Title: Investigating Perceptions, Adoption, and Use of Digital Technologies in the Canadian Beef Industry

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Abstract

This research investigated digital technology adoption in the Canadian beef farming industry. The study was carried out from the point of view of two different stakeholders, farmers and veterinarians, to understand current perceptions, level of awareness, and experiences with digital precision livestock farming (PLF) technologies being used on Canadian beef farms. The study specifically focused on the beef feedlot sector in the Canadian province of Ontario. Data from 11 interviews and 24 surveys were analyzed for key themes and patterns. The data was also analyzed through the lens of Rogers' *Diffusion of Innovations* technology adoption theory to help understand the potential for technology adoption among Canadian beef producers. The study findings revealed that feedlot producers use a wide variety of software and hardware technologies, but favoured mature, proven technologies that strongly aligned with their business needs. There was little up-take of PLF technologies that focused on 24/7 individual animal health and welfare monitoring, and evidence was found that current technologies that serve this purpose are both unsuitable and cost prohibitive for the farming practices and business needs of the feedlot sector. The main technology adoption barriers found in the study were costs and return on investment, technology usability, lack of awareness of technologies and their capabilities, and perceived relevance of the technology. The study findings have implications for PLF innovators and industry stakeholders, such as the need for pricing models for products and services that minimize up-front investments, and the need for user-centred design of PLF technologies that bridge the gap between technology capabilities and user needs and expectations.

Keywords: precision livestock farming, smart farming, technology adoption, beef industry, Canadian farming

1 Introduction

Beef farming in Canada is a challenging business. Rising feed and transportation costs, increased global competition, unregulated market prices, slaughterhouse closures, and other factors have led to decreased profit margins among beef producers. Globally, beef farmers are choosing to increase the number of cattle on their farms to meet increasing consumer demands and to ensure a higher return on investment (Berckmans 2014). A 2016 national agricultural census found a similar trend on Canadian beef farms, with fewer farms (down by 12.3%) managing more cattle (up by 11.3%) compared to the census take five years prior (Statistics Canada 2016).

Adopting precision livestock farming (PLF) methods, whereby farmers use advanced technologies to automate animal monitoring, disease detection, record-keeping, feed management, and other livestock farming operations, can help optimize and improve farming practices (Lima et al. 2018; Banhazi et al. 2012). Although there has been wide adoption of certain PLF technologies, such as automated handling of feed, excrement, bedding, and ventilation (Hostiou et al. 2017), the adoption of other PLF technologies has been slower in certain livestock sectors.

To date, only a few studies have been conducted on the adoption and use of precision farming (crop or livestock) technologies in Canada. To our knowledge, none have focused specifically on the beef sector. Canadian studies on crop farming (Steele 2017; Duncan 2018; Mitchell, Weersink, and Bannon 2020) and dairy farming (Duncan 2018; Tse et al. 2018; Islam and Scott 2021) have uncovered barriers that can hinder technology adoption, such as the accessibility and usability of the technology and a lack of perceived relevancy of available technologies. Duncan's (2018) investigation of the social impacts of technology adoption in both the cropping and dairy sectors in Canada found that farmers often rely on technology vendors for extensive training and technology support due to the complexity of the technologies. This complexity also led to underutilization of the technology's capabilities.

Tse et al.'s (2018) study of automated milk system (AMS) use on Canadian dairy farms found significant changes were needed in animal housing infrastructure, including construction of new barn facilities, to accommodate AMS adoption. This highlights the substantial financial investment required to adopt this technology. Indeed, Duncan (2018) found that dairy farmers invested between $1.2 million to $3.2 million (CAD) to adopt AMS technology, including the costs of the technology, infrastructure changes, and service contracts.

Studies of technology adoption among crop producers in Canada found widespread use of wireless and cable Internet and Global Position System (GPS) technologies, but much less use of other technologies (Steele 2017; Mitchell, Weersink, and Bannon 2020). Technology cost and uncertain value were found to be key adoption barriers among surveyed farmers.

Outside of Canada, there is a similar lack of technology adoption studies focused on the beef industry. A technology adoption study conducted in 2011 of innovative Brazilian beef farmers found that farmers avoided technologies that lacked relevance, compatibility with existing farming practices, or did not provide a strong overall advantage over alternatives, including the status quo (de Aragão Pereira and Woodford 2011). The study also found that opportunity to trial technologies before purchasing facilitated adoption, while complexity and poor usability were barriers to adoption. Their definition of technology was very broad and focused on generalized technologies and practices, including animal identification and use of managerial software, rather than on more specialized hardware and software technologies available today. Furthermore, digital technologies have become much more common in broader society over the past ten years, which may impact farmers' likelihood of technology adoption.

A more recent Swiss study on technology adoption on ruminant farms, including beef cattle, found little uptake of technology on Swiss beef farms, with transponder collars, automated calf feeders, data transfer into herd management systems, and digital weigh systems the most commonly used technologies (Groher, Heitkämper, and Umstätter 2020). They found only 1% adoption of electronic ear tags, which is in stark contrast to Canadian beef operations where, due to government traceability regulations, cattle must be fitted with radio frequency identification (RFID) ear tags when leaving their farm of origin (Canadian Food Inspection Agency 2016).

Since most Canadian beef cattle are born on a cow-calf (breeding) operation and then sold to a feedlot operation to be raised until market ready, most will be fitted with RFID ear tags before arriving at a feedlot. Many PLF technologies are designed to leverage RFID ear tags (e.g., digital weigh scales, activity tracking ear tags); thus, there seems to be significant opportunity in Canada to utilize this existing, mandated technology in the beef industry. However, it is unclear how beef farmers are using RFID ear tags in practice and how common the use of other PLF technologies currently is.

To fill this knowledge gap, we conducted a study focused on understanding the uptake and potential barriers to adoption of PLF technologies in the Canadian beef industry. The study involved an online survey and phone interviews with relevant stakeholders in the local farming region, including beef farmers and veterinarians from the province of Ontario, Canada. The study findings revealed little adoption of real-time 24/7 individual animal monitoring technologies, but some adoption of digital technologies that support record-keeping and reporting, animal weighing, feed mixing and measuring, and herd management was found. The study revealed several factors influencing the low adoption of technology in the beef industry, including lack of awareness of the technologies, unclear potential return on investment, usability of the technologies, and perceived lack of relevance. The study also revealed key pain points of Canadian beef producers. PLF innovators can leverage the study's findings to guide the development and marketing of technologies that better meet the needs and expectations of Canadian beef farmers, and create strategies that help increase PLF technology adoption within the industry.

2 Materials and Methods

An online survey and phone interviews were conducted with beef farmers and veterinarians of Ontario, Canada between January and March 2020 to investigate technology adoption on Canadian beef farms. All data collection methods were reviewed and approved by our university's research ethics office.

2.1 Study Context

The study was conducted in the eastern province of Ontario, which contains the third largest beef population in Canada. Most Canadian beef farms are relatively small, with an average size of 110 cattle; however, regional variations exist with much larger farms (20,000+ cattle) primarily located in western Canada (Statistics Canada 2016). Beef cattle in Canada are commonly born on cow-calf (i.e., breeder) operations and then sold to feedlot farms where they are fed high-quality grain and forage until they reach market weight (Alberta Cattle Feeders' Association 2017). While cow-calf operations commonly raise cattle outdoors in pasture and open range habitats, feedlot operations raise cattle in indoor or outdoor pens or yards for efficient feeding prior to slaughter (Canadian Council on Animal Care 2009).

Feedlot producers and veterinarians who specialize in feedlot cattle were recruited to participate in the study to provide a broader view of technology adoption in the region. This industry sector was chosen for a first study of adopting in the Canadian beef industry due to the more hands-on nature of animal feeding and care than typical cow-calf operations. The study focused on this producer group because of the highly controlled, high animal-contact nature of animal production where farmers provide controlled diets consisting of forage and grains and monitor animals regularly for health and dietary issues. Thus, the nature of these operations may be more likely to lend themselves to existing PLF technologies on the market that focus on individualized health and welfare monitoring of livestock.

