyekumhene et al., 2018; Harris and Achora, 2018). Taking all of the above into consideration, Weidner et al. (2019) argued that if not designed well, urban agriculture initiatives supported by ICTs may primarily benefit affluent consumers and entrepreneurs, while excluding marginalized groups and reinforcing existing power structures.

Various strategies have been proposed to address these challenges and ensure inclusive and equitable benefits from ICTs, such as investing in digital infrastructure and literacy, developing context-specific ICT solutions, and promoting multi-stakeholder partnerships (Deichmann et al., 2016; Tsan et al., 2021). Moving forward, future ICT initiatives for small-scale producers must carefully diagnose localized barriers, priorities, and digital literacy skills to design appropriate solutions (Roberts and Hernandez, 2019). These efforts will benefit tremendously from the sustained involvement of end-users in iterative ICT co-design and evaluation (Akinnuwesi et al., 2013; Koukou and Dekkers, 2024), as well as other relevant stakeholders such as extension services, policymakers, and consumers (Steinke et al., 2019; Alfonsi, 2024). Such participatory approaches can have significant positive outcomes for ICT design and adoption, and reduce digital divides (Chipidza and Leidner, 2019; Ortiz-Crespo et al., 2020). The success of such efforts would further benefit from (a) the proactive role of the government in facilitating the involvement of different stakeholders, and (b) the development of localized implementation frameworks to support the ICTs adoption and deployment (Smidt and Jokonya, 2022).

1.3 Knowledge gaps and research aims

Considering the above, there are significant gaps in the academic literature exploring the adoption and use of ICTs by small-scale food producers, including in urban settings. First, we lack a comprehensive understanding of their preferences, needs, skills, and capabilities to adopt and utilize ICTs, as well as effectively develop their skills and customize ICTs to meet their unique needs (Eitzinger et al., 2019; Mushi et al., 2022). This is particularly true in developing countries (Landmann, 2018). Second, the perspectives of small-scale food producers are often not taken into consideration when designing ICTs for them (Chizema and van Greunen, 2023), which may result in ICTs that are not fit-for-purpose or do not meet their needs, affecting their sustained adoption (Aleke et al., 2011). Third, to maximise the potential of ICTs for small-scale food producers, it is crucial to understand how to address the more systemic factors influencing digital inequalities. Specifically, for Sub-Saharan Africa, more research is needed to identify how to remove the barriers of poor infrastructure, ineffective policies, and low level of ICT skills (Ayim et al., 2022). These three research gaps are especially prevalent in emerging and developing countries. While these research gaps are widespread across developing settings, examining them in a specific context can provide valuable insights.

South Africa is an ideal context to understand ICT adoption patterns among small-scale food producers, especially in urban contexts. On the one hand, South Africa has the most productive, modernized, and diverse agricultural sector in Sub-Saharan Africa (International Trade Administration, 2021), is highly urbanized with two thirds of the population living in urban areas (Bakker et al., 2020), and ranks 3rd in Sub-Saharan Africa in terms of ICT penetration on the ICT Development Index (International Telecommunication Unit, 2017; Malanga and Simwaka, 2021). On the other hand, urban agriculture is still very prevalent in the major cities, meeting many of the livelihood and nutritional needs of poor urban residents (see Section 2.1). However, this happens in a post-apartheid context marked by an increase in social inequality (Nthane et al., 2020), making South Africa the most unequal country in the world (World Bank, 2022). Moreover, the South African food system experiences multiple sustainability challenges (Termeer et al., 2018; Sobratee et al., 2022), with the large (and predominantly black) majority of small-scale food producers still waiting for further government efforts to correct the injustices of the apartheid era (Siebert, 2020).

In this context, emancipatory initiatives that employ digital technologies to confront existing inequalities and promote alternative visions of agriculture, emphasize the political nature of digital agriculture (Hackfort, 2021). The South African ICT Research, Development, and Innovation roadmap highlights the use of ICTs to improve agricultural production, specifically assisting small-scale food producers oriented towards commercial markets to contribute to food security, exports and mitigating environmental impacts (Department of Science and Technology, 2013). ICTs are regarded as crucial for development (Anwar, 2019) and are critical enablers for knowledge management for poverty eradication (Fombad, 2018). Arguably, understanding how South African small-scale food producers perceive and use ICTs, and the factors that influence their choices can assist in designing ICT tools that effectively aid in sustainable livelihood and food security strategies. Furthermore, understanding the challenges related to ICT adoption and use for small-scale food producers can aid policymakers and development agencies in developing policies and intervention strategies to enhance ICT adoption for pro-poor agricultural activities. Beyond South Africa, such insights can be relevant for other rapidly urbanizing and digitalizing Sub-Saharan African countries that still largely rely on small-scale food producers.

The aim of this study is to understand the adoption patterns and desirable characteristics of ICTs, as well as the factors influencing them, among small-scale food producers engaged in urban agriculture in South Africa. We achieve this through in-person surveys with 85 small-scale food producers in different areas of Johannesburg and Cape Town. Section 2 describes the data collection and analysis methodology. Section 3 presents the main ICT adoption patterns, their desirable characteristics and the factors affecting user perspectives. Section 4 identifies critical areas for improvement at the interface of small-scale food production and ICT adoption in South Africa, and Sub-Saharan Africa more broadly.

2 Methodology

2.1 Study area

As in this study we seek to understand the challenges for current ICT use/non-use and the desirable characteristics and functionalities for future ICT tools for resource-constrained small-scale food producers (Section 1), we focus on such producers engaged in urban agriculture in the cities of Johannesburg and Cape Town. These cities represent two major conurbations in South Africa, with Johannesburg being the most populated and fastest-growing city, and Cape Town being the second most populated city in the country (Abrahams et al., 2018). Both cities are considered economic and technological hubs. Johannesburg is the largest economic hub and most densely urbanized area (Risimati and Gumbo, 2018), while Cape Town, labeled as 'the digital gateway to Africa' has seen significant investments in digital infrastructure and a center point for digital startups (Antenucci and Tomasello, 2022). Internet use rates are higher in such primary cities and lower in secondary cities and rural areas in South Africa (Lembani et al., 2020), and Sub-Saharan Africa more generally (Githira et al., 2020).

Importantly for this study, both cities have a vibrant urban agriculture sector that includes many small-scale food producers. Urban agriculture has emerged as a vital coping mechanism and safety net for many poor urban residents in the face of persistent unemployment and food insecurity. An array of small-scale food production activities unfolds across the intricate patchwork of urban agriculture spaces in South African cities, ranging from backyards and community gardens to school plots and unused public land (Tevera, 2022). While often small in size, such cultivated pockets integrated within neighborhoods provide vital sustenance and livelihood opportunities for residents (Figure 1). In particular, recent scholarship underscores the invaluable role of urban agriculture in addressing food access deficiencies and enhancing resilience for low-income households in Johannesburg and Cape Town (Kanosvamhira, 2019; Olivier, 2019; Atlink and Hart, 2023). For instance, urban agriculture spaces such as farms, community gardens, and homestead plots make meaningful nutritional and livelihood contributions in townships across metropolitan Cape Town (Battersby and Marshak, 2016). Likewise, in the Greater Johannesburg area, small-scale food producers cater to food insecure urban residents through farmers markets, informal trade, and other networks (Bbun and Thornton, 2013). Beyond fulfilling subsistence needs, urban agriculture also unlocks prospects for poverty alleviation, job creation, community-building, and youth engagement in these cities (Kanosvamhira, 2019).

