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Precision livestock farming: a qualitative exploration of swine industry stakeholders

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Introduction: Precision livestock farming (PLF) technology development has proliferated recently, but on-farm adoption has lagged. Understanding PLF stakeholders' views, practical applications, limitations, and concerns are necessary to understand the factors influencing the adoption of PLF technology.

Methods: Using semi-structured online interviews, 12 influential stakeholders' PLF views and lived experiences were investigated. A phenomenological paradigm was used to generate qualitative data that was analyzed using template analysis.

Results: We identified two unique groups of stakeholders, namely the PLF enthusiast and PLF cautious groups. The majority of the participants were well aware and had firsthand experience with the PLF technologies that are currently being used in the swine industry.

Discussion: We found that PLF technology was perceived to improve specificity in decision-making, better care for pigs, improve animal health and welfare, increase labor efficiency, and improve resource-use efficiency. Poor internet connectivity and the inability to use PLF data for decision-making due to needing to first complete daily on-farm tasks were considered key obstacles to its implementation. To integrate PLF technology into the existing barn environment, it is necessary to modify farm buildings and infrastructure and management protocols. Stakeholders' main concerns with PLF technology included data privacy issues and the influence of PLF technology on human-animal relationships and farmers' duty of care to the animals. In conclusion, stakeholders perceived camera systems for monitoring pig health and welfare and ensuring individual pig identification as a high priority in PLF development going forward.

KEYWORDS

adoption, challenges, precision livestock farming (PLF), perceptions, pigs

1 Introduction

Despite the rapid proliferation of precision livestock farming (PLF) technologies, on-farm adoption has been slow (Shepherd et al., 2018). Farmers, veterinarians, and other stakeholders' perspectives are imperative when considering the adoption and implementation of on-farm PLF technology (Werkheiser, 2020). The vision and role of stakeholders differ. For example, some have the capacity to direct or model the practical use of PLF technologies on farms. Others might promote PLF adoption which in turn may enable data to be used for assessment, and traceability (Vranken and Berckmans, 2017; Lima et al., 2018). Moreover, engaging a broad cohort of stakeholders in the design and development of PLF technology may address issues important to consumers' later acceptance of animal products produced with PLF technology.

According to previous work on PLF development, there are some generally acknowledged ways in which PLF could create added value for farmers and off-farm stakeholders along the pork production value chain (Halachmi et al., 2015; Kamphuis et al., 2015; Lopes et al., 2016). For instance, detailed or long-term data captured by PLF on many individual pigs could generate data on novel phenotypes for pig breeders. Continuous data captured by PLF might also provide certification organizations with indicators relevant to animal welfare assurance while providing retailers with insights into compliance with standards. Deviations in normal patterns (of feeding, body temperature, weight gain, or other attributes) detected by PLF can serve as early warnings to alert farmers to act before poor welfare outcomes may develop. Government agencies saddled with the responsibilities of protecting, promoting, and regulating animal health may also use PLF data for tracing disease outbreaks to the source or tracking disease as it spreads. However, despite these potential benefits one question remains, "*how do these stakeholders perceive the use of PLF technology in the swine industry?*" Specifically, regarding consumers, it is not clear whether they consider PLF technology as diminishing farming naturalness, or if consumers view PLF technology as an enhancement to support the pig's quality of life (Krampe et al., 2021; Morrone et al., 2022; Siegford, 2023). There is no single definition of PLF; however, in this study, we defined PLF as a management approach that uses technology to collect and process data from individual animals continuously and in real time (Berckmans, 2017).

To effectively design PLF in such a way that the various needs of key swine stakeholders can be harmoniously met, it will be important to understand their views and values. Presently, information on stakeholder PLF attitudes and societal acceptance (excluding farmers) is lacking (Giersberg and Meijboom, 2021). Specifically, it is unknown what types of pig-based outcomes key stakeholders across the pork production value chain would like measured. Additionally, information on whether stakeholders' needs match the capabilities of existing technologies and the barriers they perceive as hindering the application of PLF in their respective operating contexts is missing. It is also important to know whether stakeholders, particularly consumers trust PLF data; and what expectations they have for PLF systems (e.g., the problems they expect them to solve). To fill this lacuna, Giersberg and Meijboom (2021) suggested the need to analyze the role of PLF technology in addressing societal concerns over pig production by implementing empirical research to understand the underlying values of key stakeholders. Hence, in this study, we explored stakeholders' views, practical applications, limitations and concerns, and future innovations in precision livestock farming technology development in the swine industry.