While the term PLF "technology" covers a wide range of potential innovations, including genetic screening, nutrition design, and other animal science advances, the study focused on *digital technologies*, including desktop and mobile software applications, digital equipment, automated environmental controls, biometric sensors, and radio frequency identification (RFID) tags.

2.2 Participant Recruitment and Demographics

Recruitment of farmers for the online survey and follow-up interviews was done through various channels to try to reach as many producers in the area as possible. Study announcements were distributed via email and weekly bulletin notices from a provincial beef industry association and via social media channels (Twitter and LinkedIn) of the research team, the university, and their connections. Also, a brief talk was given to producers at a provincial industry conference and postcards were distributed in the attendees' registration package. Online survey participants had a chance to win one of five $40 randomly drawn prizes. Farmers who took part in the follow-up interview received an additional $20 for participation.

Nine farmers who completed the survey also participated in follow-up interviews. To provide a broader experience with many different beef operations, two beef feedlot veterinarians who worked in Ontario were also recruited for interviews. They were recruited by reaching out directly to large veterinary services that specialized in feedlot animal care. They were paid $20 for participation.

2.3 Survey Design and Implementation

The survey was designed in collaboration with beef industry and animal science experts. It went through several iterations based on feedback from experts. The survey was divided into four sections. The first section collected demographic information, including age, years of experience, size of farm, and farm location. The second section focused on understanding the types of technology, at a high level, farmers were using or had used in the past, what their experiences were with technology, whether and why they

had stopped using a previously adopted technology. The third section focused on understanding farmers needs and challenges, and if they had considered using technology to automate any challenging or tedious farm tasks. This section aimed to understand the gap between the perceived value of technology capabilities and actual technology adoption. The last section focused on farmers' awareness of commercially available PLF technology and identifying factors limiting adoption of this technology. Participants were invited to participate in a follow-up interview.

The survey was implemented as an online survey using the Qualtrics (Qualtrics, Provo, UT, USA) commercial survey tool[1]. Participants completed a consent section on the survey landing page before gaining access to the main survey. The Qualtrics tool was also used to facilitate the survey data analysis, specifically for descriptive analysis of the collected quantitative data. Qualitative data collected in free-form questions were analyzed together with the interview data.

2.4 Interview Design and Data Analysis

Interviews were used to provide deeper insights into the collected survey data. Two sets of interviews were designed, one for farmers and one for veterinarians. The farmer interviews had similar questions to those described for the survey design, but were framed as open-ended questions to provide more insights into the collected survey data. The veterinarian interviews had two types of questions. The first aimed at understanding veterinarians' perceived value, awareness, and perceived usability of technology used on Ontario feedlots. The second focused on identifying challenging processes on feedlots that could be automated by technology. All interviews lasted about 20-30 minutes and were conducted via telephone. Participant submitted consent forms via email prior to their scheduled interview.

Interviews were recorded (with consent). The interview audio files were manually transcribed and then coded using the NVivo (QSR International, Melbourne, Australia) qualitative analysis software tool[2]. An open coding method was used (Corbin and Strauss 1990), whereby the interview and free-form survey data were reviewed for key themes. The data was then coded based on identified themes. The resulting themes are discussed below.

3 Results

The survey and interviews revealed many insights related to the use and perspectives of PLF technologies in Canadian feedlot operations. Key themes revealed by the data analysis are discussed below, and include what technologies Canadian feedlot producers are currently using, the perceived value of these technologies, what level of awareness Canadian farmers have of existing technologies, key needs and challenges in feedlot operations, and barriers farmers face related to technology adoption.

3.1 Survey Demographics

We received 52 recorded attempts for the online survey. After filtering for completeness, eligibility (e.g., over 18, IP address from an Ontario location, feedlot producers), and logical responses to the questions, we retained 24 valid surveys from feedlot farmers to include in our analysis. Seventeen (71%) participants were male and 7 (29%) were female. Twenty-three participants indicated their job roles. Most participants (16/23) reported that they were farm owners/operator, five reported they were herdsman/lead hand, and two reported they were farm employees. Participants worked on a range of farm sizes, including less than 100 cattle/year (4/24), 100-500 cattle/year (6/24), 500-1000 cattle/year (7/24), 1001-3000 cattle/year (5/24), and over 5000 cattle/year (1/24). In terms of experience, most participants (13/23) reported they had more than 10 years of beef farming experience, six had 6-10 years of experience, and four had 2-5 years of experience.

[1] https://www.qualtrics.com/
[2] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software

Table 1. Summary of PLF technologies farmers' reporting using on their feedlots.

Reported Technologies in Use	No. of responses	Exemplar comments
General purpose computer, business software, mobile applications	8	*"MS Excel", "Excel for record-keeping", "Compass", "Quickbooks", "Quip smart phone app", "computer data entrance [sic]", "software", "smart phone", "computer system", "Bluetooth", "USB stick", "laptop"*
Specialty software for cattle / feedlot management	6	*"Performance Beef", "Performance Livestock Analytics", "data based for cattle", "cattle management system"*
Feeding software, systems	6	*"TMR"* (total mix ration feed mixer system), "feed software", "feeding"
Chute system with digital weigh scale system that scans RFID tags	5	*"digital scale TSI[5]", "chute system…animal comes on the ear tags automatically gets read", "weigh system … It has a RFID scanner", "scanner, scale", "RFID readers and weight scales"*
Animal identification and traceability technologies	3	*"RFID reader and computer system"* (RFID: Radio frequency identification), *"Gallagher" (HR3 hand-held RFID reader)[6]*
Crop / Planting technologies	2	*"Precision planting technologies", "GPS on tractors for planting", "Autosteer"*
Environmental controls	1	*"thermostat fans"*

3.2 Technology Currently in Use

The survey provided opportunities for farmers to identify general or specific technologies used on their farms in free-form comments in response to the questions, *"In your opinion, which technologies you have implemented have been the most valuable on your operation?"* and *"How are you currently keeping records and collecting data on your farm?"*. Farmer interviews revealed additional technologies. Table 1 summarizes the technologies reported by farmers. General purpose and business desktop and mobile applications, such as Excel[3] (Microsoft, Redmond, WA, USA), Quickbooks[4] (Intuit Inc., Mountain View, CA, USA), laptop, computer, and Bluetooth, were most commonly reported. Specialized farming software and equipment were also reporting, including cattle and feedlot management software and feeding systems and software. Various technologies that integrate RFID ear tag reading capabilities were reported, including digital weigh scales and chutes and portable RFID readers. Eight out of 24 farmers reported using either solely or partially paper-based record-keeping methods (e.g., *"notebooks", "handwritten paper",* or *"Paper based and MS Excel"*).

Farmer interviews clarified the use of some reported technologies, for instance, to what extent the RFID-based ear tag technology is integrated into farm infrastructure (e.g., cattle weigh scales) for automatic data collection, and processes around data collection and sharing. There was wide variety of reported systems and practices in place related to animal tracking and monitoring. No participants reported any fully automated system for individual animal monitoring. Some farmers used digital weigh scales that automatically scan RFID ear tags to connect weight measurements with individual cattle identifiers, but the collected data had to be manually transferred via a universal serial bus (USB) stick (i.e., thumb drive) to their computer for processing in a spreadsheet like Excel. Other farmers used a hand-held RFID reader to collect individual cattle data but only used it for cows entering or leaving the farm, and others collected paper-based records only, without using the RFID ear tag data.

