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Digital technologies in local agri-food systems: Opportunities for a more interoperable digital farmgate sector

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Agriculture e-commerce technologies are transforming how small and medium-scale farmers distribute food, consumers access local food, and market vendors negotiate sales. However, most of the social scientific literature exploring digital agriculture concentrates on big data analytics in the context of commodity farming systems and conventional supply chains. In this paper we review the social scientific literature on agriculture e-commerce technologies and situate this literature within broader debates over digital agriculture and its uneven social and economic dynamics. We find that most social scientific literature does not include agriculture e-commerce in its definition of digital agriculture, instead defining it predominantly in terms of production (e.g., variable-rate technology) or verification (e.g., blockchain) technologies. We contextualize this review with results from a series of focus groups exploring the challenges faced by Ontario's "digital farmgate sector"—the suite of agriculture e-commerce platforms that organize local food sales for hubs, farmers' markets, and small- and medium-scale farmers—related to lack of platform interoperability. We find that local food systems actors are increasingly adopting e-commerce platforms, particularly in the context of the pandemic, and observing substantial business-related benefits to their adoption. Yet, there are common frustrations with digital tools due to market fragmentation and lack of platform interoperability. We recommend the collaborative development of an open standard for e-commerce platforms that allows for the cross-platform sale of local food and farming products.

KEYWORDS

local food, e-commerce, digital agriculture, food system, political economy, interoperability, platform

1. Introduction

It is clear that a "digital revolution" is underway in agriculture (Fraser and Campbell, 2019). On-farm, a suite of data collecting devices (e.g., sensors, drones), combined with Internet of Things (IoT) technologies, communicate with decision-support software to inform farmers' management of fields at ever-finer spatial and temporal scales: where and how to apply pest or weed management strategies, to harvest, or to water (Balafoutis et al., 2017; Fountas et al., 2020). Some suggest that, mid-stream, blockchain technologies are poised to secure distribution systems contributing to food traceability goals from farm to landfill (Weersink et al., 2018; Nayal et al., 2021). Finally, at the downstream end of the supply chain, the e-commerce sector has risen to prominence in recent years, across the globe. The entrance of Amazon into the market, through its acquisition of Whole Foods, signals how major corporate actors are beginning to shift food retailing and shopping habits online (Hillen and Fedoseeva, 2021). The pace of e-commerce adoption substantially increased as a response to COVID-19 restrictions (Galanakis, 2020). While digital agriculture tools are not new, the pace of development appears to be increasing. Some observers say these tools will fundamentally transform the way we manage food, paving the way for massive increases in agriculture's contribution to national employment and social, environmental, as well as economic goals across scales (Stackhouse, 2019; Basso and Antle, 2020).

Scholars have explored the social and economic dimensions of digital agriculture technologies for over three decades. In the 1990s, political economists began to scrutinize precision agriculture as a suite of technologies and were critical of its potential implications for the environment and for farmers (Wolf and Wood, 1997). More recent work has highlighted the experiences farmers have with using digital tools and what factors lead to or prevent farmers from adopting technologies (see e.g., Higgins et al., 2017; Eastwood and Renwick, 2020). Critical scholars advance questions regarding farmer autonomy and sovereignty with respect to digital tools. These researchers suggest that digital tools risk further consolidating power within the food system, between farmers who can and cannot access them (see Rotz et al., 2019b) and between farmers write-large and the technology companies that develop them (see Miles, 2019; Duncan et al., 2021). Others have evaluated discourses and perceptions regarding digital agriculture, noting the tensions between technology providers who are optimistic for digital agriculture and farmers who may be more skeptical (e.g., Jakku et al., 2019).

Broader governance considerations for digital tools have also begun to be explored, with researchers documenting the actor networks and policies that are mobilizing around diverse digital tools (Klerkx and Begemann, 2020; Lajoie-O'Malley et al., 2020). Recent literature catalogs this mobilization, reviewing topics such as technology use and adoption, effects of digitization on farmer practice, power and ethics in digitalization, knowledge and innovation systems change, and the economics and management of digital value chains (Klerkx et al., 2019; Lajoie-O'Malley et al., 2020; McCampbell et al., 2022). Overall, there is much critical scholarly debate around who owns digital tools and the data they generate (Bronson and Knezevic, 2016), who possesses the knowledge and capabilities to use digital tools in meaningful ways (Carolan, 2018), who is excluded from the digital revolution (Rotz et al., 2019a), and how digital data are to be managed equitably and transparently (Weersink et al., 2018). Responsible innovation has emerged as a key approach to realizing inclusive governance mechanisms and more equitable outcomes in digital agriculture (Bronson, 2018; Fleming et al., 2018; Jakku et al., 2022).

One under-researched area where these debates around ownership, use, power, and equity crystallize is in the interoperability of digital agriculture tools. Interoperability refers to a condition in which two or more technologies can communicate and interface with each other, even if those technologies are developed from different companies or organizations. Calls for increased interoperability in the digital economy have increased in recent years, as seen in the design and implementation of FAIR (findable, accessible, interoperable, and reusable) principles in multiple sectors, such as academia (Wilkinson et al., 2016) and even agriculture (Phillips et al., 2019; Arnaud et al., 2021). In the case of agriculture, a lack of interoperability between hardware or software platforms means technology users (e.g., farmers), become locked-in to a user-agreement with a company. This poses a technical challenge to farmers, making business management more time-consuming and inefficient (Bahlo et al., 2019; Hansen et al., 2021). Limited interoperability is not just a technical challenge but a political issue, as farmers have decreased ability or agency over what tools they use or what is done with their data (see e.g., Rotz et al., 2019a).

1.1. Contributions

In this paper we analyze the technical and political dimensions of interoperability with respect to agriculture e-commerce tools (AEC)–tools that organize the sale of agricultural goods between producers, distributors, and consumers. Much of the research and policy focus regarding digital agriculture is on larger-scale, commodity-farming; that is, how digitalization and big data are promising efficiencies and environmental benefits in agronomic (production) practices across global value chains (see e.g., Kamilaris et al., 2019). While non-governmental and international organizations have begun to explore AEC as a part of the digital agriculture revolution (FAO and ZJU, 2021; Stephenson et al., 2021), critical social scientific literature has yet to examine these technologies in substantial detail. Our study is among the first in this body of critical social scientific literature to do so.

We contribute to critical social scientific literature on digital agriculture technologies in four ways. First, we explore the extent to which AEC tools are discussed within the digital agriculture literature. It is important to examine agricultural applications of e-commerce platforms, as these tools are more accessible to small and medium-scale farmers compared to more expensive digital tools such as autonomous tractors that often require existing ownership of large-scale capital and land (Rotz et al., 2019a). We examine some of the top-cited digital agriculture papers, exploring how they define digital agriculture and if, and in what ways, they discuss the digital farmgate sector. In doing so, we broaden the critical literature on digital agriculture into an aspect of food systems it has neglected: e-commerce. Second, we explore how local food system stakeholders are using e-commerce tools in practice, by presenting the results of a series of focus groups conducted with local food system stakeholders. We describe how disruptions in farmgate marketing and sales, through e-commerce platforms, are offering opportunities and challenges to farms that sell in multiple direct-to-consumer channels. Factors such as the COVID-19 pandemic and increased consumer interest in local food have accelerated the adoption of existing e-commerce tools, making it important to evaluate their current use. Third, we highlight interoperability-related issues faced by producers and how they navigate these in practice. Fourth, we recommend solutions to some of the stakeholder-defined challenges related to interoperability that we found through this research. We contribute to digital agriculture scholarship by moving beyond a broad focus on critique to solution, drawing from design process methodologies (Chou, 2018). Specifically, we explore potential mechanisms through which to address some of the political economic barriers identified in this literature (e.g., interoperability-related challenges) that prevent the widespread realization of benefits of digital farmgate platforms.