2 Materials and methods

2.1 Phenomenology

This study employed semi-structured online interviews to collect qualitative data as part of the USDA Inter-Disciplinary Engagement in Animal Systems (IDEAS) project collaboratively undertaken by researchers from Michigan State University, Scotland's Rural College (UK), Iowa State University, and North Carolina State University. The study explores influential swine industry stakeholders' understanding of PLF uses and usefulness, values (i.e., benefits, limitations, and concerns), and desired future innovations using a phenomenological approach. The phenomenological method is an inductive, richly descriptive qualitative research method with the purpose of describing lived experience of study participants (Giorgi, 1997). The main goal of phenomenological research is to explore the lived experience of a specific phenomenon from the perspective of those who experience that particular phenomenon. In this study, we focused on individuals who, either because of their positions, professional roles, and responsibilities within key organizations in the swine or livestock industry are considered influential stakeholders. The rationale for choosing a phenomenological approach for a qualitative study such as this centers on its capacity to elicit information on participants' experiences of phenomena in the form of rich, descriptive accounts which can be analyzed in the selected phenomenological tradition; in this study interpretive phenomenology (see Langdridge, 2007 for additional detail on interpretive phenomenology).

2.2 Participant recruitment and demographic characteristics

This study is part of a larger project examining perceptions of PLF that influence adoption by the US swine industry stakeholders. The first objective of this project was to create an advisory board that encompassed a wide range of stakeholders across the swine industry. We broadly categorized these stakeholders into technology developer, on-farm user, and off-farm user groups. The technology developers include academic researchers or industry professionals developing or commercializing PLF tools. The on-farm users are stakeholders who have direct interaction with PLF and use PLF data to care for pigs. This group includes swine farmers, veterinarians, and breeders. The off-farm users are stakeholders who indirectly use PLF data for bigger purposes such as disease surveillance, meeting legislative requirements, or

certification assurance. This group was made up of stakeholders from the government, food processing and retail companies, and animal welfare certification organization (see participants' details in Table 1).

Six months prior to taking up their advisory board duties, these stakeholders served as our interview subjects without access to information that could have influenced their opinions of PLF. We focused on US-based participants for on and off-farm user groups because we wanted their specific perspective on how PLF would impact US swine farming and agriculture. We did not place a similar restriction on the technology developer group because PLF technology development and implementation have a wider global reach and are not country-specific. Hence, we included two participants from Australia and Spain who have developed and patented several PLF technologies and are globally recognized as experts in PLF development with extensive experience in PLF technology implementation and usage to complement the perspectives of US stakeholders. Using open-ended narrative questions encompassing global applications of PLF technology in the swine industry (see Appendix 1), participants were asked to reflect on their experience and then share their perspectives of PLF technology.

Study participants were individually recruited through email or phone calls. Very limited information about the study, sufficient to allow stakeholders to decide whether to participate in the study or not without biasing their views in the interview later, was shared during the invitation. Specifically, participants were not primed with information or views that could have influenced their awareness or perception of the value of PLF technologies in general or certain technologies in particular. Participants did not know who else was serving on the advisory board or participating in this component of the study before, during, or immediately after the interview. The 12 participants assumed their stakeholder advisory roles six months after the completion of the interview.

This study was determined to be exempt (from closer scrutiny) under 45 CFR 46.104(d) 2i. following evaluation by the Michigan State University Institutional Review Board (IRB) with the MSU Study ID: STUDY00005432. All interviews were conducted and recorded on Zoom after obtaining consent verbally from each study participant. As with any qualitative study, the main goal of this study was not to generate findings that could be generalized to all stakeholders in the swine industry but to gain an in-depth understanding of how those stakeholders that were interviewed perceived PLF usage in the swine industry.

The descriptive characteristics of the 12 stakeholders that participated in the study are presented in Table 1. Given the potential usefulness of PLF technologies in the swine industry from pig conception to pork consumption, industry representatives across different sectors within the swine industry were chosen to participate in the study. Sixty-seven percent (67%) of the study participants were male while 33% were female. The stakeholders were experts in animal breeding and genetics, technology development, agricultural engineering, animal care and compliance, swine welfare, swine veterinary medicine, animal welfare auditing, animal health regulation, and consumer advocacy. Fifty percent (50%) of the participants held Ph.D. degrees in animal science and related disciplines whereas approximately 17% held DVM, MSc., and bachelor's degrees respectively.

2.3 Interview guide design

The interview protocol was designed following a phenomenological approach (Groenewald, 2004) to elicit information by examining the experiences of the study participants through their PLF descriptions during the interview. These experiences are called lived experiences since participants are individuals with experiential knowledge of the subject (i.e., PLF) being investigated. The goal of phenomenology studies is to describe the meaning (in participants' words) that experiences hold for each participant. This type of study is generally considered one of the most effective approaches for researching

TABLE 1 Study participants' demographics.