Additionally, there are signs of ICT adoption, as well as a diverse mix of markets (e.g., informal markets, farmers' markets, supermarkets of various sizes) with links to small-scale food producers engaged in urban agriculture in the two cities. In more detail, there are many sites dedicated to urban agriculture across Johannesburg, including in the informal settlements (Atlink and Hart, 2023). Furthermore, there has been significant support for urban agriculture within Cape Town for

FIGURE 1
Urban agriculture site in Cape Town.

very long time (Rogerson, 2010 in Kanosvamhira, 2019) and the sole city in South Africa that has implemented an urban agriculture policy (Olivier and Heinecken, 2017, in Kanosvamhira, 2019). Finally, urban agriculture in both cities has been significantly strengthened through the support of government agencies, non-governmental organizations, and citizen-led urban greening initiatives (Cilliers et al., 2020). This support has been instrumental in establishing urban agriculture in numerous areas across both cities and is possibly linked to the adoption of ICT tools by many small-scale food producers.

At the same time food insecurity is a major challenge for many urban residents in the two cities. More than 40% of urban households in Johannesburg are food insecure (Atlink and Hart, 2023) and approximately 68% of households are severely food insecure in selected township areas of Cape Town (Battersby, 2011; Hunter-Adams et al., 2019). In such highly food insecure urban settings, urban agriculture could help markedly enhance food security (Vidal Merino et al., 2021), as well as job creation, poverty alleviation, community-building, public health, education, and economic empowerment (Olivier, 2019; Kanosvamhira, 2023).

For this study we focus on exactly such underprivileged areas within Johannesburg (Johannesburg Central Business District, Soweto, Orange Farm), and Cape Town (Gugulethu, Philippi and Khayelitsha) (Figure 2). Encompassing the Central Business District, Soweto, and Orange Farm, the Johannesburg area is a bustling metropolis of approximately 4.8 million residents, with a slight male predominance, and about 33.3% of the population not attending any educational institution (5 to 24 years) (Statistics South Africa, 2022a). Despite grappling with food insecurity affecting many urban households, this region has emerged as a dynamic epicenter for urban agriculture, demonstrating its potential in bolstering food security, fostering job creation, alleviating poverty, and nurturing community development. Urban agriculture is a thriving practice in Cape Town's areas of Gugulethu, Philippi, and Khayelitsha, where it serves as a vital lifeline in addressing the food insecurity faced by many people, while also contributing to public health, education, and economic empowerment. The city of Cape Town, home to approximately 4.8 million residents, is marked by a female predominance of 51.7% and 31.2% of the population (5 to 24 years) not engaged in any educational institution (Statistics South Africa, 2022b). This region, grappling with socio-economic challenges such as poverty, low-income distribution, high unemployment rates, and various social issues, underscores the critical role of urban agriculture in these communities.

2.2 Data collection

In total 85 surveys were collected from small-scale food producers engaged in urban agriculture between 28 February and 18 March 2019. Of these, 64 were located in Johannesburg, specifically in Johannesburg Central Business District (19%, $n = 16$), Soweto (22%, $n = 19$), Orange Farm (34%, $n = 29$). Twenty-one respondents were located in Cape Town, specifically in Gugulethu (9%, $n = 8$), Philippi (7%, $n = 6$), and Khayelitsha (8%, $n = 7$).

To access the urban agriculture communities in the two cities, the research team identified key informants in each study area that provided information pertaining to local small-scale urban agriculture initiatives. These key informants connected the team with lead farmers, specifically those holding leadership roles among their peers due to experience, reputation, or formal appointment. As community liaisons proficient in English, these lead farmers introduced the research team to other local small-scale food producers. Thus, a snowball sampling method was

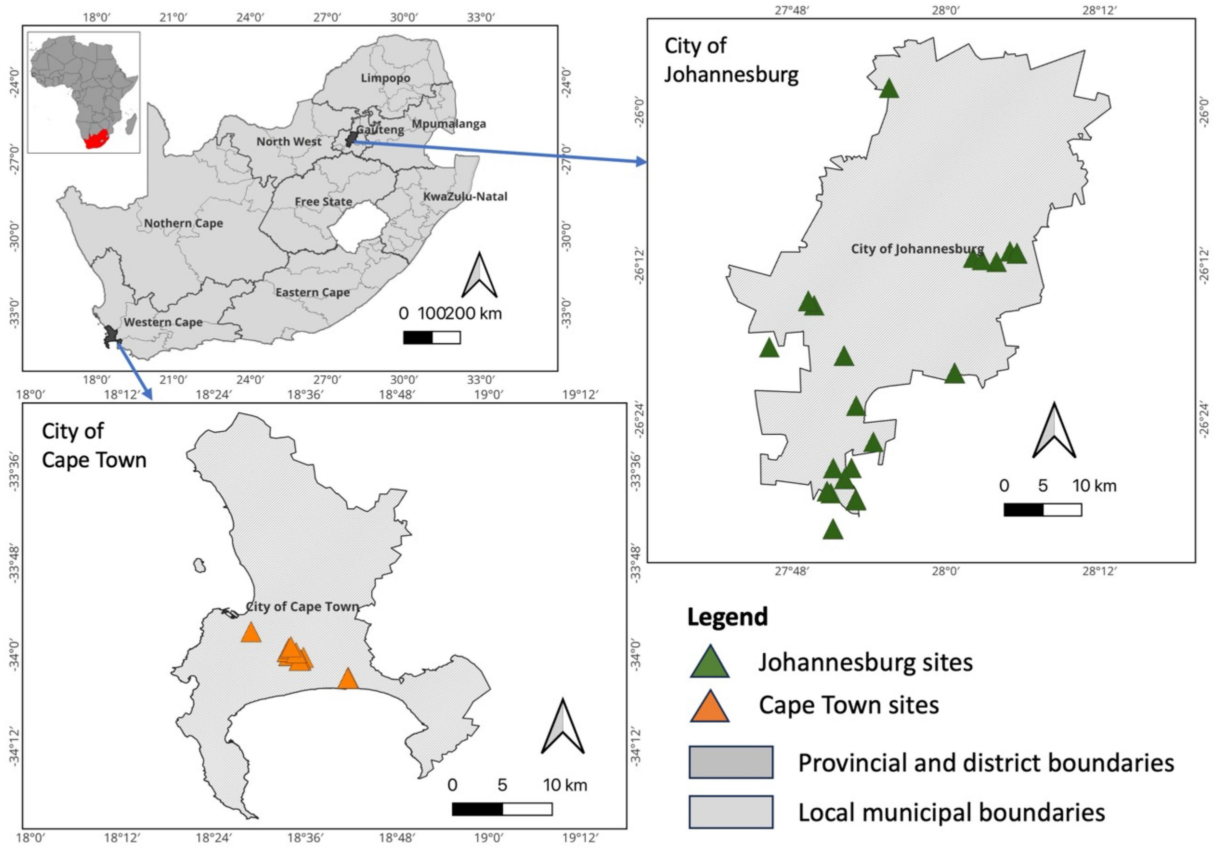

FIGURE 2
Study sites in the Gauteng and Western Cape provinces.