2. Methods

2.1. Defining agriculture ecommerce tools

AEC are online intermediary tools that coordinate online market transactions across the food system. Platforms may integrate additional features designed for producers to catalog inventory, market products, and organize distribution and pickups with customers (wholesalers, consumers, restaurants, etc.). Digital platforms in general, beyond food or agricultural e-commerce, have only recently begun to be systematically explored (de Reuver et al., 2018). The body of research exploring AEC is even more recent and rapidly evolving. The results of a recent systematic review of AEC research indicate that the predominant focus of this field of study is on the microeconomic factors that influence a firm's adoption of e-commerce tools, and work has been regionally concentrated in the United States and China (Zeng et al., 2017). More recent efforts have begun to distinguish multiple types of AEC tools, considering their function either for value transfer between firms and consumers or for the governance and creation of grassroots interactions and networks (Oncini et al., 2020). Crucially, this literature has highlighted the present as a pivotal moment for the food platform economy, where major corporate actors such as Amazon have yet to consolidate and control the market, while multiple smaller players have geared their operations for multiple types of markets, including local and ecological food sectors.

In this paper, we focus on AEC tools designed for local and regional food distribution as part of what we term the "digital farmgate sector." In turn, we typologize digital farmgate sector platforms as either "tailored" or "generic." Tailored platforms are those that are designed to fit the needs of local food systems specifically by, for example, accommodating community-supported agriculture (CSA) business management practices and organizing multi-vendor sales channels. Tailored platforms prioritize local value exchange by disrupting distribution patterns in a way that favors the growth of decentralized supply networks (see Glaros et al., 2021). They aim to do this by directly connecting farmers to other farmers, distributors, wholesalers, restauranteurs, and individual consumers. Generic platforms such as Shopify or Etsy are used for commerce of all kinds, including, in some cases, the local and regional sale of agricultural products (Figure 1). Generic platforms most often host single storefronts and are not designed to facilitate network interactions, instead prioritizing single business sales and services.

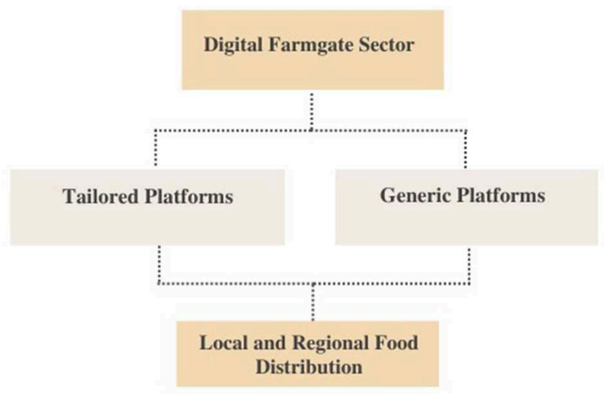

FIGURE 1
Digital farmgate sector typology. The digital farmgate sector is part of the broader AEC sector which includes platforms for food sales at broader scales than local or regional (e.g., superstore online shopping platforms).

2.2. Focus groups: Exploring Ontario's digital farmgate sector

All research design was undertaken in collaboration with Open Food Network (OFN) Canada. OFN Canada is a not-for-profit providing e-commerce solutions and sector development support for local food system stakeholders. Open Food Network operates in over ten countries while OFN Canada is headquartered in Ontario but hosts shops across most provinces and territories in Canada. At present, their flagship e-commerce platform engages close to 1,000 community food initiatives across Canada. The platform hosts local producers, processors and artisans, small scale diversified farms, farmers' markets, food hubs, buying clubs and local economic development agencies, with the bulk of these stakeholders located in Ontario.

This research aims to identify user experiences, concerns, and challenges regarding the use of AEC in local food systems in Ontario, focusing on lack of interoperability in the digital farmgate sector. We employed a case study approach, focusing on Ontario's digital farmgate sector. A case study approach is widely used across disciplines, and allows researchers to examine a complex phenomenon, in this case interoperability, in a specific context (Baxter and Jack, 2008). A case study approach seeks to identify and recognize experiences, processes, and broad though maybe not representative patterns in a specific context, rather than to identify general trends throughout a population; its strengths are in understanding context and searching for causal pathways, rather than measuring correlation or probabilistic associations (Flyvbjerg, 2011). In case studies, it is recommended to use a variety of methods to document findings to triangulate and corroborate findings across multiple methods (Golafshani, 2003). As such, we used mixed methods including focus groups and survey.

Further, we adopted a participatory methodological approach, where we worked with local food system stakeholders to identify needs and pursue research to directly address those needs (Minkler, 2005). This paper summarizes the findings of the first of two phases for a larger responsible research and innovation agenda undertaken by OFN Canada. Extending participatory research, responsible innovation practices work to co-develop and iteratively test solutions with stakeholders in a way that better integrates and directly addresses their needs (Bronson, 2018). The two phases for this project are distinguished by the following two objectives:

Phase 1 (this paper): identify clear needs and challenges experienced by local food system stakeholders regarding digital technology use in the sector.

Phase 2 (future work): engage directly with local food system stakeholders to design e-commerce solutions that directly address those needs and challenges.

The data we report in this paper come predominantly from a set of three focus groups and follow-up surveys undertaken in

May and June of 2022. These were funded through the Ontario Ministry of Agriculture Food and Rural Affairs' Ontario Agri-Food Research Initiative, with the goal of assessing challenges experienced by local food stakeholders and proposing solutions to some of those challenges to digital technology adoption. Below, we present the descriptive results of this focus group and survey data, with three objectives in mind:

1) Assessing stakeholder perceptions of and experiences with the digital farmgate sector.
2) Highlighting common challenges experienced by local food system stakeholders, focusing on interoperability-related issues.
3) Gauging interest in potential solutions to identified challenges.