Some farmers reporting using various cloud-based software systems to facilitate data sharing among farm staff. For example, one farmer (Farmer 3), used a free productivity application, called Quip[7] (Quip, Inc.,

[3] https://www.microsoft.com/en-ca/microsoft-365/microsoft-office
[4] https://quickbooks.intuit.com
[5] https://am.gallagher.com/en-ca/products/1085/weigh-scales-and-data-collectors
[6] https://am.gallagher.com/en-ca/solutions/weighing-and-eid-solutions
[7] https://quip.com

San Francisco, CA, USA), to share Excel-based data via the cloud to other farm staff's mobile phones. Other farmers reported using the Performance Beef[8] (Precision Livestock Analytics, Ames, IA, USA) feedlot management system to share feeding schedule data via the cloud with other farm staff.

The Performance Beef system was the most commonly reported farm-specific software system used by study participants. It was explicitly reported being used by four surveyed farmers, three of whom were interviewed. The interviews revealed various ways farmers used this feedlot management system. Some farmers used its ability to integrate with feeding equipment, specifically, to get precise feeding information from a total mixed ration (TMR) feed mixer system and automatically share this information with the Performance Beef mobile application on a iPad or iPhone. Other farmers used the software application capabilities only, for instance, to input weight and feeding data, and to share data via the mobile application with other farm staff in real-time.

Analysis of the farmer interviews revealed that feedlot farmers primarily monitor their animals at the group or "lot" level, tracking feeding at the group level, typically averaging feeding and market performance across a group of cattle raised together. Consequently, herd and feed management systems were commonly reported technologies.

Interviewed veterinarians reported common technologies used on regional feedlot farms. While there was some overlap in the technologies discussed by both farmers and veterinarians, such as RFID ear tag technology and digital weigh scales, they also mentioned additional technologies like such as "bunk scoring" camera systems used to manage the feeding trough (or bunk) and smart ear tag systems that monitor cattle temperature.

Overall, the data analysis found little evidence of the use of 24/7 individual animal monitoring technologies. Only one producer, a client of an interviewed veterinarian, was reported to use such technology (smart ear tags). One interviewed veterinarian and one interviewed farmer commented that these technologies are currently not cost effective for the beef industry, as illustrated by the comment, *"There's lots of technology the dairy industry is using, like tracking animals in the pens or measuring feed per animal, things like that. I don't think we are there yet. … it's cost prohibitive." (Farmer 9)*.

3.3 Perceived Value

The survey probed the types of technologies farmers were using at a high-level, focusing on the technology capabilities and perceived value of the technologies, rather than specific technologies or brands. Farmers were asked to select from four predefined benefits in response to the question, *"How has technology improved the efficiency of your farming operations?"*. Of the 18 farmers who reported using technologies on their farms, 15 responded to this question. As Figure 1 shows, the most commonly reported benefits included improved animal health and welfare (80% and 66.7%, respectively), followed by time savings (60%) and reducing labour cost (53.3%). Six producers (40%) reported all four benefits.

The survey also asked farmers about the potential benefits of technologies they had considered adopting, asking them to rate on a 5-point Likert scale how well they felt the considered technology would improve animal health or welfare, increase profits, or reduce labour costs. Figure 2 summarizes farmers' responses. As the figure shows, many farmers (50-61% in each category) were quite positive in their perceptions of the potential benefits of PLF technologies. However, there were still many farmers (39-50% across categories) who were either neutral or disagreed with the potential benefits.

[8] https://www.performancelivestockanalytics.com/performance-beef/

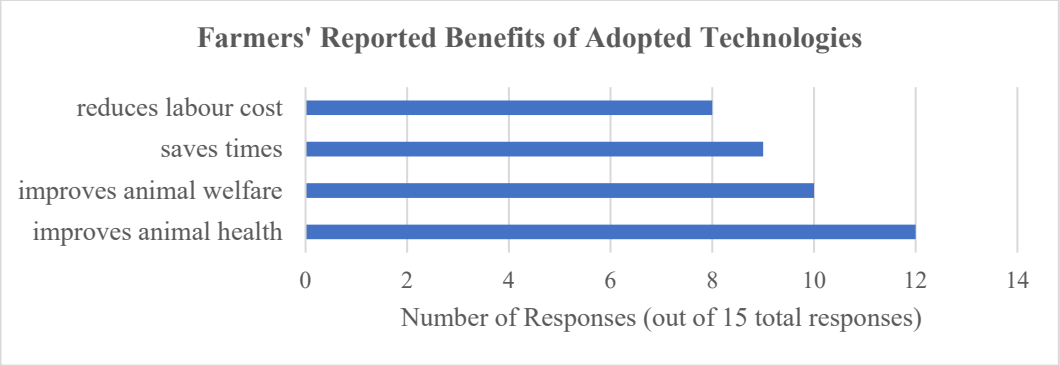

Figure 1. Survey responses to the question *"How has technology improved the efficiency of your farming operations?"* (15 total responses).

Farmer interviews confirmed the survey findings and provided a deeper picture of the benefits provided by PLF technologies currently used by feedlot farmers. Farmers mentioned many of the technologies reported in Section 3.2. Several farmers discussed their adoption of automated weigh scales, which enabled more accurate and efficient data collection and farm decision-making, as illustrated by the comment, *"The weigh scale is way more accurate. We used to have to truck the cows out to get weighed. Now we have it there and it's way better for data collection. It's made a huge difference for us and how we evaluate our farm." (Farmer 8)*.

One participant (Farmer 3) reported that one technology they had been using for three years, the Performance Beef application, had been *"Life changing"* because it allowed them to easily communicate their custom feed schedules to other farm staff. They, along with several other farmers, commented on how useful this application was for record-keeping, especially when multiple people were involved in farm operations. Its cloud-based design stored all farm data in a central place that allowed for real-time data access from multiple devices.

For farmers who had adopted only a minimal level of technology, for instance, a hand-held RFID ear tag reader, they still valued the positive labour aspects this technology provided, including efficiency and safety during routine, if infrequent, cattle processing, as illustrated by the comment,

> *"It helps us capture a series of numbers which eliminates manual tag reading and harm that could come from trying to reach in and grab the ear… it does add [value] to peak processing periods in the year. About 4 times a year … when we bring in and process cattle." (Farmer 4)*.

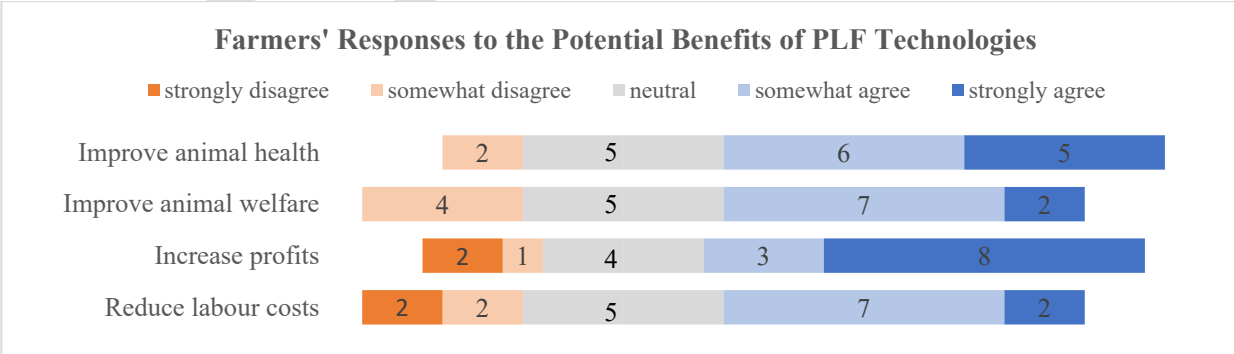

Figure 2. Survey responses to the question *"Do you think this technology would have the following benefits?"* (18 total responses), where "this technology" referred to a technology they had considered adopting.