Participants	Gender	Education	Organizations	Groups
Technology developer	Male	Ph.D.	PLF technology company	PLF enthusiast
Technology developer	Male	Ph.D.	PLF technology company	PLF enthusiast
Technology developer	Male	Ph.D.	Academic institution	PLF enthusiast
Technology developer	Male	Ph.D.	Academic institution	PLF enthusiast
On-farm user	Male	Ph.D.	Large-scale swine farming	PLF enthusiast
On-farm user	Male	BSc.	Large-scale swine farming	PLF enthusiast
On-farm user	Male	DVM	Swine veterinary consultancy	PLF enthusiast
On-farm user	Female	MSc	Swine veterinary association	PLF cautious
Off-farm user	Female	Ph.D.	Food processing company	PLF cautious
Off-farm user	Female	MSc	Animal welfare certification	PLF cautious
Off-farm user	Male	BA	Food retailer company	PLF cautious
Off-farm user	Female	DVM	Government	PLF cautious

little-known or hard-to-reach areas of knowledge (Christley and Perkins, 2010). To really understand participants' lived experiences of PLF, we followed the recommendation of Fischer (2009) and identified anticipated discoveries from the study based on previous literature and then put them aside in a process called bracketing. The interview protocol focused on stakeholders' experiences as recommended by Brinkmann (2013) and was structured into four topic areas; namely PLF views, practical application, limitations and concerns, and future innovations (see Appendix 1).

2.4 Definitions of some key terminologies

To aid understanding of the study methodology, here we define some key terminologies that are important to the understanding of template analysis that was implemented in the study.

Theme: The term 'theme' in qualitative analysis (implies repetitions) may be defined as the recurrent and distinctive features of participants' discussion (in the interviews) that characterize perceptions and/or experiences and are seen by the researcher as relevant to the research question of a particular study (Braun and Clarke, 2006; King and Horrocks, 2010; King, 2012).

Coding: Coding is the process whereby a label (code) is attached to a section of text within the interview transcript to index it as relating to a theme. Within a template analysis there are some codes that do not necessarily index themes but rather serve as 'placeholders' (placeholders in this study include PLF understanding, uses, values, and future innovations) (Gibbs, 2002). The placeholder is used to organize associated themes into different groups (King, 2012).

Bracketing: The term bracketing in phenomenological research can be explained in two ways. First, bracketing is how the researcher engages with data and with evolving findings from the study. This entails identification and temporary setting aside of the researcher's assumptions. Second, is the hermeneutic revisiting of data and of one's evolving comprehension of it in light of a revised understanding of any aspect of the topic (See Fischer, 2009 for details on bracketing).

2.5 Template analysis

The 12 interview recordings were fully transcribed and imported into the MaxQDA software package for qualitative data analysis. Template analysis is a type of thematic analysis that involves the development and refinement of themes using a hierarchical coding template (King, 2012) for data analysis. The flexibility of template analysis allows for inductive coding without imposing a specific number of coding or hierarchical levels, thereby making possible detailed development of the template where necessary to reflect depth and complexity in the data and consequently the analysis. The flow chart of the template analysis steps which is discussed below is presented in Figure 1.

In stage one, the first author who was the interviewer and the coder read the 12 transcripts to become familiar with the overall accounts to be analyzed in the study. In stage two, the preliminary codes were developed using *a priori* themes (i.e., pre-selected themes) from Kanis et al. (2003) on societal concerns about pork and pork production and Giersberg and Meijboom (2021) on the extent to which PLF can mitigate societal concerns related to pig production. Neither of these two studies collected empirical data on stakeholders' perceptions of PLF in the swine industry, in fact, Giersberg and Meijboom (2021) suggested further study that will investigate swine industry stakeholders' perceptions thus making the current study important. The *a priori* themes identified in stage two were used to identify relevant themes to the study, and they formed the main topic areas in the interview guide and served as placeholders in the coding process. These *a priori* themes were tentatively used and refined or removed along the way if they did not prove to be useful for the analysis. It was from this initial engagement with the data that the coding structure was developed. In stage three, themes from the interview transcripts were organized into meaningful clusters and connected to each other within and between these clusters. This clustering was hierarchical whereby narrower themes were nested within broader ones.

Stage four, the initial template was created by implementing the procedure discussed in the first three stages using a subset of the interview transcripts (6 transcripts, 2 from each of the three groups). After coding the 6 transcripts, we were convinced that this subset covered a good cross-section of the issues and experiences of PLF discussed in the 12 interviews. The initial template included three top-level themes, and the first author kept the open phenomenological attitude necessary for the analysis while simultaneously remaining sensitive to the thematic areas. The phenomenological approaches of bracketing and consistent critical self-reflection throughout the analysis were used by the first author to identify their own presuppositions about the phenomena under investigation and foreground the participants' own experiences as lived. In stage five, the initial template was refined to further code the remaining 6 transcripts. At this stage, existing themes that did not readily 'fit' the new data

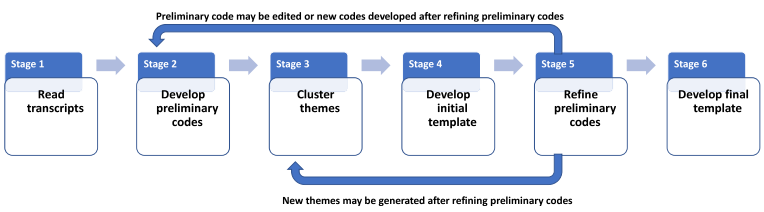

FIGURE 1
Template analysis flow chart.

were modified by inserting new themes or modifying or deleting existing themes if they were too narrow and then developing a new version of the template. This iterative process of generating new versions of the template continued until we were satisfied that we had a rich and comprehensive representation of the interpretation of the data. In stage six, we refined the template and applied this 'final' template to all 12 transcripts (see Brooks et al., 2015 for additional information on template analysis).