employed to identify additional potential respondents through these referrals. During the initial interviews, respondents were asked to recommend other local small-scale food producers who could potentially participate in the study. These respondents were then contacted and also invited to suggest other respondents, allowing researchers to gradually build up a sample through referral chains.

Several on the ground realities dictated the adoption of this snowball sampling approach for respondent identification. First, there was no comprehensive list containing all small-scale food producers engaged in urban agriculture in each study area, thereby precluding the possibility of using proportionate or randomized sampling from lists. Second, other respondent identification and randomization techniques such as transect walks were deemed as unfeasible due to safety and security concerns, and general wariness of local residents to outsiders considering the high criminality within the study site areas. Despite some methodological concerns and limitations (see Section 4.5), many scholars have argued that snowball sampling can prove highly effective in accessing hidden or hard-to-reach populations (e.g., Gray, 2014; Kammerer et al., 2019), often requiring collaboration with gatekeepers (whether individual or organizations) that facilitate this process. Furthermore, snowball sampling can foster trust among respondents, especially in contexts where respondents can be cautious to external entities (Bonevski et al., 2014), as has been the case in our study areas. For such reasons, several studies have adopted snowball sampling approaches for similar surveys in small-scale food production contexts in Sub-Saharan Africa (Barau and Oladeji, 2017), including urban agriculture (Brown et al., 2020).

Data was collected through a structured, face-to-face, and paper-based survey consisting of predominantly closed-ended quantitative and semi-quantitative questions divided into four sections: (a) producer socioeconomic and demographic characteristics, (b) agricultural production and practices, (c) adoption and use of smart devices, (d) actual adoption and use of mobiles and apps (ICTs) for food production and sale, as well as preferences and attitudes towards food apps. The few open-ended questions were intended to capture qualitative insights to complement the quantitative and semi-quantitative data. However, the overall approach centered on the standardized survey instrument (see Supplementary material for the full survey). The survey was written and administered in English, as this is the working language in South Africa. In case some respondents struggled with understanding certain questions, the local lead farmer accompanying the research team (see above) clarified those questions in Zulu, Xhosa and Sotho, depending on the primary language of the respondent.

Lastly, the Ethics Review Committee of the University of Tokyo confirmed that this research study did not require ethical review in accordance with the governmental research ethics guideline in Japan ("Ethical Guidelines for Life Science and Medical Research Involving Human Subjects), and "The University of Tokyo's Research Ethics Regulation." Informed consent was obtained orally from participants after explaining the purpose of the survey and assuring them of their anonymity.

2.3 Data analysis

All data was manually digitized, entered an MS Excel (Version 16) spreadsheet to generate descriptive statistics and then imported into R (Version 2022.07.2) for further analysis. First, descriptive statistics were used to summarize respondents' socioeconomic, demographic and farming/food production characteristics, as well as the use and desirable characteristics of ICTs (Section 3.1–3.2).

Regression analysis was used to assess the strength of relationships between a series of dependent variables and independent variables (Corporate Finance Institute, 2022). As dependent variables we used "smartphone use," "confidence in smartphone use," "daily internet use" and "food app use" (Section 3.3.1). As independent variables we used various socioeconomic and demographic factors such as age, education level, number of children, land size and income (Section 3.3.1).

Redundancy analysis (RDA) was used to summarize the linear relationships between multiple dependent and independent variables in a matrix (Xia, 2020). In the RDA figures provided in Section 3.3.2, arrows are used to depict the relationships between dependent (outcome) variables and independent (explanatory) variables. The length of an arrow signifies the strength of the relationship, with longer arrows indicating a stronger correlation with the dependent variable. The direction of an arrow, on the other hand, represents the nature of the relationship. An arrow pointing towards the dependent variable suggests a positive relationship, while an arrow pointing away implies a negative relationship. For the RDA analysis in Section 3.3.2 we used as dependent variables the desired functions, and the desired uses for food apps identified in Section 3.2. As independent variables we use the socioeconomic and demographic variables used in the association analysis (Section 3.3.1). The statistical significance of the Redundancy Analysis (RDA) was assessed using R and a permutation test with 999 permutations. This test was conducted under a reduced model incorporating response and explanatory variables. The anova function was utilized to compare the full model against a reduced one and to ascertain the significance of each constrained axis. p-values for each axis were subsequently calculated. Any canonical axis from the RDA yielding a p-value less than 0.05 was deemed statistically significant.

Supplementary Table S1 contains the explanatory independent variables and the outcome dependent variables used for the regression analysis (Section 3.3.1) and the RDA (Section 3.3.2).

2.4 Positionality statement

As researchers, we recognize that our own backgrounds and experiences inherently shape the lens through which we approach a study. It is thus pertinent to articulate our positionality. The first author is a white male Italian national who has lived and worked for over a decade in South Africa as an academic on the topic of ICT for development. The second author is a woman of Indian heritage who is a South African national and has worked as an academic specializing on sustainability science in her native country. The third author is a white male Greek national with no living experience in South Africa, but extensive experience conducting similar empirical research across Sub-Saharan Africa.

The first co-author possesses both extensive in-country expertise on ICT research and teaching hundreds of undergraduate students on ICT, as well as an external vantage point that comes from not being a native South African. The second co-author lends crucial knowledge and direct experience with the on-the-ground cultural, social, political, and economic realities in South Africa, as well as through an academic network that facilitated access and trust-building. The third co-author has extensive experience in designing, conducting and analyzing >20 large-scale surveys on food production and nutrition in rural and urban contexts of nine countries in Sub-Saharan Africa. In summary, this complementarity has enabled the research team to bring both insider and outsider perspectives that enrich research design, data analysis and interpretation, and reduce possible biases to the extent possible.

3 Results

3.1 Household characteristics

Table 1 contains summary statistics for the sample. In summary, 49% of participants are female and 51% are male, with their average age being 47 years old. Most participants (78%) have children, with an average of 2.16 children per producer. In terms of education, 60% of producers have not completed high school, 26% are high school graduates, 12% have an undergraduate degree and 2% have a graduate degree.