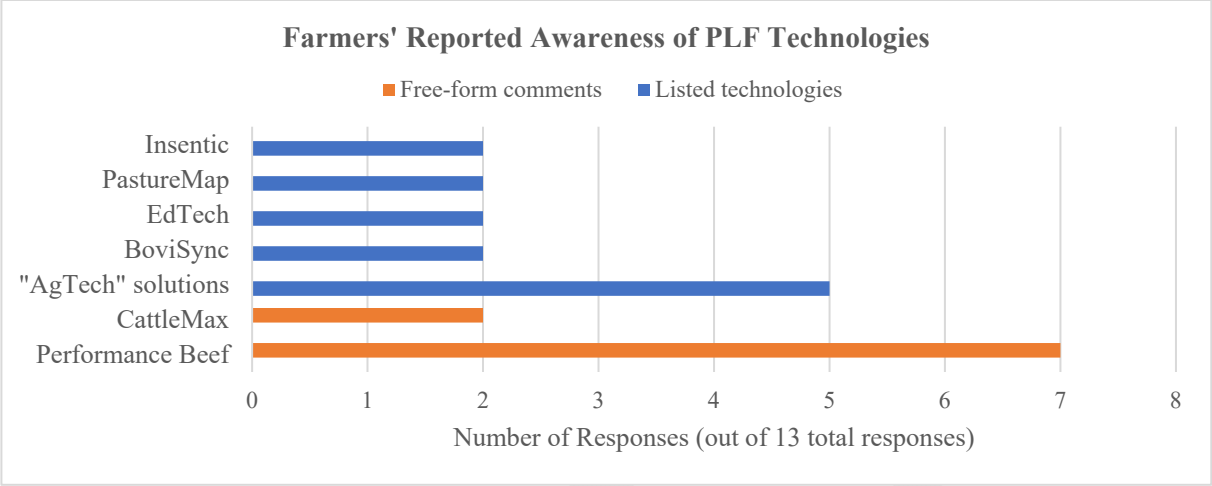

Figure 3. Survey responses to the question *"Which of the following feeding and herd management technologies are you aware of?"* (13 total responses). Farmers most frequently reported free-form comments are also shown.

3.4 Awareness

The survey probed farmers' knowledge of existing PLF technologies. Participants were asked to identify available cattle feeding or herd management technologies they knew, from a prepopulated list, including general "AgTech" (agricultural technology) solutions for herd management, and specific commercial products for herd management, including BoviSync[9] (BoviSync, Fond du Lac, WI, USA) and EdTech[10] (Milc Group, San Luis Obispo, CA, USA), a grazing and land management solution, called PastureMap[11] (PastureMap, San Antonio, TX, USA), and an automated feeding solution called Insentec[12] (Hoko Farm Group, Marknesse, The Netherlands). They were also given an opportunity to report other herd management and/or feeding technologies they knew of in free-form comments.

As shown in Figure 3, only a few farmers were aware of the specific products listed in the survey, while several (5/13) knew about the general class of technologies known as "Agtech" solutions. Additional technologies were reported in free-form comments. Performance Beef and CattleMax (Cattlesoft Inc, College Station, TX, USA) herd management and record-keeping software systems were reported by multiple farmers, while individual farmers reported the DNS (Dynamic Nutrition System; RUM&N Sas, Reggio Emilia, Italy)[13] feed ration software and the ADC[14] (Ag Data Coalition) non-profit organization that collects agricultural data. One farmer provided an ambiguous response ("Cattle Tracker"), which to our knowledge is not a specific product name, but may refer to herd management and record-keeping systems like those mentioned above.

Low awareness of PLF technologies was confirmed by the interviews, as illustrated by the comments,

> *"I think one big problem beef guys have is that a lot of them don't realize some of the technology exists. Access to it and also knowing about it is one of the biggest barriers." (Farmer 3)*, and

> *"For the people selling it, more trials and show them first-hand. If I wasn't involved, I don't think my dad would think about it or even known about it." (Farmer 2).*

[9] https://bovisync.com/en/
[10] https://www.milcgroup.com/one/
[11] https://pasturemap.com/
[12] https://www.hokofarmgroup.com/ric/
[13] https://www.rumen.it/en/ndspro
[14] http://agdatacoalition.org

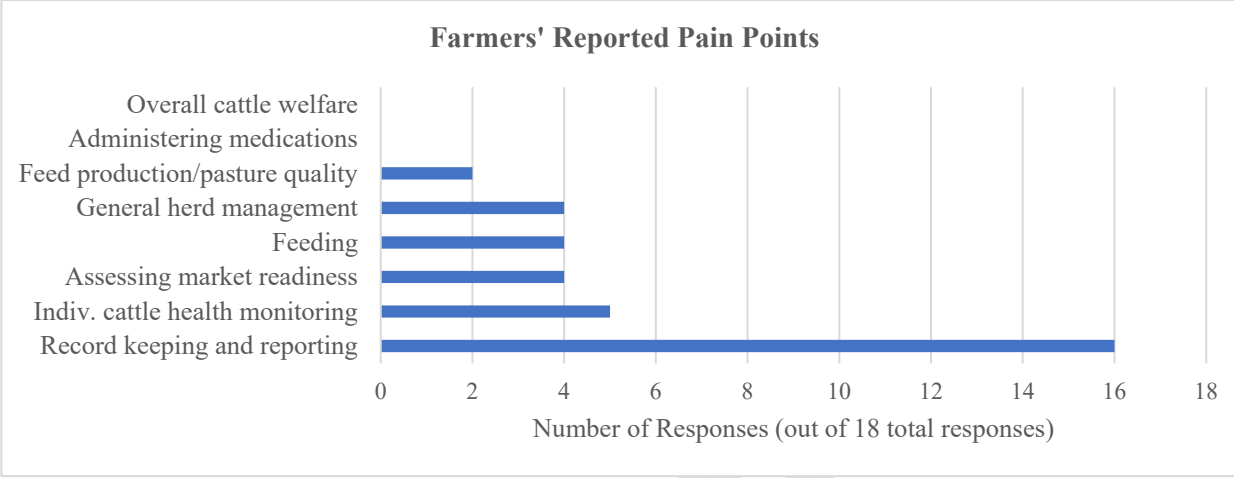

Figure 4. Survey responses to the question *"What are the most difficult aspects of your job?"*. (18 total responses.

3.5 Farmers' Needs and Challenges

To understand farmers' needs and pain points the survey asked participants to select from a list of potentially difficult aspects of their job. Potential pain points and farmers' responses are shown in Figure 4. As shown, record-keeping and reporting was the most commonly reported pain point of their job (16/18 farmers). It was selected by *three times* more farmers than any other job aspect, with individual cattle health monitoring (5/18) the next most commonly reported pain point. Notably, managing cattle welfare and administering medications were not selected by any farmers as challenging tasks.

Pain points identified by farmers in free-form comments include marketing fed cattle and dealing with the packers (slaughterhouses). Interviewed farmers identified additional pain points, as summarized in Table 2. Both the interview and survey responses show that while most farmers find record-keeping and reporting difficult, there is also wide variation in the challenges and pain points reported by farmers, as summarized in Figure 2 and Table 2.