2.6 Limitations of the study

Like all studies, this study has some drawbacks. First, we do not claim that the study's findings represent the full range of experiences and viewpoints of all swine industry stakeholders, and our findings should not be interpreted as such. We selected participants based on their specific roles within the swine industry to cover aspects ranging from on-farm production and pig health care through off-farm stakeholders representing government agencies enforcing regulations or certifying welfare to developers of PLF technologies. We did focus our selection of on-farm stakeholders to represent farms most likely to be able to afford to invest in technology, which is typically larger. We do not make any claims that our data represents the views of small, organic, or pasture-based pig producers or of pork consumers. However, larger farms represent the majority of pigs in the US, and the financial resources of these farms are likely to influence PLF innovation and commercialization, and this population was of most interest to our funding agency. Further, several of our off-farm stakeholders do represent alternative production perspectives and voiced those in the interviews and many also have expertise in areas such as nutrition, genetics, and marketing that also added to the breadth of perspectives covered by our interviewees. Additionally, as we are directly surveying a larger number of swine producers, veterinarians, and members of the public in other parts of this study, a greater diversity of views will ultimately be represented. Lastly, the Template Analysis approach employed in this study unavoidably results in some loss of comprehensive insight in relation to individual accounts because the focus of Template Analysis is often on across-case analysis rather than within-case analysis. However, any thematic approach to qualitative data analysis has this drawback, which becomes more obvious in investigations with greater sample sizes. Consequently, we interpreted our data with caution taking this limitation into consideration.

3 Results and discussion

This section presents the results and discussion of findings from the template analysis described in section 2.5. The exact statements from participants are in Appendix 2. We identified two groups of participants from the data. The first group, the precision livestock farming enthusiast group was made up of four technology developers and three on-farm users (58% of participants). These were individuals with direct and advanced knowledge of precision livestock farming design and usage and were very enthusiastic about the potential of PLF in the swine industry. The second group, the precision livestock farming cautious group, comprises one on-farm and four off-farm users (42% of participants) (see PLF Knowledge column in Table 1). The majority of these participants had an indirect and limited understanding of how PLF works and how it is being used in the swine or livestock industry.

Our findings build on existing studies (De Greef et al., 2000; Kanis et al., 2003; Makinde et al., 2022) on the perceptions of precision livestock farming technologies among key stakeholders (i.e., citizens, consumers, and farmers). We also extended these findings to other influential stakeholders such as technology developers, veterinarians, certification organizations, and government officials on which information is currently missing, particularly in the swine industry (Giersberg and Meijboom, 2021). Recently, Giersberg and Meijboom (2021) advocated further empirical research including attention to the underlying values of currently missing stakeholders regarding their views toward pig husbandry in general, and of those of the wider society toward PLF usage in the swine industry. The current study attempts to fill this gap.

3.1 Stakeholders expressed different views of precision livestock farming

Here, we discuss how stakeholders view PLF. Although some stakeholders were cautious of PLF claims and potentials, however, most stakeholders view PLF positively and were enthusiastic about its potential and benefits to the swine industry. According to Kanis et al. (2003), different stakeholders' views of precision livestock technologies will be different because of differences in their focus based on their roles and responsibilities. To gain an understanding of stakeholders' PLF knowledge, we asked stakeholders about their awareness of technologies that can monitor and collect data from individuals or groups of animals continuously and in real time. We noticed a high level of awareness of PLF technology among the technology developer and on-farm user groups. Most of the PLF enthusiast group members had been involved in PLF technology development and had on-farm application experience. The technology developers were fully aware and familiar with PLF technologies being used in the swine industry, and often mentioned electronic sow feeding systems and RFID tags as good examples of PLF technologies. When discussing their views of PLF, the technology developers, and on-farm users who constitute the PLF enthusiasts often mentioned the technologies they or their company have developed or specific PLF technologies they often used and the tasks they performed with these technologies. The swine farmers among the PLF enthusiasts almost always focused on individual sow identification, sow feeding, sow record-keeping, tracking of individual sow performance, and cough detection. The on-farm user group is more interested in using PLF technology for monitoring pig health, welfare, and productivity, with particular emphasis on their most valuable animals, who also stay on their farms the longest. This finding corroborated the results reported by Homola et al. (2019) and Sinisalo et al. (2012) on how producers'

knowledge of animals' poor health or the presence of damaging behavior such as tail biting negatively impacts animal growth performance and productivity.