Our research builds upon previous consultation undertaken by OFN Canada with local food system stakeholders in Ontario (see Thomas et al., 2021). This sought to understand how local food system stakeholders were using digital tools to navigate the challenges of pandemic-related lockdowns. Farmers' market and food hub managers were overwhelmingly positive about their use of e-commerce tools. Nevertheless, the key challenge they identified was lack of inter-platform interoperability–that is, they were unable to seamlessly transfer data between different platforms that could not digitally communicate with one another. Recognizing this challenge, OFN Canada partnered with a separate organization that is actively working to address this issue, the Data Food Consortium (DFC), for the focus groups undertaken in this research. The Data Food Consortium is a consortium of research institutions, platforms, and food organizations (e.g., Open Food Network France, Socleo, INRAE), created in France, with the vision to develop an "open, fair, and transparent food system" (Data Food Consortium, 2022). It operates with the goal to scale short supply chains for local food and encourage collaboration among actors to make local food systems more efficient. The DFC created an open standard[1] for secure data exchange for tailored platforms. The DFC standard acts as a shared architecture across which participating tailored platforms can communicate; it creates a more modular system to transparently track the flow of goods across systems of platforms in a local and regional context. The DFC open standard is currently being used by a group of digital farmgate platforms, food co-ops, farmers, and markets in the United Kingdom (Food Data Collaboration, 2022).

For the three focus groups, we recruited local food system stakeholders who use digital tools in the management of their businesses. We recruited individuals by distributing advertisements through Open Food Network Canada's email listserv (∼1,000 members), consisting mainly of farmers and market vendors, as well as several (>40) markets and hubs) as well as running social media advertisements. For the first two focus groups we asked stakeholders questions regarding their use of digital technologies: what successes they had, if the COVID-19 pandemic had affected their decision to use e-commerce tools, and what challenges they had experienced, especially related to interoperability. We also assessed stakeholder interest in potential solutions to some of those challenges they identified. For the third focus group, we asked the same questions and facilitated a similar discussion as previous focus group events, but also included a demonstration of the DFC open standard. The DFC demonstrated how the open standard prototype works and fielded specific questions about its applicability to the focus group participants' business needs.

TABLE 1 Overview of focus group participants.

	Number of unique focus group participants
Farmers	11
Market and hub managers	8
Community food organizations	2
Chef/Restaurant managers	2
Total	25

The recruitment process for the focus groups was designed to gather feedback from a diverse array of local food system stakeholders, though only two local food/community food organizations and chefs took part in this study. Despite being part of OFN Canada's network, not all the participants currently use or have used in the past OFN Canada's e-commerce platform. In total, 28 ($N = 28$) individuals attended our focus groups, though three of these individuals attended both one of the first two focus groups as well as the third focus group, as they were interested in attending the product demonstration from partner organizations (Table 1).

The markets and hubs who took part in this research were of varying size, from small to medium-scale, representing rural areas, towns, and cities across Ontario. The largest market or hub that took part in this research aggregates products from over 100 farmers and vendors across Southern Ontario. We did not ask about the size of the farms who took part in this study but focus group discussion indicated that most were small-to medium-scale, selling direct-to-consumer or *via* local aggregators. The majority of stakeholders (69%) who took part in this research were between the ages of 26 and 50. Per our intake requirements, all stakeholders use or have used some form of digital farmgate technology for their farm, restaurant, community organization, or market/hub.

Surveys were distributed to focus group participants immediately following the focus group. In the follow-up surveys we echoed the focus group format and questions asking about the types of tools stakeholders were using, their experience was in using digital technologies, and the role they saw (if any) for local food systems in Ontario. In total, the survey was distributed to a total of 25 ($N = 25$) individuals and was answered by 23 ($N = 23$). Following data collection, we transcribed focus group audio tapes and undertook a thematic content analysis of the transcript data. In doing so, we identified and grouped quotes from participants that were conceptually similar and repeated by multiple individuals. We focused on identifying themes regarding successes with digital tools, common pain points, and interest in the DFC open standard as compared to other interoperability solutions.

1 An open standard is a common technical language through which various software platforms can communicate with each other. Open standards enable rapidly changing industries to "keep up" and attempt to enable fairer competition between firms (Simcoe, 2006). The goal of the DFC open standard is to enhance interoperability and secure data sharing amongst platforms and tech providers that cater to local food systems and short supply chains for local food and farming products (see https://www.datafoodconsortium.org/en/).

There are under 20 commonly used tailored and generic platforms across Ontario, varying in size (number of users) and operating across major urban centers and smaller rural areas. In this way, Ontario's network of local food systems represents a microcosm of e-commerce use. We suggest the findings of this study may be generalizable to similar geographic contexts where local food systems cater toward a relatively affluent portion of the population that purchase food from farmers' markets, community-shared agriculture systems, or food co-ops. However, care should be taken in generalizing these findings to other contexts, particularly from the Global South, where e-commerce plays a much more significant role in securing smallholder farmer livelihoods (Zeng et al., 2017).

3. Results

3.1. Definitions of digital agriculture

We begin this section by presenting key definitions of digital agriculture from the top-cited digital agriculture literature and count the technologies included within those articles. We highlight the extent to which digital farmgate sector tools are defined and discussed within this scholarship. We then shift to explore digital farmgate technologies in practice, presenting the results of three focus groups on the use of and perspectives regarding digital platforms and e-commerce tools in Ontario.

We performed a keyword search in the Web of Science and Agricola databases, searching for the terms "digital agriculture," "agriculture 4.0," and "digital agriculture revolution" (see Bertoglio et al., 2021). We did not look for terms such as "precision agriculture" or "smart farm" used in other reviews such as Klerkx et al. (2019) and Duncan et al. (2021) as these specific terms are more clearly associated with on-farm systems management as opposed to management across agri-food value chains. Our search returned a large number of results ($N = 684$ from Web of Science and $N = 163$ from Agricola). We refined the results to only consider reviews focused on suites of digital agriculture technologies, resulting in a total of ($N = 67$) journal articles to review. We searched each article to record its definition of digital agriculture and what specific technologies that definition includes (Table 2).

Most definitions we found describe digital agriculture as an approach to making food production more efficient. Efficiency is supposed to be realized through the streamlined communication of high-quality data. Through optimization, food systems can realize social, environmental, and economic goals, such as increased yield, more nutritious food products, greater transparency, better animal welfare, and more ecological production. While all definitions emphasize the potential for digital tools to increase agronomic/production efficiencies, many also emphasized impacts across value chains. For example, among the top-five most cited review papers from our selection, four ($n = 4$) indicated that digital transformation was occurring across all parts of the agri-food value chain.

We found that e-commerce tools are rarely included in digital agriculture review papers, despite those papers' definitions of digital agriculture as a suite of tools affecting all parts of the value chain. Of the review papers that we examined, only nine ($n = 9$) explicitly mentioned e-commerce technologies as an example of "digital agriculture," "agriculture 4.0" or as part of the "digital agriculture revolution" (Figure 2). The most common technologies included in definitions of digital agriculture were "big data" (or big data analytics), sensors, and the Internet of Things (IoT).

Of those nine papers that mentioned e-commerce or digital marketplaces, only one explored these technologies in a significant way (Bahn et al., 2021). Bahn et al. (2021) describe the benefits of e-commerce, including enhanced market access, restructuring value chains, connecting consumers and producers directly, as well their challenges, such as increased concentration of market power with a few select platforms.

E-commerce has yet to receive substantial scholarly treatment in the digital agriculture literature. However, there is substantial potential for e-commerce platforms to disrupt how people access

TABLE 2 Definitions of digital agriculture from the top-five cited papers found through the literature search.