Table 2. Summary of interviewed farmers' responses to the question *"What are the most difficult aspects of your job as a beef producer?"*

Reported Challenges	Responses	Exemplar comments
Marketing related tasks	4	*"Stressful would be the market, what is out of our control" (Farmer 2); "90% of my day is marketing. Chores are easy compared to that." (Farmer 8)*
Barn chores	2	**"***Time consuming … cleaning and bedding cattle, hauling manure" (Farmer 2); "Time consuming would be bedding" (Farmer 1)*
Feeding / feed production	2	**"***Time consuming would probably be the whole feeding. Feeding cattle, making feed… try to limit waste … and maximize the gains." (Farmer 4)*
Processing cattle	1	**"***weighing each animal on arrival for implant time"* (Farmer 9)
Managing herd health	1	*"Stressful would be herd health, we all want to do a good job of keeping them healthy … sometimes that's not possible." (Farmer 5)*
Dealing with weather effects	1	*"Time consuming … weather. Things melted … the barn flooded" (Farmer 5)*
Meeting regulatory requirements	1	*"Meeting regulatory requirements. Things are always changing … add[s] a lot of stress … it requires time to make sure you meet regulations." (Farmer 4)*

3.6 Usability of Technology

To understand farmers' user experiences with adopted technology, the survey asked participants whether they required any expert assistance to learn or use a technology they were using. Many farmers (10/18) required some type of expert assistance, while fewer reported being able to use their technology without assistance (7/18). One reported being unsure. The interviews offered additional insights into what farmers found easy or difficult about using their technologies. Two farmers who used the Performance Beef software reported that it was *"super intuitive and easy to get onto" (Farmer 2)* and *"Very easy to use, very basic." (Farmer 6)*.

An interviewed farmer who used an automatic RFID ear tag reading system reported finding data management and use difficult, as illustrated by the comment,

> *"[M]anaging the data is where you need the expert assistance to set up the template or download the app, those types of things. The actual tool is easy to use, but capturing the data and effectively making use of the data requires assistance, like higher tech than I am." (Farmer 4)*.

Another interviewed farmer commented that because they were a *"pretty young farmer"* the phone-based application they used to manage their automated barn fans was easy to learn and use, but that they had to *"tinker with it"* to get it set up in a way that their father could use, stating that, *"The way it came, it would have been difficult to analyze unless you knew what you were doing." (Farmer 8)*.

Some farmers reported that they stopped using previously adopted technologies due to their poor usability. For example, one survey participant reported that *"lack of tech support" (Farmer 2)* was the reason why they abandoned a previously adopted technology.

The veterinarian interviews confirmed the importance of technology usability for adoption and use. One veterinarian specifically reported that ease of use of the technology was a key challenge to technology adoption, as evidenced by their comment,

> "*Ease of use is a big one [challenge to adoption], to a lot of our producers if they are going to use it. There are young guys starting to take over, and there are a lot of older generation farmers. If it is not intuitive and easy to use and implement, then it won't get used." (Vet A).*

While some PLF technologies, such as smartphone-based applications, leveraged farmers' familiarity with this technology in their everyday lives, as per the comment, *"Everyone has smartphones today. So, I think if you can run a smartphone you can handle any of the stuff my clients have." (Vet A).* However, the interviews also suggest that not all technology capabilities, even technologies that appear simple to use on the surface, are being fully utilized by farmers, suggesting usability or perceived relevance issues, as illustrated by the comment,

> *"A lot of producers have technologies that are underutilized. It is important if you are going to invest in this stuff that you are religious with using and managing it. Because it will pay you to have it if you manage it properly." (Vet B).*

3.7 Barriers to Adoption

To understand the potential barriers farmers face in addressing their farming needs through technology adoption, the survey asked farmers to select from a list of potential barriers in response to the question, *"What are the barriers stopping you from automating or using technology to help manage the operations?"*. Figure 5 shows the listed barriers and farmers' responses. These findings are presented below, along with related data from the farmer and veterinarian interviews.

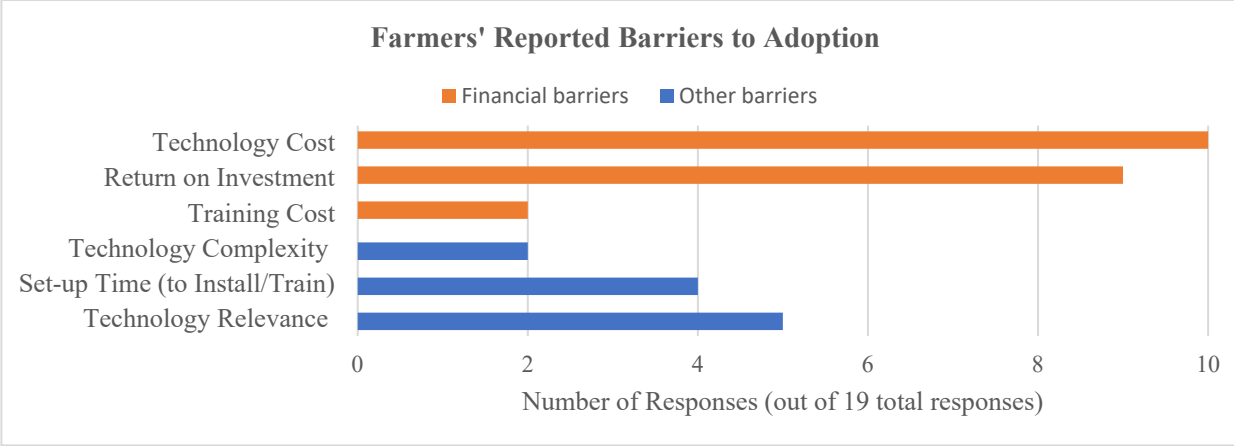

Figure 5. Survey responses to the question *"What are the barriers stopping you from automating or using technology to help manage the operations?"* (19 total responses)

Costs and Return on Investment. Financial barriers were the most commonly reported barriers on the survey. Fifteen of 19 farmers reported at least one of three financial barriers (technology costs, training costs, and return on investment). Veterinarian interviews also highlighted the financial stress local beef farmers faced, from profits being less than they used to be and from the closure of a large local processing plant that was having wide-scale impacts on the beef industry.

The survey also asked the 18 farmers who reported using technology about the relative cost of their technology purchases. Only one reported it as a large expenditure. Most farmers (10/18) reported the technology as a moderate expense, while others (6/18) considered the cost small relative to farm size.

The interviews provided further insights on technology adoption costs. One farmer reported investing over $150,000[15] in a total mix ration (TMR) feed mixing system, while the maximum amount of investment reported by other farmers was $8,900 for a weigh scale and integrated digital reader and computer to use with it. This shows that some farmers may be willing to invest a large amount on technology if they are convinced of its effectiveness. Most farmers, however, reported more modest technology expenditures on the order of $1,000 to $5,000 (e.g., weigh scale, iPad, digital scale for existing feed mixer, computers and software to interface with RFID readers and for record-keeping).

It was also apparent from the interview comments that some farmers omitted certain technology expenditures, possibly because a system was older or they did not think was relevant to the study. For example, several farmers reported purchasing upgrades ($400-$3,000) to the scale heads on their existing TMR feed mixer systems to enable data collection and communication with the Performance Beef software application. They mentioned the costs of the scale head upgrade and the Performance Beef software subscription (~$200/month), but they did not mention the cost of the TMR feed mixer.

The large expenditures either implicitly or explicitly reported by participants suggest that return on investment may be the more important factor limiting technology adoption rather than the sticker cost of the technology. As business owners, farmers need to consider the long-term payoff of any technology investment, as illustrated in the comment, *"Money would be the biggest [barrier]. If it outweighs the cost of labour and probably maintenance/repair. They need to be fairly durable and reliable." (Farmer 3).*

The interviews also revealed important industry factors that play a role in the financial decision-making around technology adoption. One factor is the short time beef cattle spend on a feedlot, which makes

[15] Dollar amounts in the paper represent Canadian dollars (CAD).

some technologies unsuitable, including non-reusable wearable technologies like smart ear tags that record temperature, as illustrated by the comment,

> *"the animal is only alive 6-18 months after that ear tag goes in. That's quite the expense per animal … it can't be reused … In dairy, you could … spread out that cost over time for a dairy cow to monitor sickness … it doesn't pay out in the beef world." (Vet A).*

This view was shared by a farmer who operated the largest feedlot in our study (>5,000 cattle) and who had recently participated in a trial for smart ear tags that supported individual health monitoring. They commented that, *"If it was $20 per head investment one time, it would be too much. If we could buy those tags for a third of the pricing and you could use them 10 times, I think that would be something. Right today, it's just too much." (Farmer 9).*

Farm size was another factor raised in interviews. The overall investment in time and money needed to set-up, learn, and maintain new technology may not be worth it for the relatively small size of most Ontario feedlots, as illustrated in the comment, *"I would say in Ontario it [a challenge to adoption]… might be the size of the feedlot. The initial investment. Get the stuff onboard, hooked up, figure out how to use it and management along with the monetary investment.*" *(Vet B)*.

