REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

Precision Livestock Pig Farming System for Evaluating Animal Welfare: An Exhaustive Review

Mr. Yaduvir Singh[1]*, Deepak Mehta[2], Pawan Chaudhary[3]
*[1]Assistant Professor, Department of CSE (Artificial intelligence), Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh, India, Email Id- yaduyash@niet.co.in, Orcid Id-0000-0002-2552-4797
[2]Associate Professor, Department of Computer Sceince and Information Technology, Jain (Deemed to be University), Bangalore, India, Email Id- m.deepak@jainuniversity.ac.in , Orcid Id- 0000-0001-8502-1203
[3]Assistant Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India, Email Id- pawan.chaudhary@muit.in, Orcid Id- 0009-0000-7596-2341

Abstract

The term sustainable and moral pig farming methods are becoming more and more important as the need for pork production develops around worldwide. By using cutting-edge technology to monitor, manage and enhance animal welfare, precision livestock farming (PLF) that has emerged as a viable approach to address this issue. Pig farming is a form of animal husbandry that uses domestic pigs are raised and grown to use as livestock. To better understand the ways that present PLF technologies aid in pig welfare assessments, this study set out to investigate that possibility. Pigs are exhibit characteristics distinctive to their species and have more opportunities to behavior linked to exercise with posture, eating as well as drinking, other behaviors, physical state and health were measured. Pig farming is referred to as pig husbandry, to represents the disciplined breeding and care of domestic pigs for a variety of uses, mostly the production of meat. Pigs are carefully managed during all stages of their lives from birth to market or breeding age in that agricultural process. This comprehensive review investigates the use of PLF in assessing and advancing pig farming's animal welfare. A description of the essential elements of PLF systems, such as sensor technology, data analytics and automated monitoring equipment, provides at the initial of the assessment. A review of the study concludes that PLF has the potential to improve animal well-being in pig farming.

Keywords: Precision Livestock Farming (PLF), Pig, Animal Welfare, Farm, Feed, Sustainable

INTRODUCTION

Precision livestock farming (PLF) is a method of managing cattle that combines computerized tools and methods. PLF includes an automated animal monitoring to enhance animal welfare, health, productivity and reproduction along with their environmental effect. The three components of animal well-being are fundamental well-being performance, emotional moods and natural living as shown in Figure (1).

Figure (1). Pig Welfare
(Source link: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTl0VUPYxn3yzvJQxLpvSr9eBUDD9SiYXoelQ&usqp=CAU)

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

Animals live in their natural state according to their behavioral requirements daily (1). Animal moods and emotions range from negative to pleasant and these experiences are referred to as affective states. Natural biological processes and animal fitness are the subjects of basic health. These three aspects of animal well-being are evaluated using indicators that are focused on the animal, although the environment is capable of offering insightful data (2). Compared to resource-based measures, animal based indices offer a high accurate assessment about animal welfare. One animal derived measure utilized by Welfare Quality (WQ) is its physical health rating and widely used procedures for evaluating animal welfare, to determine that there is no extended hunger. A resource-based indicator is the availability of water that is utilized instead of a reliable animal-based indication to determine whether or not there is persistent thirst (3). This indicator is limited to provide information about a single component of the environment. Farmers in modern livestock farms require dependable and reasonably priced technology to assist and facilitate everyday job management to ensure precise and ongoing monitoring of individual animals (4). PLF is the management, modelling and monitoring of animal production through the application of technological concepts and methodologies to livestock farming. To satisfy the growing demand for meat while assisting farmers and other livestock supply chain stakeholders, precision livestock farming appears to be the practical solution (5). The goal of PLF is to improve the farmers' capacity to maintain a personal touch with each animal despite the rising intensity of livestock production. Through the behavioral interpretation, observation as well as management of the smallest feasible number of animals, it seeks to establish farming that is socially, ecologically and economically sustainable (6). It assists farmers decrease down on operating expenses including feed, medicine and electricity. The fact that pigs are very hardy, grow fast, have big litter and remain alive on subpar nutrition has contributed to the widespread production of pigs in early agricultural cultures. Pigs remain a central topic of discussion while it pertains to farm animal welfare (7). Pigs had a significant role in the picture of Animal Machines, which is renowned for providing a plain explanation of the problems with farm animal care that arose in the second decade of the 20th century (8). Among additional devices, this law specifies that pigs housed in groups have access to litter or other items that allow them to explore and make themselves comfortable. The pig's habitat is made more enriched to lessen aggressiveness and other abnormal behavior. Tail biting is one of the biggest issues in intensive pig production system (9). The increasing demand from consumers for animal welfare considerations has an impact on farmers perception of animals. Recent developments in pig farming and management practices, such as the implementation of PLF, farm size growth and stall free accommodation for gestating sows, that have an impact on the kinds and numbers of human animal encounters (10). It is examined by looking to find out the care for farm animals, working conditions, especially the ergonomics of workstations, the labour-intensive nature of the task and the work schedule. Addressing farmers about their opinions, experiences and understanding of farm animals is another way to assess it (11). The intensification of pig farming has made it possible to monitor pigs more closely, which has reduced energy losses, optimized space, raised productivity and decreased production costs. Although from an animal welfare perspective, contemporary production practices expose pigs to dubious treatments and modify their natural behaviors (12). Animals were given an assortment about stressful circumstances throughout a productive cycle, including regrouping, high stocking rates, early weaning, prolonged hunger, poor air quality and invasive treatments including castration, tail docking and teeth trimming. There are discussions over the management practices along with confinement conditions in manufacturing processes, which are linked to low well-being, since animals rose in artificial and constrained environments are more likely to experience stress that display undesirable behaviors (13). One significant issue is the risk of relying excess on technology to solve problems, which unintentionally ignores the animals overall requirements. This study aimed to explore the potential to get a better understanding of current PLF technologies used to support pig welfare estimates.