All participants are considered small-scale food producers, with 27% allocating <100 m^2 (0.01 ha) of land for cultivation, while 16% >10,000 m^2 (1 ha). Most producers (89%) do not own the land they cultivate, with practically all (97%) of these small-scale food producers accessing the land through a government department. Most of the respondents (82%) did not pay any fees to utilize the land.

All producers cultivated vegetables on their land, and many cultivated maize, fruit, legumes and herbs. Almost all producers cultivate organic products (96%) citing health, safety, and overall wellbeing of the local community as the main reasons to do so. Most producers (69%) earn below USD 800 *per annum* from their produce, followed by 18% who earn between USD 800–1,600, and 5% who earn between USD 1,600–2,400. Finally, most producers (83.5%) sell their produce at farmers markets at least once a week, 11.8% sell once or twice a month, and 2.4% never sell at farmer markets. Regarding sales at supermarkets, most producers (88.2%) do not sell their produce to these markets, while the remainder sell their produce to supermarkets at least once a week (4.8%) once or twice a month (4.8%). Finally, almost all respondents (98.8%) do not sell online, indicating that this type of market is still out of their reach.

3.2 Perceptions and attitudes for ICTs

Approximately 60% of participants own a smartphone. The reasons for not owning a smartphone articulated from the remainder of respondents include inability to afford purchase (44%), lack of knowledge how to use a smartphone (15%), feeling too old to own a

TABLE 1 Household characteristics.

Variable	Fraction
Gender	Female: 49% Male: 51%
Marital status	Single: 65% Married: 32% Other: 3%
Children in household	Yes: 78% No: 22%
Education	Did not complete high school: 60% High school degree: 26% Undergraduate degree: 12% Graduate degree: 2%
Cultivated land size	<0.01 ha: 27% 0.01–0.05 ha: 20% 0.05–0.1 ha: 20% 0.1–1.0 ha: 17% >1.0 ha: 16%
Land ownership	Not own cultivated land: 89% Own cultivated land: 11%
Access to land	Through a government department: 97% Other: 3%
Fees for land use	82% Did Not Pay Any Fees
Production of organic products	Yes: 96% No: 4%
Annual agricultural income	<USD 800: 69% USD 800–1,600: 18% USD 1,600-2,400: 5% USD 2,400-3,200: 2% USD 3,200-4,000: 4% >USD 4,000: 2%
Sales at farmers markets	No: 2.4% Sell at least once a week: 83.5% Sell once or twice a month: 11.8% Other: 2.3%
Sales at supermarkets	Not sell: 88.2% Sell at least once a week: 4.8% Sell once or twice a month: 4.8% Other: 2.2%
Sales online	Yes: 1.2% No: 98.8%

smartphone (12%), dislike of smartphone technology (6%), and other reasons including the possibility of smartphone being stolen/lost or lack of interest in the specific technology (23%). Among smartphone owners, 10% spent <USD 1.60 per month, 10% spent between USD 1.60–4.00 per month, 23% spent USD 4.00–8.00 per month, 37% spent USD 8–40 per month, 18% spent USD 40–160 per month, and 2% > USD 160 per month. About 35% of the respondents owning a smartphone stated that they are extremely confident when using their device, 51% that are moderately confident, 10% that are somewhat confident, 4% that are slightly confident (no respondents stated that they are not confident at all). Finally, most producers owning a smartphone reported affordability as the most desirable characteristic (82%), followed by brand reputation (51%), customer assistance (49%), social status (18%), low environmental impact (12%) and being trendy (12%).

Of the 51 producers that use a smartphone, 78% ($n = 40$) actively use at least one mobile application to help them produce and/or sell food. Most common were social media applications such as WhatsApp (98%) and Facebook (50%), with only one mobile application, Khula!,[4] designed especially for small-scale food producers (13%). According to Figure 3A, they actively use the app to specifically learn new information (42%), expand their networks (34%) and marketing (26%) (Figure 3A). When asked about the desirable functions that a hypothetical app should have to improve their food production and/or sales, respondents identified mainly functions for enabling price comparisons (73%), sharing of best practices (73%), and obtaining health tips (67%) (Figure 3B). When asked about the desirable characteristics that a hypothetical app should have to improve their food production and/or sales, respondents identified ease of use (86%), low internet data consumption (76%), and affordability (67%) (Figure 3C). Finally, when asked about the most desirable activities to use such apps, respondents identified assistance with finding sale points (84%), keeping financial records (84%), cultivating crops (84%), undertaking logistics (73%), and keeping inventory (53%) (Figure 3D).

3.3 Factors associated with ICT perceptions and attitudes

3.3.1 Association analysis

Table 2 present the associations between different demographic and socioeconomic characteristics of the respondents with smartphone use, confidence in smartphone use, daily internet use, and food app use. Education level and land size are significantly associated with smartphone use (Table 2). Age is significantly and negatively associated with confidence in smartphone use (i.e., older respondents are less likely to be confident in smartphone use), while education level is significantly and positively associated with confidence in smartphone use (Table 2). Land size is significantly associated with daily internet use (Table 2), while age has a significant negative association with daily internet use (i.e., older respondents are less likely to use the internet daily). Finally, and interestingly, the number of children is the only variable significantly and positively associated with food app use (Table 2). This might reflect that children might influence parents to actually adopt and use food apps.

3.3.2 Redundancy analysis

Figure 4 outlines the RDA exploring the relationship between socioeconomic/demographic factors (Table 1) and desirable functions for hypothetical food apps among producers (Figure 4). The results suggests that older respondents would tend to prefer app functions that allow them read about product reviews. Conversely, younger respondents would be more inclined to prefer app functions that help

4 Khula! is a mobile app and web-based platform designed to assist small-scale food producers to access the formal marketplace and connect to suppliers (Aguera et al., 2020). The app enables farmers to list their produce, track real-time inventory and meet market demand (Born et al., 2021). Refer to www.khula.co.za.