One interviewed farmer reported co-purchasing and sharing a hand-held RFID reader system with a neighbouring producer to minimize the per-head cost. This strategy showed creativity in managing technology costs.

Relevance of the Technology. Five surveyed farmers reported relevance of the technology as a barrier to adoption. This finding, coupled with the previous finding of many farmers' lack of awareness of PLF technologies, may further indicate a lack of knowledge about available technologies and their capabilities, as evidenced by one farmer's free-form comment that *"knowing what is out there" (Farmer 3)* stopped them from automating certain aspects of their farm.

Yet, the interviews also revealed that some technologies do not meet Ontario farmers' needs due to regional climate or farming practices, as illustrated by the farmer and veterinarian comments,

> *"Technology seems to come out with a trial…then you find it's either not safe, not cold safe, or winter safe. Then the second or third evolution is improved and that's when it would be wise to buy. It develops a 'wait and see' attitude …to wait [until it] is more 'farm ready'". (Farmer 4)*, and

> *"There is a lot of research [on technologies for the beef industry] out there, a lot of it comes from the West and sometimes it doesn't fit in Ontario." (Vet B).*

One veterinarian also commented that some technologies from other livestock industries, such as dairy, are not relevant because of the different farming practices that can lead to different animal health and welfare concerns. For instance, feedlot producers try to handle beef cattle infrequently to minimize their stress levels, which can impact cattle health and feeding behaviour.

Other Factors. Four surveyed farmers reported set-up time (to install/train/etc.) and two reported complexity of the technology as barriers that prevented them from adopting technologies they were considering to support farm operations. Both responses further suggest the importance of technology usability. Free-form survey comments and the interviews identified additional adoption barriers, including access to internet, lack of processing capacity, and religious beliefs. The latter barrier refers to regional beef farmers who follow certain religious practices, such as Old Order Mennonites, who are not "*religiously able to adopt technology in the barns…no matter how easy [it is] to use, [they] would be prohibited to use it in any way." (Vet A)*.

4 Discussion

Many of the findings from this study are consistent with previous precision farming technology adoption studies, but the study also uncovered unique barriers to the beef feedlot industry in Canada. This section will review these similarities and differences and provide recommendations for how PLF innovators can support this livestock sector. This section also explores PLF technology adoption in the Canadian beef industry through the lens of Roger's *Diffusion of Innovations* theory (1983) that describes the typical five stages of adoption of ideas or technology and characterizes the different types of adopters at each stage. This exploration helps to understand the potential for technology adoption within the Canadian beef industry. Finally, we discuss the future outlook of PLF technology adoption on Canadian beef farms and provide guidance for innovators to help develop relevant and cost effective technologies for this sector.

4.1 Perceptions and Use of PLF Technologies

The study found a wide variety of technology adoption on Ontario feedlots. Most commonly reported were various software technologies, including popular productivity software like spreadsheets and accounting programs, and more rarely, specialized farm software. Mobile phone applications (or "apps") and cloud-based applications were also reported, demonstrating that many farmers are following modern computing trends. The study also found various types of digital farm equipment being used by feedlot farmers. RFID ear tag systems were reported by both farmers and veterinarians. These tags were used in simple systems, for instance, to track incoming and outgoing cattle with handheld tag readers, or more complex systems like integrated readers in digital weigh scales that automatically read and store individualized weight information digitally and in formats easily exported to desktop or cloud-based data management systems. Automated bunk monitoring and feeding systems were also reported by veterinarians that help feedlot producers optimize feeding operations.

There was some alignment between farmers' reported pain points and the types of digital technologies reported in the study. Record-keeping and reporting were by far the mostly commonly reported pain point for feedlot farmers and adopted technologies primarily supported this activity. Data management systems such as spreadsheets and accounting software (e.g., Excel, *"data base for cattle"*, Quickbooks) were among the most frequently reported software, followed by herd and feed management systems, like Performance Beef, that automated feed record-keeping and calculating cattle performance data. However, although the next commonly reported pain point included monitoring individual animal health, no individual animal health monitoring technologies were reported by farmer participants, and few were mentioned by interviewed veterinarians.

Our study findings had similarities and differences to the technology use uncovered by Groher et al. (2020) in their recent study of technology adoption on Swiss beef farms. Both studies found herd management systems and digital weigh scales among the most adopted digital technologies on beef farms. Unlike our study, Groher et al. found the use of automated calf feeders on Swiss beef farms, which is a technology irrelevant to most feedlots in Canada because calves are typically born on cow-calf operations. Another difference in study findings was the level of adoption found of individual animal tracking technologies. The Swiss study found little use (only ~1%) of electronic ear tags, where we found prevalent use of this technology. Among our surveyed farmers, 33.3% explicated reported using portable RFID tag readers or weigh scales with integrated RFID tag readers. Veterinarian interviews confirmed that RFID readers (portable or integrated into weigh scales) were commonly used among their clients. The large difference in adoption of this technology between studies is likely due to government mandates in Canada that require all cattle arriving on a feedlot to have electronic ear tags installed, whether the farmer leverages these tags or not. Instead, the Swiss study found more prevalent use of transponder collars for tracking their cattle, possibly for GPS location tracking on pasture.

Our study also probed farmers' awareness and perceptions of PLF technologies as knowledge and perceived value of a technology can play a major role in its adoption (Holden and Rada 2011). The survey revealed that many farmers are not aware of available PLF technologies. This finding was also confirmed by the interviews, during which one farmer commented, *"I think one big problem beef guys have is that a lot of them don't realize some of the technology exists." (Farmer 3)*.

The study also revealed that participants using PLF technologies on farms generally have a positive perception of the impact and capabilities of these technologies. All 18 participants who reported using technology also reported that it performed well based on at least one of the investigated performance metrics (improving animal health, improving animal welfare, increasing profit, or reducing labour costs). Several participants expressed that the technologies had been transformative for their operations, even *"life changing"*. However, a key observation from the study was that feedlot farmers favored mature hardware and software technologies that focused on supporting business productivity, optimizing feeding, and herd management.

The most "modern" PLF technology producers reported using was the Performance Beef cloud-based mobile application and its capability to integrate accurate feed tracking per cattle group. However, while many producers knew of this product, only four explicitly reported using it. Unlike recent PLF studies of the Canadian dairy industry (Duncan 2018; Islam and Scott 2021), no producers in this study reported using any 24/7 individual animal health and welfare monitoring technologies. Only one veterinarian mentioned having a client using smart ear tags that record temperature. Several participants mentioned that these technologies are currently *"cost prohibitive" (Farmer 9)* for the feedlot industry. Instead, feedlot farmers often managed cattle by group, rather than individually.

4.2 Technology Adoption Lifecyle

To understand the potential for technology adoption in the Canadian beef industry, we examined our findings through the lens of Rogers' (1983) well-known *Diffusion of Innovations* technology adoption lifecycle model, which has been used to understand technology adoption in a wide range of contexts, including technology adoption on livestock farms (de Aragão Pereira and Woodford 2011). The model includes five categories of technology adopters characterised by their motivation and ability to take risks. These categories include innovators, early adopters, early majority, late majority, and laggards. The typical characteristics of each adopter is described below and compared to the characteristics of beef farmers from our study and more generally from other studies of this industry.