Using PLF for Pig Production

A process of feed intake sensors, growth monitors, cameras and microphones, the PLF technique extends the use of established environmental indicators to directly evaluate animal reactions. The concept maintains that an animal serves as a sensor and the systems utilize an animal's recorded responses to provide crucial metrics for optimal performance, to improved animal welfare and sustainable agricultural methods (14). PLF technology intend to assist farmers in generating daily management choices in the future and provide an early warning system when anything goes wrong in the production system. The sensors output is connected to elements of

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

animal welfare and health, including readiness or respiratory conditions. The farmer is alerted while sensor signals begin to diverge from their predicted levels is shown in Figure (2). The farmer is able to intervene quickly to prevent any detrimental effects on production performance from the identified change in animal reaction (15).

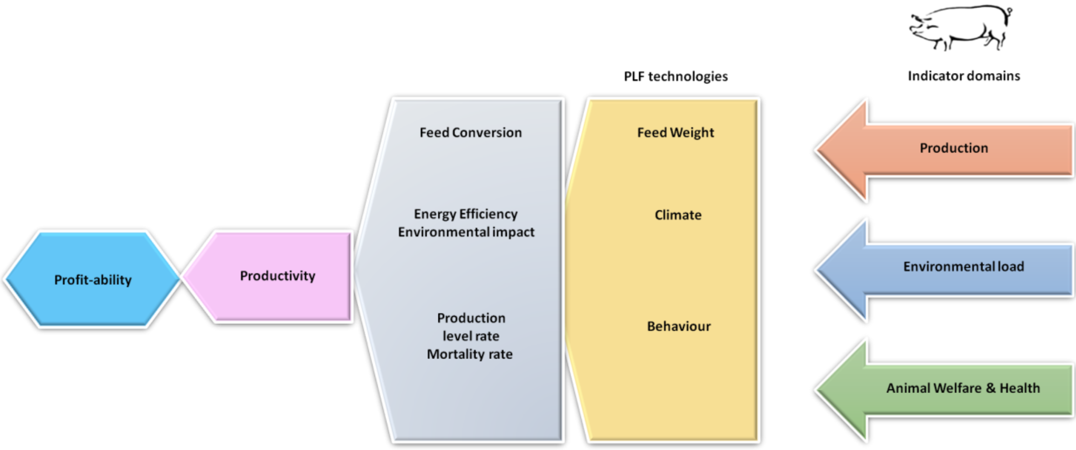

Figure (2). Precision Livestock Pig farming

(Source link: https://d3i71xaburhd42.cloudfront.net/ccb90ce4448fafb6a62866cbf921ed398142f88d/3-Figure2-1.png-)

These include to resolving technical issues like a pressed feeding tube, modifying the temperature and feed control settings, or initiating a soft preventative medical therapy for the animals. Preventive medical care stops respiratory illnesses from spreading inside the confinements and it is possible to limit or eliminate the need for antibiotics. The PLF sensors that are used with pigs include water meters, feed supply monitors, animal weight sensors, video systems that track animal movements and sound monitoring devices that check for respiratory conditions. A sequential strategy is used in the commercialization of the PLF systems, starting with weight, feed intake and water intake (16).