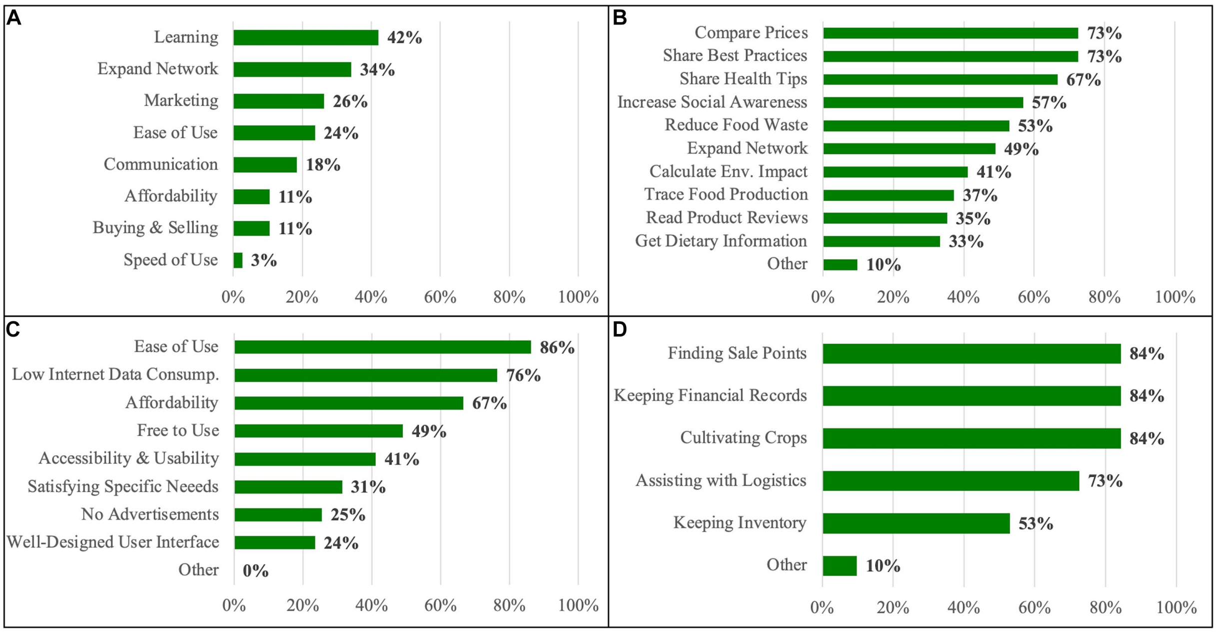

FIGURE 3
Actual uses of food mobile apps **(A)** and desirable app functions **(B)**, characteristics **(C)** and uses **(D)**.

them compare prices, share health information, expand their network, and calculate their own environmental impact. Female and married respondents, as well as respondents with higher levels of education, higher incomes, more children, and larger land holdings would tend to prefer app functions that allow them to access dietary information, share best practices, increase social awareness about food, reduce food waste, and trace food along the supply chain. The RDA indicates a statistically significant association between socioeconomic and demographic factors with desired functions for food apps ($p = 0.04$, from 999 permutations). The first two axes explain 11.08% (8.14% for RDA1, 2.94% for RDA2) of the total variance, and the biplot of the RDA is shown in Figure 4.

Figure 5 outlines the RDA examining the relationship between socioeconomic/demographic factors, with the desired uses for food apps among producers (Figure 5). The results reveal that producers with more children, larger land holdings, that are married, and older would tend to prefer food apps for keeping financial records, cultivating crops, and assisting with logistics. Conversely, male respondents and those with higher levels of education and income would tend to prefer a food app that can assist them with inventory management and finding new customers. The RDA indicates a statistically significant association between socioeconomic and demographic factors with desired uses for food apps ($p = 0.002$, from 999 permutations). The first two axes explain 20.15% (13.7% for RDA1, 6.45% for RDA2) of the total variance, and the biplot of the RDA is shown in Figure 5.

4 Discussion

4.1 Synthesis of main findings

Most participants are relatively old with comparatively low levels of formal education, and do not possess the land they cultivate, which make them heavily dependent on governmental and other forms of support for their agricultural activities. Most producers have adopted organic cultivation methods. These findings reflect the characteristics of small-scale food producers engaging in urban agriculture in South African cities quite well (Bbun and Thornton, 2013; Bisaga et al., 2019; Cilliers et al., 2020; Atlink and Hart, 2023), as well as other parts of Sub-Saharan Africa (Davies et al., 2021; Maina et al., 2023).

A substantial fraction of these small-scale producers engaged in urban agriculture does not use smartphones or similar smart electronic devices. Among those owning and using smart devices, the average monthly expenditure on internet data is considerably high, which aligns well with findings from studies which underscore the elevated cost of internet data in South Africa compared to other developing nations (Gillwald et al., 2018; Venter and Daniels, 2020). In particular, South Africans can spend as much as ZAR 85 (equivalent to USD 5.29) per GB of data, a cost that translates to nearly 4 hours of labor for individuals earning the minimum wage, which is stark contrast to the approximate cost of USD 1.53 per GB in North Africa and USD 2.47 in Western Europe (Harrisberg and Mensah, 2022). According to Gillwald et al. (2018) such high costs of mobile phones and data are obstacles for the adoption and utilization of ICTs in South Africa.

The majority of respondents possessing a smartphone reported using some apps to aid in the cultivation and sale of their produce. Interestingly, with the exception of Khula!, a dedicated food-related app used by few food producers, all other apps were social media platforms (Fawole and Olajide, 2012). However, this can be linked to sub-optimal outcomes among adopters due to lack of development and adoption of dedicated apps for small-scale food producers or the poor-quality information provided in generalist apps (Costopoulou et al., 2016). Most advancements in digital agriculture are geared

TABLE 2 Relationship between socioeconomic and demographic characteristics with smartphone use, confidence in smartphone use, daily internet use, and food app use.

Respondent characteristics	(a) Smartphone use				(b) Confidence in smartphone use				(c) Daily internet use				(d) Food app use			
	Estimate	Std. error	z-value	Pr (>|z|)	Estimate	Std. error	t-value	Pr (>|t|)	Estimate	Std. error	t-value	Pr (>|t|)	Estimate	Std. error	z-value	Pr (>|z|)
(Intercept)	−2.4773	1.8665	−1.327	0.18442	3.74227	0.65602	5.704	1.14E-06****	4.67889	1.0073	4.645	3.49E-05****	−4.9711	3.1085	−1.599	0.1098*
Location province	1.8227	1.3313	1.369	0.17096	0.37493	0.49635	0.755	0.45434	−0.18202	0.76213	−0.239	0.8124	3.0683	2.7476	1.117	0.2641
Location group	−1.2172	0.7579	−1.606	0.10828	−0.14722	0.23890	−0.616	0.54114	−0.08768	0.36682	−0.239	0.8123	−2.5345	1.3671	−1.854	0.0637*
Gender	−0.8995	0.7537	−1.193	0.23270	0.17319	0.21427	0.808	0.42358	0.19602	0.329	0.596	0.5546	0.8960	1.2573	0.713	0.4761
Marital status	0.3292	0.7382	0.446	0.65566	0.00359	0.22059	0.016	0.98709	−0.1294	0.33871	−0.382	0.7044	0.9821	1.7195	0.571	0.5679
Age	−0.4956	0.2858	−1.734	0.08287*	−0.29626	0.09478	−3.126	0.00325***	−0.33443	0.14553	−2.298	0.0267**	−0.7269	0.5319	−1.367	0.1717
Children number	0.3559	0.2603	1.367	0.17155	0.07297	0.08274	0.882	0.38300	0.23838	0.12705	1.876	0.0678*	1.6579	0.6622	2.504	0.0123**
Education	1.6006	0.6802	2.353	0.01862**	0.23172	0.11048	2.097	0.04216**	0.26854	0.16964	1.583	0.1211	1.7658	0.9555	1.848	0.0646*
Income	−0.2234	0.6889	−0.324	0.74571	−0.05669	0.10985	−0.516	0.60856	−0.05811	0.16867	−0.345	0.7322	−0.8045	0.6762	−1.190	0.2341
Land size	0.7363	0.2548	2.889	0.00386***	0.03787	0.05786	0.655	0.51643	0.1999	0.08884	2.25	0.0299**	0.3799	0.3728	1.019	0.3082

Signif. codes: ****p<0.001; ***p<0.01; **p<0.05; *p<0.1.

towards high income countries and large-scale food production, with few tailored for low- and middle-income countries and small-scale food producers (Chandra and Collis, 2021).