Moreover, a swine farmer stakeholder strongly emphasized that PLF technologies will be the next frontier of how producers capture more value out of their livestock systems thereby reiterating a similar point by Schillings et al. (2021). Another swine farmer however stressed that it is currently much easier to use PLF to manage and collect information from a group of pigs than it is to manage individual pigs. Hence, this stakeholder tacitly disagreed with the notion that PLF technology must monitor and collect information at the level of an individual animal. This stakeholder perceived that PLF technologies that target a group rather than an individual pig are likely to increase intensification rather than better welfare, as group-level approaches will allow more efficient management of many animals but fail to recognize and care for pigs as individuals thereby supporting Giersberg and Meijboom (2021) and Schillings et al. (2021) previous concerns. Previously, Werkheiser (2020) opined that managing animals with PLF at group-level approaches will not be as precise, and may, therefore, be less labor efficient and more wasteful of resources such as feed, antibiotics, or energy. All four on-farm users unanimously agreed that PLF technology was mostly used for individual pig monitoring and data collection on sow farms and rarely at the pig level on the grower and finisher farms.

Lastly, all off-farm users who are more cautious of PLF had a limited and indirect understanding of PLF technologies. Those that were familiar with PLF technologies had gained their knowledge through farm visits and inspections (without necessarily using it), particularly in the dairy industry. The off-farm users tend to focus more on pigs rather than the tasks performed by PLF technologies when discussing their views of precision livestock farming technologies. For instance, an off-farm user said, "*I have heard that term, but I would not be able to define what is included in it*". Although most of the stakeholders in this group had never developed or used PLF technology, many of them had heard about PLF and were aware of its potential. While expressing concerns, an on-farm user cautioned that "*precision livestock farming is not meant to replace caretakers.*" Surprisingly, an off-farm user thought PLF sounds like a marketing term and said, "*it sounds like something the salesperson might talk to a producer about.*" (See Appendix 2 for extracts from individual participant transcripts.)

3.2 Practical applications of precision livestock farming

To understand how PLF technologies are being used (i.e., practical applications) in the swine industry, participants were asked to reflect on their work experiences and discuss how it is being used. Most of the stakeholders generally consider PLF technologies to be useful, however, a few think some PLF technologies are more useful than others and less useful in contexts where the externalities outweigh the benefits. The PLF technologies that stakeholders perceived to be useful are the ones that reduce labor, save substantial amounts of time relative to the cost, and bring a high return on investment. Radio Frequency Identification (RFID) tags were generally cited as an example of a useful PLF technology because they are often used for individual identification and alongside Electronic Sow Feeding (ESF) systems.

Moreover, a technology developer mentioned smart tags could be used for tracking the movement and body temperature of pigs as a good example of how PLF is practically being used in the swine industry. The stakeholder however added that this work is at a developmental stage and will not be commercially useful until it is completed. Similarly, another technology developer mentioned that PLF data can be used to generate a farm's profit and loss statement, which can be used to make inform-decisions on the farm. Another practical on-farm application of PLF emphasized by a PLF technology developer was the measurement of pig feed intake, and pig weight, determining feed conversion ratio (FCR), and measuring the environmental conditions of the farm. This according to a technology developer is the Holy Grail of animal production and would have the most important impact on how the animals will convert feed to meat.

Furthermore, precision livestock farming was perceived as being able to contribute to the efficiency of the livestock production process and labor. This was thought to be achieved through early detection of illness, improved animal welfare, improved production efficiency, improved labor efficiency, and substituting technology for labor. A swine farmer emphasized that if PLF is correctly used, it can enable livestock caretakers to improve animal welfare by improving actual specificity in livestock production systems and thereby help caretakers to make better decisions. At the core of it, on-farm users perceived better animal care and welfare as the ultimate good of precision livestock farming. Importantly, most stakeholders agreed that PLF can only be considered useful if it simplifies the life of the animal caregiver and makes their jobs easy. They also reiterated that any technology that creates more work for the pig caregiver will not be adopted, because limited adoption will constitute barriers to PLF usefulness and that PLF will only be useful if users buy into it, which is currently a challenge. Lastly, stakeholders perceived that PLF can be very useful if users have the expertise and time to explore the data it provides.

3.3 Key limitations hindering on-farm precision livestock farming adoption

In this section, we discuss the factors hindering the adoption of PLF technology. Various roles and experiences of the stakeholders were likely to lead them to perceive different limitations regarding the use of PLF in the swine industry. As these perceived disadvantages to PLF must be weighed against perceived benefits, we explicitly asked stakeholders to identify and discuss what they considered to be the main limitations of PLF technology. Among the major factors limiting the optimum utilization of PLF technology on farm identified by the stakeholders were internet connectivity, the need to adapt on-farm daily routines to use PLF data (i.e., use PLF data to make actionable decisions), the need to

modify existing farm buildings and infrastructure to make PLF technology fully implementable, and shortage of skilled labor.