The Welfare of Animals in Pig Farming

Pigs are housed in groups on solid floors, while root and find bedding made of straw or other materials. There is less congestion, conflict, boredom and tail-biting, but there is more chance for natural behavior and unrestricted mobility inside the pen or shed despite the lack of outside access (17) Worldwide pig production and consumption observed strong fluctuations between 2015 and 2022, which were mirrored in changes of the supply and demand for food. Pork output increased steadily throughout the period due to better breeding techniques, higher feed efficiency and increasing mechanization of pig farming. Several areas observed increased output, which contributed to the overall growth of the pork industry are depicted in Figure (3) and Table (1).

Table (1). Numerical outcomes of Production and consumption (2015 - 2022) (Source: https://www.pig333.com/3tres3_common/art/pig333/17895/home.jpg)

Unsorted	Production and consumption		
	Production	**Consumption**	**Imports**
2015	57	58	6
2016	55	56	20
2017	54	55	17
2018	53	54	16
2019	44	45	28

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

2020	36	42	54
2021p	52	58	48
2022p	41	48	51

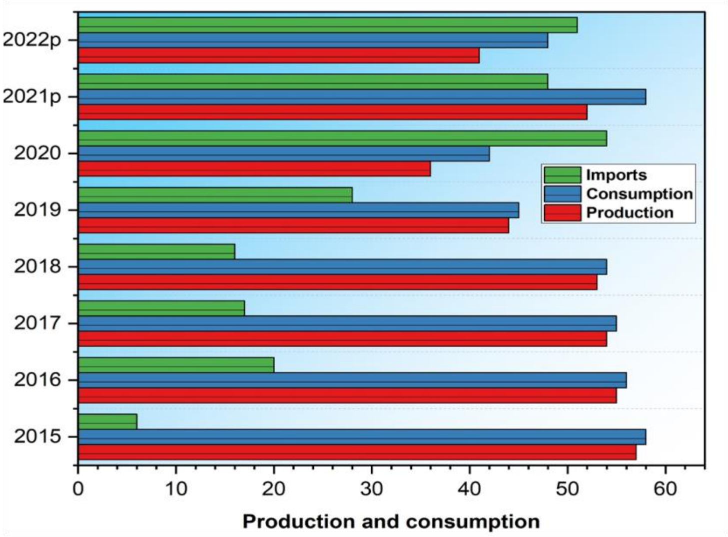

Figure (3). Production and consumption (2015 - 2022)

(Source link: https://www.pig333.com/3tres3_common/art/pig333/17895/home.jpg)

Consumers believe that animals raised organically grow up to very high standards. Although it is difficult to provide an accurate definition for the term, it is unclear that the way consumers believe that animal welfare entails. Living in a tolerable state of physical and psychological harmony with their surroundings represent the definition of animal welfare, the environment has to a calibre that allows the animal to adapt to its surroundings (18). The worldwide output and pig population dynamics of the pig farming industry observed notable developments between 2011 and 2020. Pig output increased during this time due to an increase in the demand for pork products worldwide. Pig populations fluctuated across different locations due to a variety of circumstances, including disease outbreaks, market needs and regulatory changes. Increased output was a result of better breeding techniques and technological developments in certain fields as shown in Table (2) and Figure (4).

Table (2). Numerical outcomes of Production and population (2011 - 2020) (Source: https://www.researchgate.net/publication/359894305/figure/fig1/AS:11431281202021153@1698683802418/Pig-population-and-pork-production-in-Sri-Lanka-2011-2020-Data-source-Department-of.png)

Year	Pig Population	Pork Production (mt)
2011	82000	110000
2012	88000	120000
2013	90000	120000
2014	70000	120000
2015	93000	120000
2016	130000	120000
2017	150000	130000
2018	190000	170000
2019	170000	150000
2020	170000	150000