Overall, our findings suggest that producers favor ICTs that facilitate the easy access to (and dissemination of) information for pricing comparisons, best practices, and health-related information (Figure 3B). Such functions can be highly valuable to food producers, as according to Eitzinger et al. (2019) their use can enhance crop output and improve farm management by sharing both their successes and challenges with each other (and with experts). Furthermore, respondents identified ease of use, low internet data consumption, and affordability (i.e., low cost for ICT purchase) as the most crucial desired characteristics for food apps (Figure 3C). This is not surprising considering the very low economic status of most respondents, with research indicating that for poor food producers to adopt and consistently use these applications, the associated costs must be kept at a minimum (Qiang et al., 2012; Chandra and Collis, 2021). Additionally, the perceived ease of use and usefulness of technology can significantly impact willingness to adopt it (Wu, 2022).

The socioeconomic and demographic factors mostly associated with the adoption, perceptions, and choice of ICTs (Table 2) include age, education level, and family size (especially number of children). Older respondents are less likely to own a smartphone, and be confident in smartphone and internet use, often citing their lower digital literacy as a key reason for non-adoption (Table 2). Howland et al. (2015), for example, have suggested that older farmers often experience a general sense of anxiety towards using modern ICTs and lack the necessary skills for functions beyond making telephone calls. Similarly, Hoang (2020) have found that the use of mobile phones for fruit marketing was inversely related to the age of farmers. One of the more interesting findings was that the only characteristic significantly associated with actual app use was the number of children (Table 2). Studies have alluded that larger households are more probable to have at least one member that uses some app (influencing the others) (Maina et al., 2023) or that younger and more digitally literate family members can indeed influence older members to adopt ICTs as they can get some initial help for their operation (Winstone et al., 2021; Vassilakopoulou and Hustad, 2023). Additionally, Wu (2022) found that the number of family farm laborers has a significant positive impact on the willingness to adopt ICT technologies.

Producers with more children, higher levels of education and those who are married, are more likely to adopt food-related applications with desired functions to share best practices and acquire dietary information (Figure 4). Furthermore, the number of children and the size of the farm were found to significantly influence the desired use of food apps by producers to cultivating crops, assisting with logistics and keeping financial records (Figure 5). This corroborates the findings of Mittal and Mehar (2016), who found a positive and significant association between the use of mobile phone-based information among farmers and farm size. Similarly, Parmar et al. (2018) discovered that landholding size positively influences farmers' access to ICT systems, while Min et al. (2020) suggest that larger farm sizes encourage the use of smartphones in households. Moreover, Wu (2022) found that family farms with a larger area of arable land were more luckily to adopt new technologies compared to smaller sized farms.

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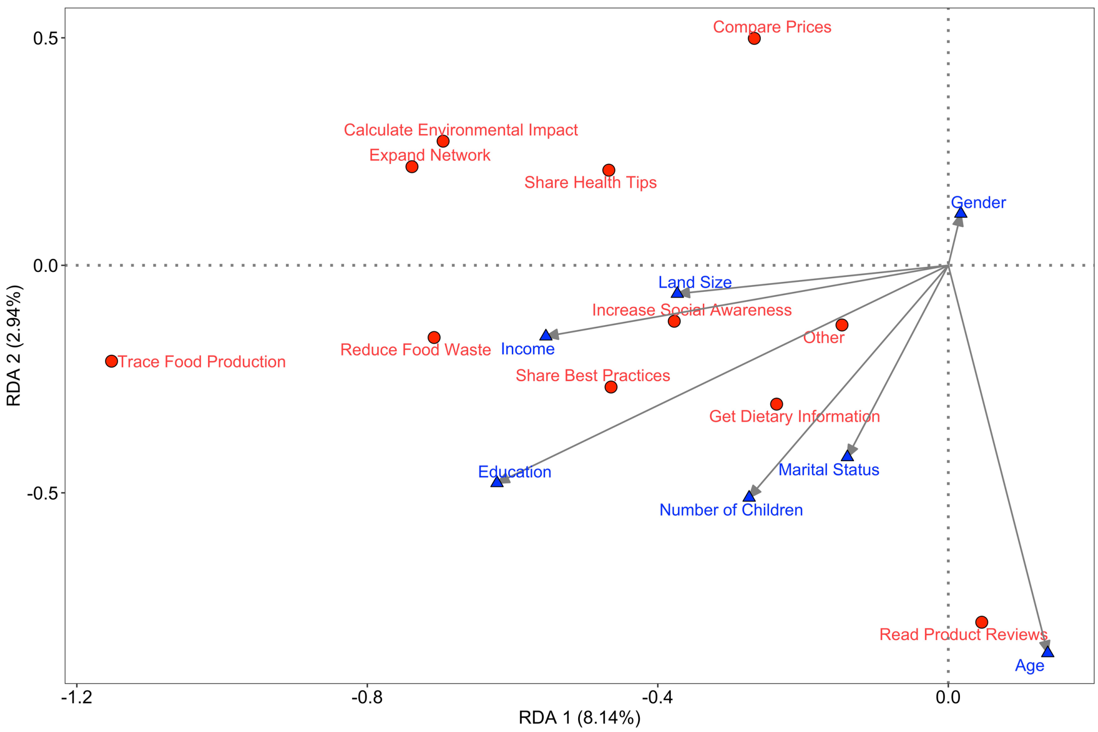

FIGURE 4
Relationship between socioeconomic and demographic characteristics of respondents with desired functions for food apps.