Klerkx et al. (2019)	"Digitalization in agriculture is thus expected to provide technical optimization of agricultural production systems, value chains and food systems. Furthermore, it has been argued that it may help **address societal concerns** around farming, including provenance and traceability of food… animal welfare in livestock industries…and the environmental impact of different farming practices. Digitalization is also expected to enhance knowledge exchange and learning, using ubiquitous data…and improve monitoring of crises and controversies in **agricultural chains and sectors…**"
Lezoche et al. (2020)	"Hence, "Agriculture 4.0" emerges to provide advanced technologies to the famers in order to meet agri-food production challenges, hence, to achieve more affordable prices for open market and the minimum cost for farmers. Thus, the expectation for the further coming years, is that Agri-Food 4.0 should help meeting sustainable challenges by increasing the **agri-food supply chain stakeholders** revenues as well as decreasing their pressure for handling complex and external factors they cannot control, such as weather, market behaviors and policies, but also to react on time by visualizing current trends in needs."
Klerkx and Rose (2020)	"It has been noted that Agriculture 4.0 has the potential to be disruptive and transformative in many ways. It may have biophysical, economic and social impacts on food and nutrition security, as well as on the ways in which **agricultural production systems** are designed and operated. It will also have implications for the way agriculture is embedded in ecosystems and landscapes. Furthermore, it is likely to change the way agricultural **supply chains** function, and the ways in which products are composed by food manufacturers, sold by retailers, bought by end-consumers, and food waste is prevented."
Zhai et al. (2020)	"Nowadays, the evolution of agriculture steps into Agriculture 4.0, thanks to the employment of current technologies like Internet of Things, Big Data, Artificial Intelligence, Cloud Computing, Remote Sensing, etc. The applications of these technologies can **improve the efficiency** of agricultural activities significantly."
Zambon et al. (2019)	"Agriculture 4.0, like to Industry 4.0, stands for the combined internal and external interacting of farming operations, offering digital information at all **farm sectors and processes**. Even in agriculture, as in the industrial sector, the 4.0 revolution represents a great opportunity to consider the variability and uncertainties that involve the agri-food production chain…"

Emphasis placed in bold.

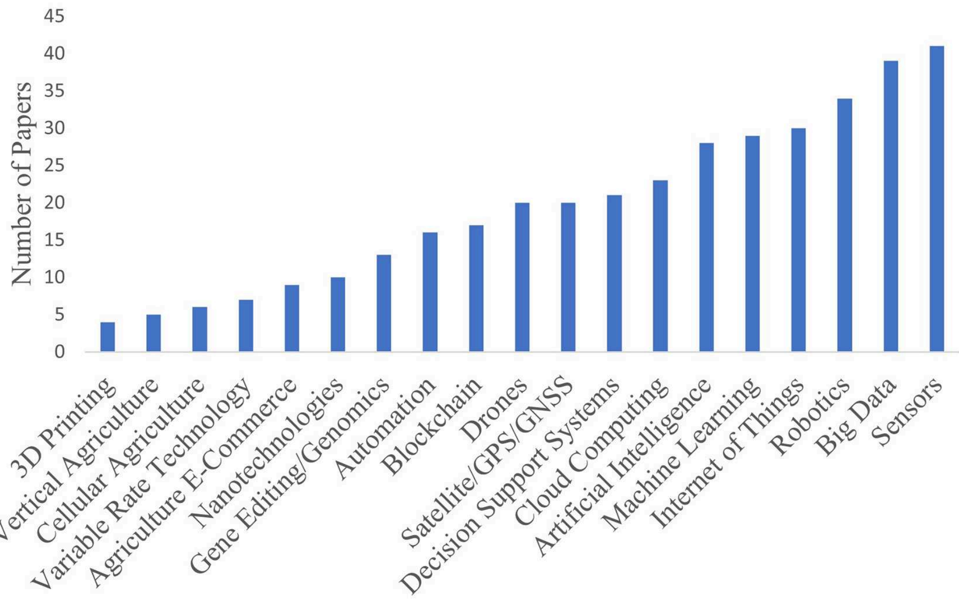

FIGURE 2
Technologies mentioned as "digital agriculture" in review papers.

food from superstores, markets, and local food stores, as well as how producers earn additional income (Oncini et al., 2020; Bahn et al., 2021). The robust field of scholarship on digital agriculture can provide important insights into what forms of social and economic disruption e-commerce tools may entail for food systems. It is thus crucial to situate e-commerce as a component of the digital agriculture revolution, situating these tools within this abundant social scientific literature, which we return to in the discussion.

3.2. Ontario's digital farmgate sector

3.2.1. Use and benefits

In our focus groups, we asked individuals to indicate what e-commerce platforms they use. We grouped the results into tailored and generic platform categories. Farmers' markets and hubs more commonly use tailored platforms (80%), while farmers and vendors have a slight preference for generic platforms (60%). The majority of focus group participants (>75%) indicated that they have observed numerous business-related benefits due to digital tools and believe these technologies will bring opportunities to the local food sector as a whole. Many used an e-commerce platform for the first time during COVID-19 lockdowns, and most have continued using a platform following the lifting of lockdown restrictions. Most survey respondents (>90%) agreed that digital tools made overall farm management easier (Figure 3). They also agreed that digital tools save them time and money. All participants agreed that they have seen positive impacts on their sales since using digital tools. We stress here that these benefits are described by stakeholders, yet very little critical digital agriculture has engaged with these tools and/or reported their observed benefits.

One farmer indicated that they had substantial increases in sales following their participation in their farmers' market's online platform:

> "During COVID-19, we participated in a digital platform for our local farmers market, where we've been farmer vendors for over 12 years...We were astounded to find that our farmers' market orders increased our expected sales" (Farmer, 2022).

A farmers' market manager expressed similar increased, in platform adoption, following the commencement of the pandemic: "...since I started using [a digital farmgate platform] live for customers, I've probably added about 60 new vendors" (Farmers' Market Manager, 2022).

Other participants suggested that, since adopting digital tools, they could not see functioning without them. Talking about their digital farmgate tools, this food hub manager argued that they made their operations more time and labor efficient: "But in terms of efficiency and effectiveness, I think I couldn't imagine us being able to replace them at this point" (Food Hub Manager, 2022). Further, most survey respondents (>75%) agreed that digital tools could result in sector-wide benefits, such as increasing the number of people who buy local, connecting producers and consumers, and helping smaller-scale farmers compete with larger businesses (Figure 4). Fewer survey respondents (<55%), though still a majority, agreed that digital tools could generate systemic changes, such as helping to redistribute power from food and farming corporations or making food more accessible to lower income individuals. About half of respondents believed that digital tools could lead to more sustainable or regenerative farming methods.