3.3.1 Internet connectivity is a key obstacle to PLF adoption

Many stakeholders mentioned internet connectivity as a key barrier to PLF adoption in the swine industry. Most PLF technologies require a strong and reliable internet connection to collect information and send data to the cloud. Any programs that send data to the cloud must be supported with strong internet otherwise such programs cannot be used. Stakeholders emphasized that internet connections tend to be weak or nonexistent in the countryside where swine farms are often located. They also mentioned that the barn or pen where pigs are housed is often made of steel, which makes the internet signal weaker inside the barn than the outside. Internet connectivity, according to many stakeholders is a major issue in Europe, Australia, and the United States.

3.3.2 Farm building design and SOPs constitute barriers to PLF adoption

Other important key barriers to PLF adoption on swine farms are the way old farm buildings were built. A swine farmer said that the existing barns were not designed to accommodate PLF technology—in terms of structural issues such as ceiling height, access to power, and sensitivity of technology to power washing. Another key barrier mentioned by other participants was the difficulty in integrating PLF data into existing standard operating procedures (SOPs) on the swine farm. According to stakeholders, PLF technology has to be able to almost seamlessly integrate with a producer's management system to be adopted. They are of the opinion that if a technology involves a significant process change to be implemented, it is unlikely that such technology will be adopted by a producer. Moreover, they perceived PLF technology as a problem-solving management tool that generates new information necessary for management decisions. They, however, thought that this new information often does not fit within the existing management practices on the farm, thus making the new information unusable. To address this, stakeholders felt that there is a need to make substantial changes to daily SOPs, which will in turn affect how farm workers perform their daily tasks, thus requiring a significant cultural change on the part of the technology users. All these changes constitute impediments to the optimum usage of PLF technology. Another key barrier to PLF adoption emphasized by stakeholders is the lack of labor with the requisite training and skill to operate PLF and use PLF data to take actionable decisions. They perceived the labor shortage issue as an important problem confronting the livestock industry. Altogether, practical implementation was felt to necessitate changes to existing infrastructure, production system processes, and labor force before PLF technology could be fully implementable on US swine farms.

3.4 Data privacy and human-animal relationships are two key PLF concerns

This section discuss stakeholders' concerns (i.e., fears and worries) about the use of PLF technology in the swine industry. Two major concerns regarding PLF usage in the swine industry perceived by stakeholders are data privacy and the possible threat to human-animal relationships. Stakeholders believed ensuring the privacy of data generated by PLF technology will be a key concern going forward. A recent study by Hazrati et al. (2022) also emphasized this issue and established that farmers are increasingly worried about unauthorized access, collection, and sharing of their data with third parties by agricultural technology providers and cyber-attackers. Another concern mentioned by the stakeholders is the possibility that PLF technology may negatively impact human-animal relationships by affecting farmers' duty of care (Schillings et al., 2021). A participant said PLF technology may transform the livestock industry into something digital. Another study by Fountas et al. (2005) had previously reported that the daily activity of the farmer is gradually changing with the adaptation to PLF technologies that enables less contact compared to traditional farming management. This new adaptation to the PLF concept may compromise human-animal relationships.

3.5 Desired future precision livestock farming innovations

To effectively guide PLF development efforts, it is important to know what PLF technologies stakeholders in the swine industry wish to see developed in the future. To get at this, we asked: "Thinking about precision livestock farming in the future, could you please tell me what innovation you'd like to see?" Most of the innovations discussed here emerged in response to the limitations of current commercially available PLF technologies. Among the existing PLF technologies, RFID, ESF, and cameras seem to be the three technologies for which stakeholders want substantial improvement and innovation. Stakeholders generally believed that these technologies are currently not optimally used due to the existing limitations, drawbacks, and concerns. Stakeholders suggested some innovative PLF technologies they would like to see developed alongside their rationale for wanting these technologies. Some stakeholders only discussed the PLF technology development process that would lead to practical application on the farm and promote buy-in from the users.

In terms of what future PLF technologies should do, stakeholders wanted to see significant improvement in how cameras are used on swine farms. Beyond the current usage of cameras for pig monitoring, they would like to use cameras to identify outcomes (i.e., pig's reaction to their environment) and then automatically use the knowledge to make operational decisions in an automated fashion (i.e., no extra work for humans) that is not disruptive or stressful for pigs. For example, this could be a proactive approach to prevent pigs from getting sick. Another important improvement on the existing use of cameras would be the ability to visually monitor a large group of animals and individually identify welfare and health issues without using an RFID tag. This would also help producers to raise pigs without missing the target weight for each animal and suffering financial penalties as a result.

Besides improved camera systems, innovative PLF technologies for maintaining individual pig identification over time are important to

swine industry stakeholders. Stakeholders are interested in technologies that would help to identify individual pigs from birth to slaughter and record all the information that goes into the production process without using ear tags. They think technology like this will fundamentally change the way pigs are raised by facilitating precise and accurate monitoring of the amount of inputs (e.g., feed, water, etc.), used and outputs (e.g., weights, meat, etc.), generated at the level of individual animals. Given that swine production is a commodity-based production system, and the profit margin is often thin, maintaining individual identification of pigs could help the business to increase the profitability and sustainability of the swine production system through an efficient traceability system. Having reliable individual identification of pigs will also ensure consistent and reliable monitoring and data collection in a cost-effective manner, and foster engagement and buy-in from the end users.