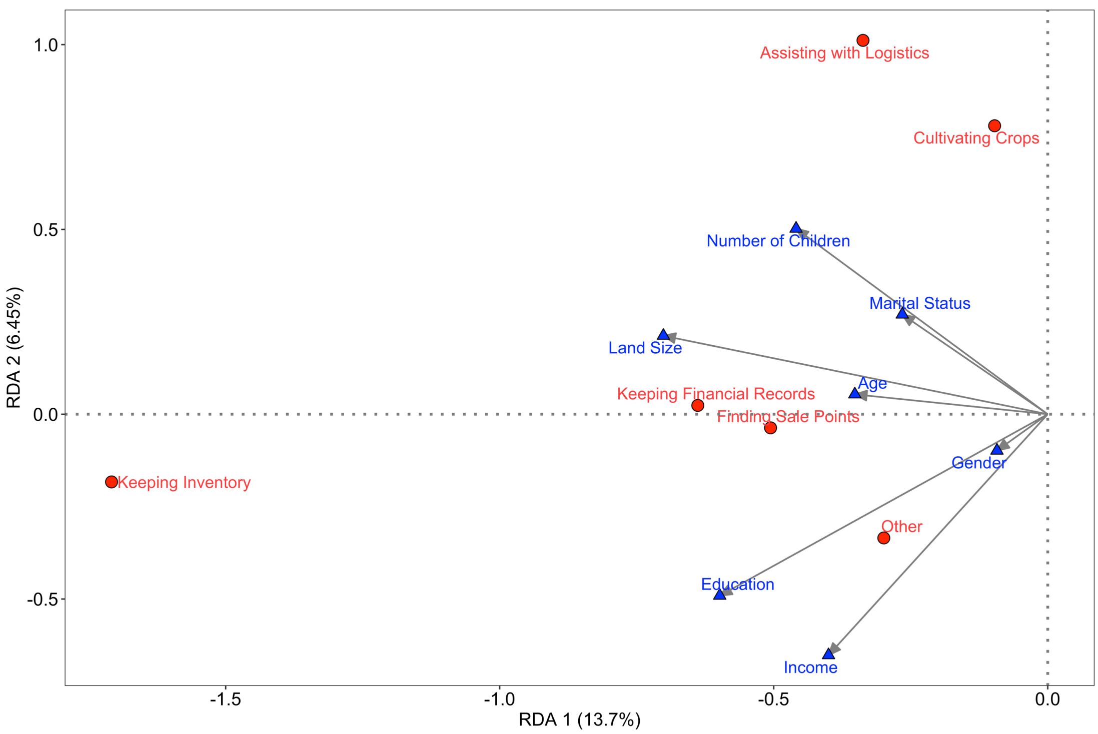

FIGURE 5
Relationship between socioeconomic and demographic characteristics of respondents with desired uses for food apps.

4.2 Comparison with knowledge from other developing countries

The findings of this study align with other research conducted in developing regions that have examined the adoption of ICT by small-scale food producers. For instance, a study conducted by Awuor and Rambim (2022) on the use of ICT for marketing agricultural produce among small-scale food producers in Kenya found that most of these farmers are still using basic mobile feature phones. They suggested that there is a need for capacity building initiatives to help these farmers transition to the use of smartphones.

Similarly, research conducted by Ayim et al. (2022) in Ghana revealed that older farmers are less likely to adopt e-agriculture platforms. They recommended the development of interfaces that are more user-friendly for older users. In Nigeria, a study found that the cost of ICT tools and the lack of a stable electricity supply are the major constraints that farmers face when it comes to using ICTs (Idu et al., 2023).

The importance of app characteristics such as affordability, ease of use, and low data consumption on ICT adoption is also highlighted in research focusing on agricultural development in Sub-Saharan Africa. A review by Baumüller (2018) emphasized that many existing tools have been designed without considering the abilities, accessibility, and actual information needs of small-scale food producers. Therefore, ease of use remains a key criterion for the adoption of these tools. The International Telecommunication Unit (2022) also found that high costs are a major constraint for users of ICT services in Africa, calling for the development of affordable and context-specific ICT solutions.

The findings of this study confirm that collaboration between multiple stakeholders and sustained support from the government are crucial for the successful development and adoption of ICT innovations focused on small-scale food producers. This is supported by studies from Nonet et al. (2022) examining sustainable agriculture development in Africa and Asongu et al. (2020) focusing on ICT, governance, and insurance in Sub-Saharan Africa. These studies highlight the need for focused policies and public-private partnerships (PPPs) for inclusive ICT development in the agriculture sector. In particular, the multi-stakeholder approach aims to ensure that the benefits of ICT reach all farmers, including small-scale food producers, and contribute to sustainable agricultural development.

4.3 Effects of the COVID-19 pandemic on ICT adoption and use

This research was conducted in early 2019, thereby offering insights into the pre-COVID landscape regarding ICT adoption and usage among small-scale food production. Thus, the elicited perspectives and patterns should be viewed with this in mind, considering that the COVID-19 pandemic had profound effects on ICT adoption and use (Plekhanov et al., 2022; Kafi et al., 2023). As outlined in the literature scan below, such effects were also observed on ICT applications in agriculture globally and within rural small-scale food production contexts in South Africa.

For example, multiple studies have found that lockdowns and mobility restrictions compelled food producers to harness digital solutions to sustain operations, access markets, and minimize supply chain disruptions (Kansiime et al., 2021; Alam et al., 2023). For instance, digital tools enabled farmers to pivot to online sales, tap mobile money platforms, benefit from digitally enabled logistics, and access agriculture and market information (Mabhaudhi et al., 2022). In South Africa, there has been some evidence that small-scale food producers have harnessed ICTs as coping mechanisms, with rural communities relying extensively on mobile phones and social media platforms to coordinate planting, access inputs, connect with traders, and engage government support schemes during lockdown periods (Sekabira et al., 2023). However, persistent obstacles like network availability, cost barriers, and sub-optimal content have continued hampering usage and benefits (Ayim et al., 2022).

In a sense, the pandemic necessitated an accelerated uptake of ICTs, serving as an impetus to digital transformation across food systems (Tricarico, 2021). However, it is not clear whether such patterns are observed following the pandemic (Singh and Srivastava, 2023).

4.4 Implications for policy and practice

Overcoming the barriers related to ICT design and access is crucial for their successful adoption and sustained utilization for sustainable food systems in developing countries, including Sub-Saharan Africa, especially food systems anchored on small-scale food producers. Below we discuss some of the implications of the findings and make recommendations for the design and promotion of ICTs.

First, it would be essential that the characteristics and functionalities of such ICTs cater to the needs, priorities, and capabilities of such producers, while their development approaches should follow to some extent a co-design mentality to ensure that these are reflected in the ICTs. For example, our results strongly suggest that such ICTs should be multifunctional and pro-poor, taking into account literacy levels (simple interface, ease of use), broadband consumption (low data needs, offline capabilities), user age and household structure (convenient access to tech support, intergenerational relevance and benefits), and farmer priorities (access to pricing information, information on best practices, sharing of health-related information, and affordability). Considering that producers with children tend to exhibit a greater willingness to adopt ICTs, ICTs for small-scale food producers should be designed in a way that allows their usage and benefits across different generations within the households. Given that the average age of South African farmers is over 60 years old (Born et al., 2021), and older farmers are generally hesitant to adopt unfamiliar technologies, while younger farmers are more receptive to ICTs (Mdoda and Mdiya, 2022), younger family members could play a crucial role in supporting the adoption of ICTs for farming activities. However, this support is contingent upon these tools being perceived as beneficial for their households and communities. This could potentially foster intergenerational learning and possibly stimulate the entry of more young black entrepreneurs into the South African agricultural sector.