Most of the comments respondents provided at the end of the survey discussed the potential for digital tools to bolster local food systems by making them more efficient and transparent. For example, one survey respondent indicated that digital technologies could build networks and connections between actors: "Digital tools can - when used appropriately - make systems more efficient be it collaboration with actors within a local food system or building a connection to the eater." A different participant listed similar benefits they see to

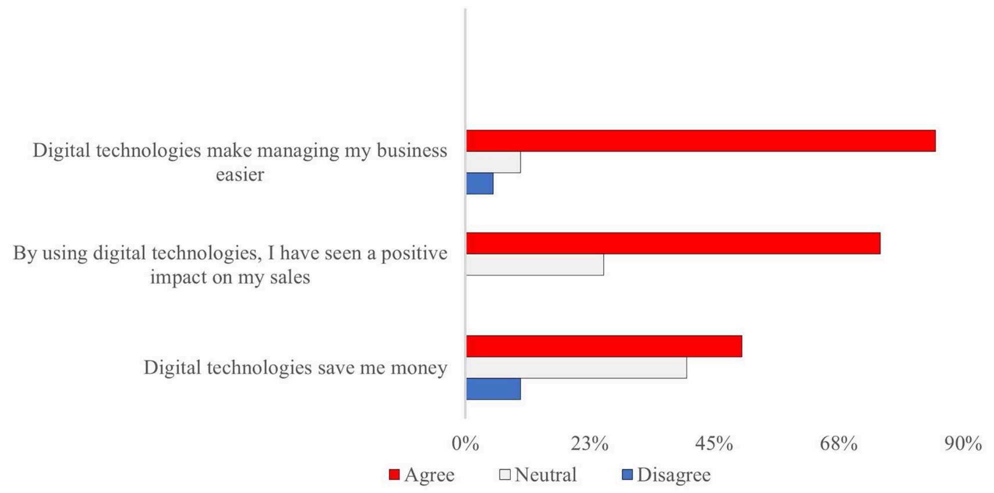

FIGURE 3
Perceived benefits of digital technology use.

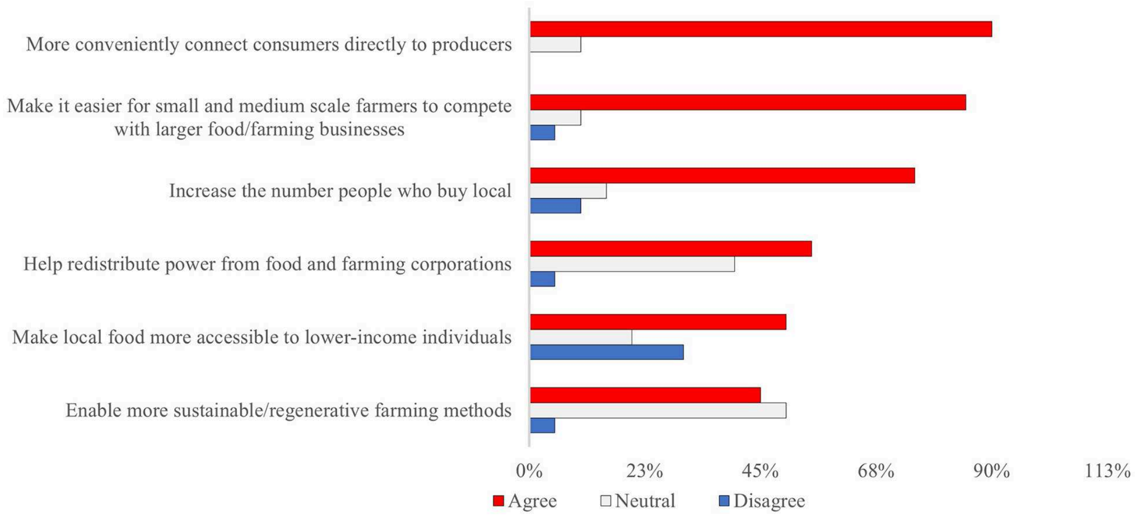

FIGURE 4
Perceptions of broader impacts of digital tools in local food sector.

using digital tools in local food systems: "Food transparency and food safety. Origins of local farmers."

One community food organization commented on the tensions they see between digital farmgate platforms and food accessibility. They described how on the one hand platforms make it easier for folks with limited income and accessibility barriers to access food, while on the other hand platforms can lack the unique functionality required by community food organizations to make processes more accessible:

> "[We] did notice that [the e-commerce platform they use] was a big benefit for those with accessibility needs. So those who might be immunocompromised or on lower income, you know, just can't make it to an in-person market. So, it would be nice to explore the functionality of the site for those pieces. But yeah, something that we've always tried and kind of failed at is incorporating our pay what you choose or even sliding scale function on sites, it just seems like for the most part sites are not built to have, you know, adjustable prices" (Community Food Organization Manager, 2022).

3.2.2. Challenges

For farmers and market vendors, the inability to conduct cross-platform sales is a major challenge. We asked participants to indicate how much they agreed with a series of statements related to challenges posed by lack of inter-platform interoperability. A majority of farmers and market vendors (60%) agreed that it is challenging to navigate all the different platforms used across local food systems. As one farmer commented in the follow-up survey: "We are receiving more invitations to participate in digital food hubs but we cannot assume the extra time required to maintain inventory across different platforms let alone the subscription costs that come with it" (Farmer, 2022). These challenges have resulted in situations where farmers and vendors have opted out of using multiple online platforms because of the increased data management workloads and subscription costs, despite their reported sales increases. Half the farmers who filled out our survey indicated that these challenges (i.e., lack of interoperability between digital and generic platforms) had resulted in adverse impacts to their business.

We asked farmers more pointedly about some of the challenges they face in their day-to-day use of digital tools, during focus groups. Farmers identified the need to use multiple platforms to sell goods in various online markets as a key challenge:

> "Trying to divide your inventory between multiple platforms, it really makes it challenging. I think it adds another layer to what farmers are having to do, in terms of what they harvest and bring to markets... To manage all of those separate inventories on top of the work that they're already doing (out in the field for like, long hours in a day, depending on the scale and size of their team) to then have to manage all these different platforms, it just adds another layer" (Farmer, 2022).

Since e-commerce platforms cannot (yet) communicate with one another, users are forced to manually update data (e.g., inventory, sales) across different markets. For farmers' markets and food hubs, interoperability related challenges were also present.

The vast majority (>75%) of survey respondents indicated that they experienced increased data management workloads due to lack of platform interoperability (Table 3). Market managers and farmers both experienced increased data management workloads, even though their capacity is already limited:

> "The challenge I found, as a market manager, is that there are so many different platforms that people use. So the integration was challenging and just to get the capacity for vendors to manage different inventories across different platforms. That was really a barrier for them because they are dealing with inventories split between different markets" (Farmers' Market Manager, 2022).

Many farmers' market and food hub managers reported that their online markets lost potential suppliers due to lack of cross-platform sales functionality. This led a significant number of the hubs and markets that we surveyed (70%) to consider halting their use of e-commerce platforms altogether due to vendor recruitment issues (Table 3), despite the fact that they reported substantial business-related benefits since their adoption. A number of the market and hub managers–who are sometimes working in a volunteer capacity–reported that the added demands on their time and resources are not sustainable.