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

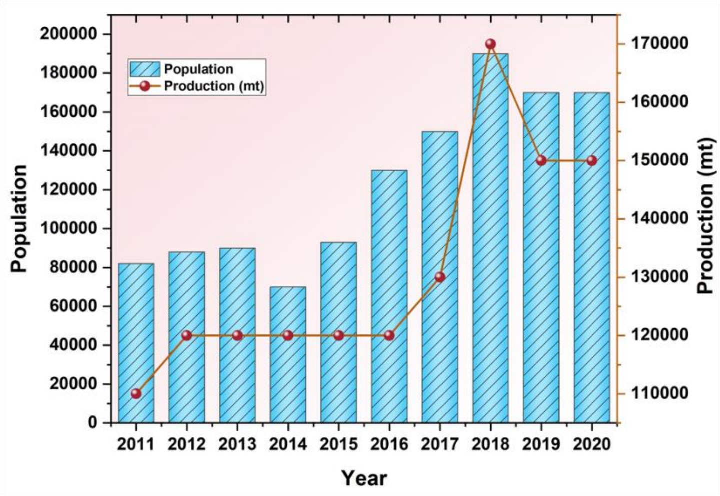

Figure (4): Pork Production and Pig Population (2011 - 2020)

(Source link: https://www.researchgate.net/publication/359894305/figure/fig1/AS:11431281202021153@1698683802418/Pig-population-and-pork-production-in-Sri-Lanka-2011-2020-Data-source-Department-of.png)

It has been made for the inclusion of scientific and moral components in animal welfare. The majority of customers probably believe that animal welfare concentrates on the facts related to values and animal emotions, it is essential to bring up these issues in discussions. It is crucial to focus on animal behavior and health rather than animal sentiments to get quantifiable outcomes (19).

The farmer reflects significant importance

The data available fails to endorse the idea that an organic pig has a better health. There are similarities between the specifications and advice given for conventional and organic farming. Recognize that the primary responsibility for the welfare of farm animals lies with the farmer and the following regulations offer an opportunity to ensure the animals have a pleasant existence (20).

Space, roughage and behavior

The main contrast among standard and ecological animal management is the degree that an animal's natural behavior is honoured. These days, natural behavior is taken into consideration by Nordic animal protection laws, but it is more significant in organic farming. Pig welfare depends on bedding and roughage in many different ways. Pigs have a limited capacity to control their body temperatures consequently it is susceptible to change temperature (21). Pigs like to bite and root as well. To eat straws instead of each other, for example, it is more pleasant. Organic farms prohibit tail-docking. That makes sense since biting one's tail is a reliable sign of diminished well-being and eliminating the sign fails to address the real root of the issue. Additionally beneficial to intestinal health, roughage lessens feelings of hunger (22). Straw is an essential ingredient for the farrowing sow to build the facility. The sow's well-being is enhanced by the opportunity to engage in nest-building activities. While gestation with a box is beneficial for the sow, it is sometimes be deadly for the piglets. According to organic standards, each pig has at least 0.6 m^2 of solid floor since pigs like to rest on solid surfaces. Pigs sleep at a live weight of between 100 and 110 kg, which is sufficient (23).

Healthcare and medications

The primary goal of organic farming is to avoid infections by choosing the right breeds, providing animals with wholesome food and creating ideal environmental circumstances for animals. It has been recommended that smaller breeds with exciting skins are used to assist pigs in providing excess heat and prevent sunburn (24). The health of the farm gets greater consideration while producing pigs. Get rid of serious immunosuppressive

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

diseases like organized and enzootic pneumonia is difficult on small organic farms. As organic farms grow in number and scale, the state of their fundamental health becomes even more crucial (25). One of the main tenets of organic farming is the idea that prevention is better than therapy. Wider space regulations and animal population restrictions lower the risk of illness and lessen the demand for antibiotics on the farm (26). Pig stress is decreased by using roughage and straw, as well as by letting animals move freely. This helps in preserving the pigs' healthy immune. Piglets are prevented from infections by using effective procedures such as early castration and teeth grinding (27).

Technologies using Cameras

In several instances, the internal validation of vision-based technologies yielded very encouraging outcomes, with accuracy levels above 95%. Few external validations are able to bolster performance results with the same excellence in nature for vision-based monitors. Using image analysis, it is possible to evaluate the postures of sows during pigs are standing, lying and sitting, to assess the patterns of lying in pigs kept in groups, determine the location of animals, recognize between drinking as well as drinker playing behavior, recognize feeding behavior, realize the aggression events, tail biting and estimate body weight (28).