Second, our research implies that organic farming can offer a promising niche for ICT tools. On the one hand, most respondents have adopted organic production practices and have sold their produce at farmers markets. On the other hand, organic products can offer higher incomes to small-scale food producers for certain market segments compared to those engaged in conventional agriculture (Qiao et al., 2018; Benedek et al., 2021), having positive implications for food security (Ume, 2023). In this sense, fit-for-purpose ICT tools that can help farmers properly implement agroecological crop production practices, find related markets, facilitate cooperative operation, and strengthen bargaining power could play a pivotal role in achieving this objective (Gamage et al., 2023).

Third, significant efforts should be directed towards two key areas: (a) optimizing the development, maintenance, and promotion of ICT tools, and (b) addressing broader systemic barriers, such as economic and digital divides. Regarding the development of ICT tools, it is crucial to recognize that this process is time-consuming, expensive, and requires advanced programming skills as well as substantial long-term investments. As for the systemic barriers, it is essential to acknowledge that ICTs has the potential to perpetuate or even exacerbate existing power imbalances between resource-constrained small-scale food producers and well-established large-scale commercial food producers. Achieving inclusive development and widespread use of technology that empowers small-scale food producers would likely require targeted public policy and investment (Woodhill et al., 2020). To accomplish these multi-faceted objectives, it is essential to develop multi-sectoral collaboration involving stakeholders from various sectors including telecommunications, banking, health, and agriculture, as well as non-governmental organizations, academics, and government departments working in the domains of food security, sustainable development, and ICTs. For example, reducing the costs of internet data for small-scale food producers or providing financial support for the adoption and use of livelihood-related ICTs to facilitate broader adoption and sustained use of such tools would require the coordinated efforts of multiple stakeholders.

4.5 Study limitations and future research

The overall study has three primary limitations related to: (a) possible biases arising from the use of snowball sampling, (b) the limited size of the study sample and the focus on only the two largest metropolitan areas in the country, and (c) the data collection taking place prior to the COVID-19 pandemic. Given these limitations, the findings of the study should be generalized with caution.

Regarding (a), due to the practical constraints outlined in Section 2.2 (i.e., lack of comprehensive farmer lists, safety concerns, reluctance of local communities to engage with outsiders), we adopted a snowball sampling approach. While this sampling method offers certain advantages in study contexts such as ours, it has also been associated to potential biases (Biernacki and Waldorf, 1981; Illenberger et al., 2008; Kirchherr and Charles, 2018; Parker et al., 2019). For example, although the local guides/translators were invaluable in building trust and facilitating community entry, they might have introduced sampling biases by selecting respondents with specific characteristics, viewpoints, or locations, or interpretation biases stemming from their crucial role as cultural brokers in the community. To minimize such biases to the extent possible we employed the following strategies: (i) ensuring that diverse areas were covered in each city/community, (ii) explaining to lead farmers that we aimed to achieve a representative cross-section of the small-scale food producers in each study area, and (iii) obtaining a comprehensive understanding of the underlying phenomena related to ICT adoption by small-scale producers, and the characteristics of urban agriculture in the study cities through extensive literature reviews and expert interviews (Alfonsi, 2024; Alfonsi et al., 2024).

Regarding (b), despite the robust findings reported here, it is essential to acknowledge various methodological decisions that readers should consider when generalizing the results. First, the relatively small sample size ($n = 85$) and focus on the two major South African cities might limit generalization across geographic areas and demographic segments. Future research should address these gaps by providing insights into the realities experienced in secondary cities or rural regions of South Africa, and other parts of Sub-Saharan Africa. Second, while the statistical tools employed in this study (i.e., descriptive statistics, association analysis, RDA) can help establish relationships between ICT preferences/use and sociodemographic characteristics, they do not imply causality. Future research should aim to expand the current knowledge by using more appropriate tools for causal inference, such as randomized control trials, propensity score matching, or structural equation modelling. Third, the techno-centric approach rooted in empirical social sciences adopted here can elicit some of the factors affecting ICT user preferences, adoption, and use patterns. However, this approach risks overlooking deeper socio-cultural and political-economic forces shaping technology adoption. Further studies should adopt more interdisciplinary framings capable of capturing systemic barriers related to resource access and power relations.

Regarding (c), it is important to acknowledge that our findings reflect the pre-COVID19 pandemic situation. As such, this study should be considered a baseline that mapped pre-pandemic ICT adoption/use patterns and barriers among small-scale food producers engaged in urban agriculture. By identifying these pre-existing patterns and barriers, our findings can inform targeted interventions tailored to the needs of small-scale food producers as the technology landscape continues to evolve. While the accelerating technology integration driven by COVID-19 necessitates updated research, this pre-pandemic baseline study remains valuable for pinpointing systemic gaps and intervention needs. Further research tracking post-2020 shifts in ICT adoption, use and perspectives would enable a more comprehensive understanding of the catalysts, persistent barriers, and support required at the intersection of ICT and small-scale food systems.

5 Conclusion

This study investigates the perceptions of small-scale food producers engaged in urban agriculture in various low-income areas of Johannesburg and Cape Town about the adoption and desirable characteristics of food-related ICTs, as well as the factors influencing user perspectives. Through 85 surveys with producers, we identify: (a) the patterns and reasons for adopting or not adopting ICTs, (b) the desirable functions and characteristics of ICTs prioritized by producers, and (c) the production activities for which ICTs are most needed.

Our findings reveal clear preferences for multi-functional, user-friendly, and affordable ICT tools that facilitate price comparisons, best practice sharing, and access to health tips. User age, education, income, and family size are significant factors influencing technology perspectives and use. By highlighting key limitations related to ICT suitability, cost, and digital literacy while emphasizing farmer priorities and capabilities, this research contributes to the emerging literature on ICTs for small-scale food producers in urban contexts of South Africa, and Sub-Saharan Africa more broadly.

Such user-centered insights can inform the development of customized ICT tools and interventions, that effectively empower small-scale food producers engaged in urban agriculture across rapidly growing cities in the region. Specifically, our findings suggest that pro-poor mobile applications offering value-adding informational, networking, and selling functionalities in local languages can meet many of the needs of urban small-scale food producers. However, deliberate design adaptations and policy support are essential to overcome prevailing systemic barriers related to affordability, skills development, and social inclusion.

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 requirement of ethical approval was waived by the Ethics Review Committee of the University of Tokyo for the studies involving humans because this research does not require ethical review in accordance with the governmental research ethics guideline in Japan, "Ethical Guidelines for Life Science and Medical Research Involving Human Subjects" and "The University Research Ethics Regulation." The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because verbal consent was obtained from all participants prior to the commencement of the survey. Written informed consent was not obtained from the individuals for the publication of any potentially identifiable images or data included in this article because verbal consent was obtained from all participants prior to the commencement of the survey.

Author contributions

RMA: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft. MN: Writing – review & editing. AG: Writing – review & editing.

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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.

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

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1332978/full#supplementary-material

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