These challenges result not only in inconvenience, increased workloads, and further subscription costs for local food system stakeholders, but sometimes in online marketplace failures. As one farmers' market manager described in our focus groups:

> "We have about, I don't know 60 different farmer and artisan members. And the thing that we've come across is they all use different platforms. So when we actually tried to coordinate them all into one, it was impossible. So that's why we just stopped paying for an online platform that wasn't working for us, because half the people could join and half the people couldn't. So we're in limbo right now" (Farmers' Market Manager).

We asked participants in the survey if they had previously heard of the term "interoperability." Almost two-thirds (63%) already had. When asked where they had heard this term before, only one had heard of it in the context of local food systems or digital farmgate platforms: "I came across this [term] last year in my business when there was a suggestion from the other local food vendors [to] come together and establish a common system where we could ease our business activities..." (Farmer, 2022).

We then asked participants explicitly if lack of interoperability was something they faced in their business, and approximately forty percent (38%) indicated that it was. We then asked in what ways it posed a challenge. One farmer explained it as follows: "[lack of interoperability] limits my choices as a farmer...in adopting new technologies and creates barriers to efficiency in utilizing software from multiple providers and devices (Farmer, 2022)." A farmers' market manager described a similar challenge: "As a Farmers' Market, we'd like to have all our vendors listed, but we can't because some use a platform that is not compatible (and our platform didn't have the capacity to even list other platforms)."

We subsequently asked respondents if developing solutions to address this challenge of interoperability would be useful for their businesses and overwhelmingly participants agreed (>75%). We asked participants to indicate their preference for potential interoperability solutions in two ways. First, we asked participants if they would prefer interoperability between generic (e.g., Shopify) and tailored (e.g., Open Food Network) platforms, or interoperability between tailored platforms only. Participants preferred the generic-tailored platform integration (69%). Second, we asked participants to indicate which of three specific solutions we proposed in the focus group they would prefer. These solutions were as follows: (1) a generic-tailored integration of the OFN Canada e-commerce platform with Shopify; (2) an integration of the OFN Canada e-commerce platform with a farm management platform; and (3) the creation of an open standard that all digital farmgate platforms across Ontario could adopt. Three quarters (75%) of participants preferred the third option (Figure 5).

Three of the farmers who responded to our survey (60%) indicated that an open standard was their preferred interoperability solution, while over eighty percent (86%) of farmers' market and food hub managers preferred an open standard. As one market manager described:

> "For me, as a market organizer, I think [an open standard] would be absolutely essential, this would be the key thing that would bring us back onto an online platform" (Market Manager, 2022).

According to focus group participants, an open standard would make their lives easier and address their business needs: "[It] would make my life easier. It would remove some of my workload and likely reduce data entry errors" (Market Manager, 2022). Further, it is better aligned with their values as compared to other solutions that were presented during the focus groups. The open standard's focus on enhancing cross-platform communication across all of the local food sector's tech providers appealed to stakeholders who wanted

TABLE 3 Summary of responses related to lack of inter-platform interoperability.

Interoperability challenges	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)
"Everyone uses a different tool (e.g., sales platform) and it can be hard to transfer data between."	0	0	20	40	40
"Lack of platform interoperability has had a negative impact on my business."	0	0	12	38	50
"Lack of platform interoperability has increased my data management workload."	0	0	14	43	43
"Lack of platform interoperability has made me consider and/or has made me stop using online platforms."	15	0	15	55	15

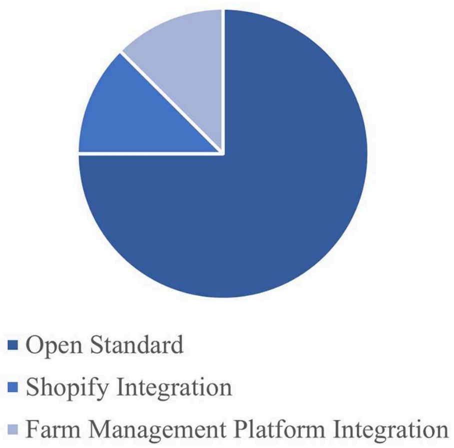

FIGURE 5
Preference for specific interoperability solutions.

complete solutions. In other words, the open standard is seen as better suited to address many of the challenges the sector all at once, in contrast to other approaches that are more piecemeal. This more collaborative approach to local food systems development was appealing to stakeholders: "The [Open Standard] initiative shifts the food tech landscape from one of competition to cooperation so farmers and producers have more flexibility in direct sales…We need this kind of positive direction in our food system" (Farmer, 2022).

4. Discussion

In our discussion, we situate the findings of our empirical research within critical digital agri-food literature. In doing so, we explore key tensions around who these platforms are for, consolidation dynamics within the sector, and concerns over proprietary data enclosure. We highlight potential recommendations to pursue a more robust, fair, and transparent digital farmgate sector, considering the needs of platform operators, small- and medium-scale farmers, local food consumers, and farmers' market and food hub managers.

In this research, we undertook a review of the digital agriculture literature to identify what is seen as its goals and constituent technologies. We show how AEC tools encapsulate many of the same technical and political issues the literature has raised for other components of digital agriculture, in addition to advancing empirical work exploring the lived challenges related to lack of data interoperability faced by producers and markets Most definitions of digital agriculture define its potential to make efficiency gains across the value chain, "from field to fork." Despite this, e-commerce platforms are not widely discussed within digital agriculture literature. In what follows, we discuss the results of our focus groups and connect these findings to the digital agriculture research that discusses power and technical issues of digital agriculture. We then discuss potential solutions to some of the challenges highlighted from the research, suggesting potential directions for e-commerce tools to realize their maximal benefits for local food systems.

E-commerce platforms can create robust, distributed food system networks and open markets for smallholder producers (Oncini et al., 2020). Our research confirms that local food system stakeholders in Ontario have observed substantial business-related benefits since adopting these tools and that they see a potential role for these technologies in bolstering local food systems. Ontario's local food context may be similar to other jurisdictions in North America, Europe, and Australia. We also found stakeholders are positive about digital technologies as a means to create systems-wide change, such as making food more accessible to lower-income individuals. Further research is required to substantiate this finding elsewhere and to see if this attitude translates into practice, given the higher market price of local, organic, niche, or ecological products and the lack of guarantee that locally produced food results in more ecological production methods or accessible prices (see Born and Purcell, 2006). Despite their multiple potential benefits and increasing use within local food systems' contexts, e-commerce tools are not widely examined or reported upon in the digital agriculture literature. It is crucial to define the challenges that face their use, and to design solutions to achieve their most widespread benefits.

We also found that study participants experienced substantial challenges related to lack of inter-platform interoperability, confirming other findings that interoperability is a challenge facing food production stakeholders (Bahlo et al., 2019). Indeed, a significant barrier that stood out from our research was that given the fragmented nature of the digital farmgate sector (where data is siloed within and between platforms, and users are forced to management multiple datasets), stakeholders are forced to develop and fill multiple "niches" within their business to use these tools. This requires extra time and labor to perform repetitive tasks (e.g., filling in the same inventory across multiple platforms), leading to frustration and even sometimes discontinuing platform use. Fragmentation also occurs between markets/hubs and farmers. Our results indicate that farmers' markets and food hubs are more likely to use tailored platforms, as compared to farmers. We found that farmers are more likely to use generic platforms (60%) to host their online storefronts (e.g., Shopify), as compared to joining tailored platforms (40%) dedicated for local food systems. Farmers' markets and food hubs indicated they sometimes have a challenging time recruiting vendors. This issue is due to markets and hubs having different, and often more complex, e-commerce needs than producers; this leads to a steeper learning curve for producers to navigate and adopt tailored platforms, and might explain their preference for generic platforms.