Innovators*:* These are the first set of customers to try a new product, they tend to be wealthier and more likely to take risks than other adopters, such as being willing to risk investing in technology that may not meet their needs (Liao, Palvia, and Chen 2009). Based on the study findings, there seems to be few feedlot producers in this category. Our study findings suggest that feedlot farmers are unlikely to take a risk on a new technology without being fully aware of its potential return on investment, how usable it is, how well it meets their needs, and fits into their farming context.

Early adopters: People in this category of adopters are typically highly educated, willing to take considerable risk, wealthy, and highly influential (Straub 2009). This description does not fit the persona of most beef producers. Many farmers in the region are over 50 with a basic level of education, as illustrated by the comment, *"…we are not particularly progressive group of people, the average age is over 50, the average education is high school at best." (Farmer 5)*. Also, Ontario feedlots tend to be relatively small compared to those in western Canada, on average managing 175 cattle (Farm and Food Care Ontario 2016)). This scale implies that most farms have modest profits, given the low per head yield in Canadian beef markets. Therefore, the likelihood of finding current beef producers willing to be early adopters of technology is low. However, as our study found, there are also young and educated farmers, often in the process of taking over a family farm, who may lead the way as early adopters of PLF

technology, depending on their farm size. Indeed, a national survey in 2016 found the first increase in young farmers (under 35 years of age) in Canada since 1991, with 11% young farmers compared to 8% in 2011 (Statistics Canada 2016). Removing adoption risks could recruit early adopters (e.g., lowering financial risks, improving knowledge about capabilities and fit with farming practices, ease of use).

Early majority: This is the category we believe beef farmers with large herd sizes fit best. While this group of adopters are relatively wealthy, they must be certain that a technology provides good value for the money and works effectively before they will invest in it. They usually will not invest in a technology until they have an in-depth understanding of its value proposition, ease of use, and limitations (Meade and Rabelo 2004). In this study, most farmers who used technologies believed they improved animal health and/or welfare, reduced labour cost or/and increased profit. The study also found, however, that a major factor motivating technology adoption for beef farmers irrespective of farm size is the potential return on investment. Therefore, effective marketing strategies are needed to ensure that farmers are aware of the existence and capabilities of the technology.

Late majority: People in this category have a very low budget for technology investment, hence, they must be extremely convinced about the value proposition the technology offers before adopting it (Liao, Palvia, and Chen 2009). Most current beef producers belong to this category, even if they are shown demonstrations and marketing campaigns that describe the technology capabilities, the chances of them adopting it are still low if a significant financial investment is required. The most prevalent barrier to technology adoption reported by study participants was financial (technology cost, training cost, return on investment). In addition to the recommendations in the *early majority* category above, a good pricing model must be in place to motivate this category of adopters. For instance, the monthly subscription model used by Performance Beef requires little low up-front investment and makes it easy to opt out at any time. Thus, it has a low barrier of entry for cautious adopters. This type of pricing model also helps ensure that manufacturers do their best to continually improve the technology to avoid losing subscribers.

Laggards and Non-Adopters: People in this category prefer traditional approaches to doing things and are very unlikely to welcome anything new (Meade and Rabelo 2004). A good example of this category of adopters in the beef industry are farmers who follow certain religions that disallow technology use. It is important for governments and industry groups to consider and consult these populations when developing new regulations, for instance, related to beef traceability, to understand how to meet industry or societal goals while respecting the culture and perspectives of these groups. Laggards who are hesitant but still able to adopt technology may be persuaded by engaging them in the technology development process in a manner that shows their perspectives are being respected. The study found practical barriers that may also create laggards of certain farming populations, for instance, farmers who live in areas that lack high-speed internet or reliable cellular phone service that a given technology requires.

4.3 Potential for PLF Technologies in Canadian Beef Industry

Beef farming is the second most common type of farming, after oilseed and grain farming, in Canada (Statistics Canada 2016). However, due to changing, globalized markets and other factors, the nature of beef farming is evolving. A national agricultural census in 2016 found that Canadian farmers were leaving the market or consolidating farms, leading to fewer but larger beef farms (Statistics Canada 2016). The census found that the average feedlot operation held 212 head of cattle, up from an average herd size of 185 cattle in prior 2011 agriculture census. Other industry studies have found wide variation in herd sizes, with many smaller farms, typically in eastern Canada, and some very large (over 20,000 head of cattle) feedlots in western Canada (Alberta Cattle Feeder's Association 2019). Based on the technology adoption lifecycle analysis above, the trend toward larger feedlots, which can help increase a producer's per animal profits, may present more opportunities for Canadian farmers to adopt available

technologies by moving farmers from the *late majority* to the *early majority* adopter category. This shift in farm demographics may help to create the critical mass needed for broader scale technology adoption.

However, our study findings suggest that regardless of farm size, the potential profit margins in the Canadian beef industry will remain relatively lean compared to other industries. Thus, potential return on investment will remain a key factor in PLF technology adoption. The study findings indicate that PLF innovators will also have to address other key adoption barriers faced by beef farmers. Potential means of addressing the financial concerns and other barriers are discussed below.

4.3.1 Creating financially feasible technology products

New technologies often have a cost that must cover innovator's initial research and development efforts. Moreover, emerging technologies often do not have the scale of production needed to reduce per unit costs. However, the study uncovered a number of strategies employed by successfully adopted technologies, and that are common in the broader technology product space, that may help PLF innovators keep product costs feasible for the beef industry.

The study findings show that to remain profitable, beef farmers must minimize input costs per animal, including feed, veterinary care, and so on. Given the relatively short time individual cattle remain on a feedlot (usually 6-18 months), PLF products or services that charge more than a minimal per-animal cost are cost prohibitive for beef farmers. This was clear from the farmer and veterinarian discussions of certain smart ear tag products that are not reusable and have a fairly high per unit cost (e.g., $20+ per tag). Thus, PLF technologies are more likely to be successful in this industry if they are applicable to multiple animals, either through reusability (e.g., reusable wearables) or because they can serve multiple animals at once, such as software for managing the herd or external sensors that can monitor multiple animals.

Technologies that leverage popular technologies in the industry also allow for lower entry costs. For instance, digital weigh scales leverage the existing RFID ear tag technology farms already use and can be used on many animals over time. Feed tracking software like Performance Beef leverage popular TMR feed mixing systems and provide additional value to this technology. Products that leveraging existing equipment and infrastructure allow farmers to adopt different capabilities over time and spread out costs.

Providing subscription-based products and services, like Performance Beef and CattleMax (another herd management system mentioned by participants), is another strategy to minimize up-front investment costs and allow hesitant adopters to try new technologies with minimal risk. These systems provide cloud-based data collection, storage, and analysis capabilities based on monthly subscriptions. These products are consistent with a growing trend in the information technology industry to offer Software-as-a-Service (SaaS) products that provide low-cost entry points to new customers and continuous revenue for product developers (Srinivasa, Jayasimha, and Nargundkar 2020; Turner 2020). Such cloud-based software services address several challenges uncovered in our study. They eliminate the need for farmers to purchase and maintain expensive computer servers, enabling access to powerful data storage and analysis capabilities in the cloud from existing or low-cost computing devices (e.g., smartphones or tablets). Also, their user interfaces, and thus their usability and utility, can easily be improved through software updates.

Subscription-based services are also possible for automated equipment. For instance, a growing trend in the automation industry is Robots-as-a-Service (RaaS), where product vendors provide and maintain robotic equipment (e.g., autonomous vehicles, food delivery robots, security robots) and all associated software services needed to run these devices for their clients (Cole 2022; Kapitonov et al. 2021). Like SaaS models, RaaS eliminates the need for large capital expenditures and allows clients to pay monthly for these robotic services. The RaaS vendor incurs the capital costs and provides upgrades as needed throughout the service period. RaaS models can work well when automated equipment is needed during

certain periods (Yates 2020; Cole 2022), for instance, a RaaS vendor might provide RFID reading equipment on a service call basis.