In terms of the new technology development process, it is important to focus on the needs of the farmers first and engage farmers during the technology development process to get buy-in and widespread adoption from farmers. There is a need for a broad discussion of ideas to avoid a situation whereby we engineer PLF technology from a human perspective but neglect the animal perspective and vice versa.

Lastly, currently, available PLF technologies produce enormous quantities of data, but information alone may be overwhelming rather than helpful. Hence, there is a need to ensure PLF data are synthesized to create actionable information of value. Users of PLF technology would like to see data that are relevant to their work in a summarized, easy-to-read, and comprehensible format. They also want data to help them track operations throughout the livestock system to gain a deeper understanding of pig welfare and health issues. Overall, any PLF data that stakeholders (particularly government and welfare certification organizations) can use to monitor records and determine whether a problem identified during a farm visit has been addressed and fixed would be useful to these stakeholders. This is important for ensuring that animal welfare issues are being addressed. The availability of such PLF technology data will help government and welfare certification organizations monitor animal health and welfare on a deeper level throughout the year and reduce the number of visits to the farms.

4 Conclusions

In this study, we found a high level of PLF technology awareness among most swine industry stakeholders. Although stakeholders perceived PLF technologies differently based on their knowledge, roles, and responsibilities, stakeholders collectively agreed to their usefulness. A key perceived PLF benefit was that it can improve specificity in decision-making among swine producers. It can also assist caregivers to provide individualized, refined, and improved pig care. Additional important benefits reported in the study were improved animal health and welfare, increased labor efficiency, and improved feed efficiency.

The study identified some limitations and concerns regarding PLF technology. The poor internet connectivity, the growing need for on-farm daily routine to make use of PLF data (i.e., use PLF data to make actionable decisions), and the need to modify existing farm buildings and infrastructure to allow for PLF technology to be seamlessly integrated into the farm environment constituted the main limitations. Stakeholders are concerned about issues of data ownership and privacy and the influence of PLF technology usage on human-animal relationships and farmers' duty of care to the animals. Finally, this study suggested some future technologies that should be developed. Value was seen in using cameras to improve the health of pigs through the automatic identification of outcomes that can help the caregiver make automated decisions without causing stress or disruption to the pigs. The use of a camera system for individual identification of pigs in a cost-effective way was expected to help the pork production business to increase profitability and sustainability. Additional research to understand a greater range of producer perceptions (i.e., those from smaller or extensive systems) and views of the public (i.e., pork consumers) regarding use of PLF to raise pigs is underway to provide a more complete picture.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by Michigan State University Institutional Review Board (IRB) and was determined to be exempt (from closer scrutiny) under 45 CFR 46.104(d) 2i. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JMS, ST, FA, BV, MB, AJ, MP-G, DR, JPS, DT, and CZ contributed to the conception and design of the grant proposal. JMS, BA, BV, ST, and FA designed the interview guide. BA and BV conducted the interviews. BA performed the statistical analysis. BA wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fanim.2023.1150528/full#supplementary-material

References

Berckmans, D. (2017). General introduction to precision livestock farming. *Anim. Front.* 7, 6–11. doi: 10.2527/af.2017.0102

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101.

Brinkmann, S. (2013). *Qualitative interviewing* (Oxford: Oxford University Press).

Brooks, J., McCluskey, S., Turley, E., and King, N. (2015). The utility of template analysis in qualitative psychology research. *Qual. Res. Psychol.* 122, 202–222. doi: 10.1080/14780887.2014.955224

Christley, R., and Perkins, E. (2010). Researching hard to reach areas of knowledge: qualitative research in veterinary science. *Equine Vet. J.* 42, 285–286. doi: 10.1111/j.2042-3306.2010.00074.x

De Greef, K. H., Bonneau, M., Dransfield, E., Horst, H. S., Klont, R. E., Oude Lansink, A. G. J. M., et al. (2000). "The green piggery initiative: Market and society driven changes in pork production," in *book of abstracts of the 51st annual meeting of the EAAP- European Federation of Animal Science* (The Netherlands: The Hague).

Fischer, C. T. (2009). Bracketing in qualitative research: conceptual and practical matters. *Psychother. Res.* 19 (4-5), 583–590. doi: 10.1080/10503300902798375

Fountas, S., Blackmore, S., Ess, D., Hawkins, S., Blumhoff, G., Lowenberg-Deboer, L., et al. (2005). Farmer experience with precision agriculture in Denmark and the US Eastern corn belt. *Precis Agric.* 6, 121–141. doi: 10.1007/s11119-004-1030-z

Gibbs, G. (2002). *Qualitative data analysis: explorations with NVivo* (Buckingham: Open University Press).