Various factors shape farmers' and vendors' use of technologies. Many technologies are expensive and often only available to already capital-intensive farmers with abundant access to land (e.g., Rotz et al., 2019b). Price was somewhat of a concern to our participants, many of whom were small- and medium-scale ecological farmers. Climate-related challenges (e.g., drought, seasonal rain variability) play major roles in farmer decision-making around technology adoption, as these likely affect return-on-investment (Higgins et al., 2017). Echoing this literature, we found that the pandemic was a major force driving increased adoption of digital farmgate sector platforms by farmers, farmers' markets, and food hubs. In the context of the pandemic and in-person market closures, farmer and vendor adoption of these tools was a common adaptation strategy.

The most definitive challenge that stood out in our results was lack of vendor/farmer interest in using new platforms, due to interoperability-related barriers. Most participants agreed that it was challenging to navigate order management, inventory lists, and sales between their various digital farmgate platform options. This was made clear in focus group conversations, where participants expressed frustrations that no digital farmgate platforms could accommodate data from other platforms, forcing them to load data manually or stop using online platforms altogether. It may be the case that farmers/vendors are not inclined to participate in whatever online solution a farmers' market or food hub has to offer if it differs from their current platform, due to additional data administration software service costs. This echoes literature documenting the struggles faced by farmers with digital hardware, where they become "locked-in" to suites of tools offered by competing firms (Rotz et al., 2019a).

We situate these challenges experienced by farmers, farmers' markets, and food hubs within a larger political economic context. Currently, an array of digital farmgate platforms exist in the marketplace to facilitate direct-to-consumer sales, such as Open Food Network, Local Line, Local Food Marketplace, Harvie, and many others. The current digital farmgate economy is fragmented and embedded in a competitive market economy (Oncini et al., 2020). Importantly, none of these digital farmgate platforms are currently integrated and cannot yet "speak" to one another: they lack interoperability. This results in the dilemmas that we observed through our research, such as farmers' markets struggling to recruit vendors, increased workload of manually transferring data between platforms, and even markets shutting down. It is crucial that digital agriculture scholarship engage with e-commerce tools, given the challenges of interoperability already defined in the literature (see e.g., Rotz et al., 2019a). Yet, it is also crucial that digital agriculture literature move beyond critique to define solutions to these challenges. We turn to some of these potential solutions below.

There are a few separate scenarios in which lack of platform interoperability could be addressed. The first is a scenario in which a single consolidated platform is commonly adopted across the local food sector or buys out competing platforms. This scenario is not unlikely, as it has occurred across most (if not all) major digital technology sectors. Since 2013, fifty of the major platforms have acquired over 400 startups, with a substantial percentage discontinued within a year after the acquisition (Lechardoy et al., 2021). Mergers and acquisitions continued during the COVID-19 pandemic as the top platform companies recorded record profits when consumers moved their shopping online. There is less data regarding consolidation within the agriculture e-commerce space, yet a few key case studies illustrate that consolidation may grow in the near future. For example, the movement of Amazon (and Whole Foods Market) into this space has pushed smaller platforms, like Farmigo, to shift from food distribution and logistics to software development for local food hubs, Community-Supported Agriculture, and smaller-scale markets (Adams, 2017). Other platforms such as Shopify have recently included guidelines on selling food and perishables. Overall, consumer interest in local food and transparent value chains is prompting industry discussion and investment within the digital farmgate space. E-commerce tools may act, in this case, as a vehicle for accumulation for large corporate giants from agriculture, tech, and potentially even other sectors. Indeed, some of the biggest companies in the world, such as Alibaba, Amazon, and Facebook, rose to prominence with e-commerce tools; will they turn their attention to agri-food e-commerce, specifically?

If most farmers, farmers' markets, hubs, and local food organizations all used a single platform, this would address many of the interoperability-related challenges identified above. However, it would do little to address power imbalances between food producers and technology providers (see e.g., Hackfort, 2021). The form of control or sovereignty that platform users would have over their data, platform development, and platform features would be at the sole discretion of the technology provider. More broadly, concentration in agri-food markets affords single private firms greater control over market dynamics, technology and innovation pathways, and policy agendas (Clapp, 2021).

The second scenario is horizontal integration, wherein individual platforms partner with each other to establish interoperability. Horizontal integration amongst individual platforms is a potentially effective approach in the short-term. Individual integrations between common digital farmgate sector platforms (both tailored and generic) would help users navigate the complexity of choosing different e-commerce tools. It would assist markets and hubs in attracting more vendors and would provide multi-channel sales options and additional markets for vendors to scale and sell more widely. However, this approach would do little to reconfigure the political economy of the digital farmgate sector. Users would still run into interoperability-related issues if their platform was not horizontally integrated with others. Consolidation could also still occur across the sector, albeit where pairs or small groups of companies dominate market share as opposed to single entities.

The third scenario would see the development of an open standard for the whole sector, where participating platforms would develop and use a commonly agreed-upon "data architecture" that would allow for inter-platform communication. This scenario is likely to be the most difficult to realize in practice but, we argue, may potentially lead to the most equitable food system outcomes. This is because an open standard is both a technical as well as a governance-based solution.

These three scenarios describing increased interoperability are embedded in policy and regulatory landscapes that shape which scenario is actualized. Importantly, government may incentivize or even mandate the design of interoperability standards within industry. The European Union has been at the forefront of such efforts, with various interoperability-related proposals in the past decade and the recent Digital Markets Act that requires a base-level of interoperability between small businesses and "gate-keeping" platforms (European Commission, 2022). However, some scholars argue that there are tradeoffs to the strong, top-down imposition of interoperability-related policies, and have argued instead that: "Before mandating access, policy makers, regulatory and competition authorities should strive to support decentralized bottom-up interoperability solutions wherever possible (Kerber and Schweitzer, 2017)."

In this light, one promising approach to addressing interoperability issues is the voluntary, cooperative development of an open standard between industry stakeholders. This interoperability solution aims to develop a common language for consenting platforms to communicate with one another in a cooperative marketplace. While this proposal might sound radical, it is already adopted in public governing bodies and called for by digital advocacy organizations. Open standards are often seen within governments and public bodies, where efficient inter-department communication is required (Sieber and Bloom, 2018). The Government of Canada, for example, has an open standard plan (Government of Canada, 2022). A variety of governments, non-governmental organizations, and international governance bodies developed the "Principles for Digital Development": a living document that guides the development of digital solutions and includes a call for open standards (Principles for Digital Development, 2022). Examples of open standards in the local food sector include the Food Data Collaboration–an application of the DFC open standard in practice. Some open standards, such as the DFC open standard, are integrated with emerging decentralized data storage and sharing technologies such as the web platform Solid (Solid Project, 2022). The need for alternative data governance standards has emerged as a hot-button issue in wake of continued misuse of user data from large platforms (e.g., Cambridge Analytica Scandal, see Confessore, 2018). Emerging technologies such as Solid allow users to store their own data in data stores and self-determine with whom they share it (Solid Project, 2022). Paired with an open standard, decentralized data storage and sharing technologies would make for a highly modular, interoperable technology ecosystem where users, rather than platforms, have agency to choose the technologies that work best for them and where and how their data is governed. In this paper we focus on solutions designed to enhance interoperability rather than data security and sovereignty. Future work that explores the intersection between solutions designed for interoperability and data sovereignty is required (Wiseman et al., 2019).