Finally, a cost mitigation strategy reported in the study was co-ownership of a new technology. This cost sharing strategy allowed a study participant to try out a technology they were initially hesitant about. The ability for them to share the financial risk was a key factor in their adoption decision. While perhaps not ideal from the technology company's perspective, the ability to gain multiple "part" clients rather than none of these clients is likely preferable and may be a needed entry point for many farmers who are in the *late majority* or *laggard* adopter category.

4.3.2 Employing user-centred design methods

Consistent with prior studies on PLF technology adoption and use in the beef and other livestock sectors (de Aragão Pereira and Woodford 2011; Berckmans 2014; Duncan 2018b; Fournel, Rousseau, and Laberge 2017), the study findings revealed that technology complexity and usability are key adoption barriers. Our study found poor usability can cause farmers to abandon technology and that ease of use was a specific concern for some farmers in technology adoption decision-making. Beyond the usability of a software or hardware technology, the study also showed that the broader user experience of a technology from "unboxing" (i.e. installing) to learning the technology and long-term use of the technology's capabilities all need to be considered during its design process. Moreover, the technology must be "farm ready", and thus, address the real-world challenges of the context in which it will be deployed, such as being "winter safe" for Canadian farms. The fields of human-computer interaction and user experience (UX) design (Sharp, Rogers, and Preece 2019; Hartson and Pyla 2012) have developed proven tools and methods for meeting these technology design challenges. For instance, the use of *iterative, user-centred design* processes that engage end-users throughout the design process help designers better understand and address the technology requirements (Sharp, Rogers, and Preece 2019).

Effective UX research and design can be done using a variety of low-cost techniques, which is especially important for industries, like agriculture, where technology developers may have limited research and development budgets. For instance, *user personas* that represent typical users and their characteristics, motivations, goals, and challenges can be created to help developers gain a deeper understanding of their intended users (Dam and Teo 2022). Industry constraints have led to the development of a number of low-cost and fast UX design and testing methods, often referred to as "guerrilla research", that can help companies produce more relevant, user-centred products even with limited time and budget (Zaki Warfel and Unger 2011; Buley 2013). Such methods may help reduce the gap between technology developers and farmers, which has been found to be a contributing factor to commercial failure of some PLF technology products (Oltjen, Forero, and Stackhouse 2018).

4.3.3 Meeting the unique needs and challenges of feedlot producers

Similar to other precision farming adoption studies (de Aragão Pereira and Woodford 2011; Steele 2017), our findings indicate that the relevancy of available technologies is an adoption barrier for feedlot producers. Generalized livestock health and welfare monitoring technologies were less valued by our participants than technologies that clearly addressed their goals of efficient feeding, safe handling of the herd, and data collection and record-keeping for both business and regulatory reasons. The predominant pain point reported by feedlot producers was record-keeping and reporting. Technologies that meet this need, for instance, to simplify processes around data collection, analysis, and reporting on animal feeding, handling, health or welfare issues, or market readiness, are more likely be adopted by this user group.

Overall, the use of user-centred design approaches as discussed above, would help ensure that the unique needs of beef producers are met. The information provided by this study provides a first step towards documenting the needs and challenges of Canadian beef farmers.

4.3.4 Improving technology awareness

Finally, the study findings revealed a lack of awareness among feedlot producers of many of the available technologies and their capabilities. This is a critical issue to address for broad scale adoption of technology among beef farmers, as Roger's *Diffusion of Innovations* theory (1983) asserts that awareness is the first stage of technology adoption. More efforts are needed by various stakeholders involved in the agricultural sector to educate farmers about the capabilities of available and emerging technologies, including government agencies, academic researchers, technology companies, and equipment vendors. As one interviewed farmer suggested, leveraging opportunities where farmers are already gathered, for instance, for beef management schools or industry tradeshows, would help to raise awareness of the capabilities and benefits of these technologies. PLF innovators should also provide easily accessible product guides and video demonstrations on company websites and social media channels like YouTube[16], Facebook[17], Twitter[18], or TikTok[19] to ensure that farmers can maximise all capabilities provided by a product or service.

4.4 Limitations

Scoping the survey and interviews to Ontario farmers and veterinarian may limit the relevance of the study findings to feedlot practices elsewhere in Canada. For instance, some feedlot producers in western Canada operate significantly larger farms than those represented in this study. Thus, production processes and associated pain points may vary. However, the study attempted to capture concerns related to general areas of operations, such as herd management or record-keeping, which will likely apply to some degree to all producers in this sector. Based on the technology adoption lifecycle analysis, those large producers may be more likely to fit into one of the earliest adopter categories, potentially *early adopter* or *innovator,* and may be more likely to adopt PLF technologies. However, comments from the interviewed veterinarians cautioned that technologies developed for the western Canadian market may not be as suitable for Ontario feedlots, highlighting the need for user-centred design processes that ensure technologies are relevant for regional production contexts.

We intentionally targeted feedlot producers who had adopted technology to understand their attitudes and experiences with these technologies. However, this decision, coupled with the primarily electronic means of advertising, and fully electronic means of administering the study, likely biased our participant sample towards younger, more tech-savvy farmers. Indeed, most farmer participants (22/24) were between 18 and 54, which is below the average age, 55 years old, of beef farmers in Ontario (Beef Farmers of Ontario 2018). Thus, the level of awareness of PLF technologies of our study participants is likely higher than the average farmer in this sector. This further highlights the need to raise awareness among the general beef farming population of PLF technology capabilities. It may also be possible the pain points reported by our participants may differ from older, more experienced farmers. On the other hand, since younger, more educated users are more likely to be *early adopters*, meeting their needs should be a priority for PLF innovators. Nonetheless, more studies are warranted to better understand the attitudes and experiences related to PLF technologies of beef producers in other regions and production stages to provide a broader understanding of the needs of all potential PLF users in the beef industry.

5 Conclusions

The goal of this research was to carry out a digital technology adoption study from the point of view of different stakeholders (farmers and veterinarians) in the beef feedlot industry in Canada. The study found little use of individualized animal health or welfare monitoring more common in other livestock sectors.

[16] Youtube.com
[17] Facebook.com
[18] Twitter.com
[19] Tiktok.com

Despite the widespread availability of RFID ear tags on feedlot cattle, this technology is only used in limited capacity for animal tracking and monitoring. Instead, feedlot farmers tend to manage and track cattle by groups or "lots", tracking the feed and weight performance over the group, rather than by individual animal. Individual tracking was reported to be currently cost prohibitive. Overall, the study findings revealed several factors hindering the adoption of digital technologies in the beef industry, including financial concerns (technology costs, training costs, potential return on investment), technology complexity and usability, lack of relevant technologies, and awareness of the technology and its capabilities.

The findings also suggest various steps PLF innovators could take to ensure that PLF technologies meet the needs and expectations of farmers and hence have a wider adoption in the beef industry. Technology products or services that leverage existing technologies and practices, require minimal up-front investment costs, and allow farmers to try out a technology with minimal financial risk are more likely to be adopted. Adopting best practices from the fields of human-computer interaction and user experience design throughout the design process would help improve the usability and user experience of PLF technologies, and ensure technologies meet beef farmers' needs and expectations. Finally, PLF innovators and vendors should increase efforts to raise awareness of PLF technologies and their capabilities.

This research suggests that PLF technology adoption is likely to increase in the Ontario, and broader, Canadian beef industry, especially as the incoming generation of young farmers, already familiar with digital technologies, start their own farms or move into decision-making roles on farms. However, the research also underscores a need for more relevant, usable, and affordable technology products and services for the beef livestock sector.

Author Contributions

AM: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing - original draft; MMI: Formal analysis, Visualization, Writing - review & editing; KMW: Conceptualization, Methodology, Writing - review & editing; EC: Investigation; MW: Investigation; SDS: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing - original draft, Writing - review & editing.

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