Giersberg, M. F., and Meijboom, F. L. B. (2021). Smart technologies lead to smart answers? on the claim of smart sensing technologies to tackle animal-related societal concerns in Europe over current pig husbandry systems. *Front. Vet. Sci.* 7. doi: 10.3389/fvets.2020.588214

Giorgi, A. (1997). The theory, practice, and evaluation of the phenomenological method as a qualitative research procedure. *J. Phenomenol. Psychol.* 28 (2), 235–260. doi: 10.1163/156916297X00103

Groenewald, T. (2004). A phenomenological research design illustrated. *Int. J. Qual. Methods* 3 (1), 42–55. doi: 10.1177/160940690400300104

Halachmi, I., Tello, A. S., Fernaíndez, A. P., van Hertem, T., Sibony, V., Weyl-Feinstein, S., et al. (2015). *Discussion: how PLF delivers added value to farmers. precision livestock farming applications: making sense of sensors to support farm management* (The Netherlands: Wageningen Academic Publishers), 113–118.

Hazrati, M., Dara, R., and Kaur, J. (2021). On-farm data security: practical recommendations for securing farm data. *Food Syst.* 6, 884187. doi: 10.3389/fsufs.2022.884187

Homola, J. J., Loftin, C. S., Survey, G., Fish, M. C., Cammen, K. M., Sciences, M., et al. (2019). Impact of health challenges on pig growth performance, carcass characteristics, and net returns under commercial conditions. *Transl. Anim. Sci.* 2, 50–61. doi: 10.1093/tas/txx005

Kamphuis, C., Steeneveld, W., and Hogeveen, H. (2015). "Economic modeling to evaluate the benefits of precision livestock farming technologies," in *Precision livestock farming applications: making sense of sensors to support farm management* (The Netherlands: Wageningen Academic Publishers), 163–171.

Kanis, E., Groen, A. B. F., and de Greef, K. H. (2003). Societal concerns about pork and pork production and their relationships to the production system. *J. Agric. Environ. Ethics.* 16, 137–162. doi: 10.1023/A:1022985913847

King, N., and Horrocks, C. (2010). *Interviews in qualitative research* (London: Sage).

King, N. (2012). "Doing template analysis," in *Qualitative organizational research*. Eds. G. Symon and C. Cassell (London: Sage), 426–450.

Krampe, C., Serratosa, J., Niemi, J. K., and Ingenbleek, P. T. M. (2021). Consumer perceptions of precision livestock farming–a qualitative study in three European countries. *Animals* 11, 1221. doi: 10.3390/ani11051221

Langdridge, D. (2007). *Phenomenological psychology: theory, research and method* (Harlow: Pearson Education).

Lima, E., Hopkins, T., Gurney, E., Shortall, O., Lovatt, F., Davies, P., et al. (2018). Drivers for precision livestock technology adoption: a study of factors associated with adoption of electronic identification technology by commercial sheep farmers in England and Wales. *PloS One* 13, e0190489. doi: 10.1371/journal.pone.0190489

Lopes, S., Bexiga, R., Arauújo, J., Cerqueira, J., Abreu, C., Paredes, C., et al. (2016). "Precision livestock farming for reproductive performance optimization: a survey," in *Food futures: ethics, science and culture* (The Netherlands: Wageningen Academic Publishers), 3197–3211.

Makinde, A., Islam, M. M., Wood, K. M., Conlin, E., Williams, M., and Scott, S. D. (2022). Investigating perceptions, adoption, and use of digital technologies in the Canadian beef industry. *Comput. Electron. Agric.* 198, 107095. doi: 10.1016/j.compag.2022.107095

Morrone, S., Dimauro, C., Gambella, F., and Cappai, M. G. (2022). Industry 4.0 and precision livestock farming (PLF): an up-to-Date overview across animal productions. *Sensors (Basel).* 12), 4319. doi: 10.3390/s22124319

Schillings, J., Bennett, R., and Rose, D. C. (2021). Exploring the potential of precision livestock farming technologies to help address farm animal welfare. *Front. Anim. Sci.* 2, 639678. doi: 10.3389/fanim.2021.639678

Shepherd, M., Turner, J. A., Small, B., and Wheeler, D. (2018). Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture revolution. *J. Sci. Food Agric* 100 (14), 5083–5092. doi: 10.1002/jsfa.9346

Siegford, J. M. (2023). "Precision livestock farming and technology in pig husbandry" in *Advances in pig welfare, 2nd ed.* Ed. I. Camerlink (Amsterdam, The Netherlands: Elsevier).

Sinisalo, A., Niemi, J. K., Heinonen, M., and Valros, A. (2012). Tail biting and production performance in fattening pigs. *Livest Sci.* 143, 220–225. doi: 10.1016/j.livsci.2011.09.019

Vranken, E., and Berckmans, D. (2017). Precision livestock farming for pigs. *Anim. Front.* 7, 32–37. doi: 10.2527/af.2017.0106

Werkheiser, I. (2020). Technology and responsibility: a discussion of underexamined risks and concerns in precision livestock farming. *Anim. Front.* 10 (1), 51–57. doi: 10.1093/af/vfz056