This voluntary approach stands to make competition between platform economies fairer. Collaboratively developing this language makes for a more responsible innovation practice (e.g., Rose and Chilvers, 2018), considering the diverse needs of platforms as well as local food system stakeholders as end users. However, this solution may be challenging to adopt, as it requires voluntary buy-in from competing firms and may involve more time-consuming, deliberative, and democratic procedures in its governance. Despite these potential challenges, an open standard between digital farmgate platforms would allow farmers, farmers' markets, hubs, and local food organizations to organize their data across diverse systems more simply and cost-effectively. Integrated with decentralized data storage and sharing tools such as Solid, technology users would maintain complete sovereignty over their data, determining what data would be sent to which platforms.

Our research responds to critical digital agriculture scholarship that often defines digital tools as being predominantly (or solely) corporate, techno-optimistic, or Silicon Valley-driven vehicles for food system transformation (e.g., Wolf and Buttel, 1996; Miles, 2019). Indeed, much of this research is skeptical of open-source solutions like the open standard, suggesting that these can be appropriated by large firms and that their potential impact and opportunity for systemic restructuring are limited, instead arguing for national and global-scale policy change. Rotz et al. (2019a) summarizes this point as follows:

> "Again, while collectivisation *via* community and user driven assemblages may help to shift farmer dependence away from the corporate food regime, it will not directly address the broader political trajectory of corporate concentration across the agro-food system, nor within ag-tech specifically" (p. 226).

We suggest that these critiques foreclose concrete solutions and obscure alternative political economies that are already being enacted by food system actors. For example, open standards are already widely developed and considered in the broader tech sector and may avoid some of the tradeoffs to government-led mandates or policy that override individual or firm autonomy. Emerging technologies such as decentralized data storage and sharing systems flip the data economy, empowering users to exercise complete sovereignty over their data from the ground-up. Such approaches increase food system actors' agency in face of interoperability-related challenges and may present an appealing approach to navigate the heterogeneity of competing values and preferences held by diverse farmers and local food system stakeholder communities (Carolan, 2020). Our approach to the debate between systemic restructuring vs. bottom-up development and organizing is more methodological in nature, borrowing from design-thinking: an approach to development and research that emphasizes the rapid prototyping and implementation of tools to address user-defined needs (Chou, 2018). It aims to advance practical, small-scale designs with potential to scale. We argue that such an approach is practical, empowering, and non-adversarial. As Balamir (2021) writes:

> "If one wishes to practice design without... perpetuating the unsustainable commodity-machine, two political courses of action are typically available. The first is to produce resistance—"many no's"—so as to build countervailing power. The second is to produce alternatives—"many yes's"—that pave the way to better outcomes. Inherently, design has far more affinity with the task of producing alternatives rather than with those of formulating demands ...It is an affirmative, not adversarial practice" (Balamir, 2021).

An open standard is one potential "design solution" to address the concerns highlighted in theory (by food systems' scholars) as well as in practice (by food systems' actors). Importantly, among other decentralized data sharing models, an open standard is designed to allow participants to share their data for a specific purpose, for a specific time, under specific conditions; there is a clear focus on data sovereignty for all participants in the system (Hummel et al., 2021).

From this research we found that the outcomes of digital tools, positive or negative, are not guaranteed. Despite widespread political economic barriers to realizing the benefits of digital technologies, the stakeholders we talked with have observed substantial business-related benefits and believe these tools can contribute to local food systems more generally. Our research adds more nuance to our understanding of digital agriculture, cataloging how individuals are experiencing these technologies in practice and engaging in discussions regarding potential solutions to the challenges they observe. We note that further research is required to clarify how AEC plays out in diverse geographic contexts, particularly from the Global South. Related, our aim here is not to generalize findings using inferential techniques, due to our small sample size. Rather, our aim is a first-cut characterization of some of the benefits and challenges faced by local food stakeholders, specifically related to interoperability. Future work that engages broader representation from local food and farming stakeholders is required. Nevertheless, our in-depth approach presented here can pave the way for future case study and design-related research that works with local food system stakeholders to develop solutions to meet their unique needs and values (such as Wittman et al., 2020; Ditzler and Driessen, 2022).

5. Conclusion

Scholars critique digital agriculture technologies for furthering inequalities between farmers and among diverse value chain actors. However, only recently has research begun to ask if and how digital technologies are being used by smaller-scale actors in the food system. Further, critical digital agriculture scholarship has yet to examine agriculture e-commerce tools as one component of the "digital agriculture revolution". In this paper, we presented the results of a literature review and exploration of Ontario, Canada's digital farmgate: the suite of e-commerce platforms that facilitate direct to consumer sales. From our literature review, we found that agriculture e-commerce tools, though an integral part of agriculture value chains, are rarely described as a component of digital agriculture. This is despite their potential ability to create more transparent and traceable local food systems, facilitating direct markets between vendors and consumers. From our focus groups, we found that farmers prefer and use different digital farmgate sector platforms than farmers' markets or food hubs. Oftentimes, markets struggle to recruit farmers due to interoperability issues between platforms.

It is clear that digital farmgate platforms are embedded in a political economic context that prevents realizing their full potential for local food businesses and the sector as a whole. A potential solution is the development of an open standard, that would bring platforms together voluntarily to establish a common data sharing protocol. In this case, any farmers, vendors, or markets and hubs on those participating platforms would be able to communicate sales, inventory, and management data with each other. This solution appeals most widely to the stakeholders who took part in our study. Yet, it requires strong collaboration between platforms and an enabling political economic environment. Despite these potential challenges, multiple examples of open standards in food systems' contexts are currently being developed and implemented. Emerging decentralized data storage and sharing technologies such as Solid are being integrated with open standards to further enhance user control and interoperability. These experiments and examples can provide instruction for the development of an open standard for the digital farmgate sector in Ontario.

Data availability statement

The raw aggregated survey data supporting the conclusions of this article will be made available by the authors, without undue reservation. The raw focus group transcript group data supporting the conclusions of this article are unavailable due to anonymity and confidentiality considerations.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AG co-led research design and data collection, as well as led data analysis, and first draft preparation. DT co-led research design and data collection and reviewed drafts. ENo co-led research design and participated in revisions. ENe and TS participated in revisions. All authors contributed to the article and approved the submitted version.

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Conflict of interest

DT and TS work for the Open Food Network-Canada.

The remaining 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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