Animal posture variations serve as health markers. While vision-based technologies can't accurately analyze specific postures, it differentiates between resting patterns and standing active actions like walking or eating. Image analysis predicted lying position is a sign of health issues. For example, alterations in the length and frequency of resting caused by illnesses, lesions and stressful circumstances are linked to harmful behavior outbreaks. The capacity of sows to nurse and maintain thermal comfort in the enclosure is inferred from their resting habits. The animals' habits of daily activities are evaluated by lying posture. To evaluate lameness, a significant welfare concern particularly with sows, image methods that identify locomotion and axial body movement are promising (29). To recognize as critical to pig welfare, image-based technology measures water consumption and drinking habits. Through the constant observation of pig behavior, vision-based technologies hold significant promise for evaluating animal wellbeing. This is used to identify alterations and departures from typical behavioral patterns that are associated with an animal's emotional condition. A pig's emotional condition is connected to some unique characteristics, such as the way its tail is positioned, which provide valuable information about tail-biting epidemics (30).

Flow meters and load cells

Flow meters and load cells are covered in the same section because of the close relationship between their use in welfare evaluation and feed-intake monitoring. Force plates are another feature of load cells. Body weight has been measured using scales that are insufficient for individual identity (31). At the group and individual levels, reported differences are around 1 kg. While using RFID in conjunction with load-cell devices, body weight is estimated with a 3% percentage error, which is less accurate than an ordinary scale. It was discovered that 90% accuracy was achieved while tracking feeding volume divided by intake of food measurement with RFID computerized stations (32).

Flow Measurements

Flow meters used to measure water consumption in addition to drinking patterns has shown that helpful to forecast a various welfare problems, including the occurrence of sickness and epidemics of tail biting. While warning algorithms were used to analyze deviations from the typical daily pattern in water intake, it was shown that the algorithms could accurately anticipate an outbreak of feces one day before any clinical symptoms appeared (33).

Forced Plates

According to the severe distress it causes and the difficulties that result in obtaining food and water, lameness is a common and significant welfare issue. Furthermore, the typical slatted floor housing used in pig farms makes the issue worse. Lameness is difficult to diagnose visually due to subjectivity in observations and stocking

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

density. While the most impacted animals miss out on meals, their bodies become less healthy (34). This captures the notice of farm workers and typically conducts observation.

Measurements of acceleration

Accelerometers are used to categorize activities and postures, with a performance range of 75% to 100% for activity detection and classification. With an accuracy of 86%, nest-building behavior is tracked by categorizing postures and activities to forecast while the piglet is predicted to born. Acceleration data have been utilized with up to 93% accuracy to identify lameness based on sow postures (35). A test to provide early illness alarms, acceleration and body temperature data together achieved 97% sensitivity and 89% specificity.

Microphones

More than 73% of vocalizations are accurately assessed and classified using microphones. Using vocalization signal length and intensity as a gold standard, one sound-analysis system was able to identify between stress vocalizations related to pain with 98% accuracy. The recognition of sounds associated with thirst, hunger and extreme heat. A 95% confidence interval was attained in cough detection utilizing microphones to locate sick piglets at barn level (36). The accurate identification ratio of suffering pigs' cough sounds was likewise observed to range from 73 to 93%. Coughing pigs have been identified through sound analysis. Coughing is a symptom of bad weather or respiratory issues at the very least. Therefore, measuring cough is a pertinent signal that aids in the evaluation of animal welfare, even though it is not done on an individual basis (37).

Thermal Cameras

The primary purpose of thermal cameras is to measure body temperature. While it reaches specific thresholds, body temperature is indicating fever, hypothermia, or both. Regarding this reason, it is important to discuss animal welfare. It seems that thermal imaging has promise for tracking physiological reactions like as inflammation linked to lameness and animal dispersal in response to housing temperature (38).

Photoelectric Sensors

The sensor type having activity measurement of external validation data, photoelectric sensors, had a precision of less than 90%. These sensors demonstrated 64% sensitivity and 88% specificity in their ability to identify changes in position of puerperal sows. Due to their ability to detect movement, photoelectric sensors provide important data on activity levels and postural changes that help to assess well-being (39).

Radio-frequency identification (RFID)

RFID is utilized for personal identification, which is necessary to adopt a welfare assessment that gets ever more customized. While combined with a variety of additional gadgets, such as scales along with automated feeds and drinks, RFID is very helpful. RFID enables the tracking of animal welfare. It has other beneficial uses, such as tracking social interactions as a potential route for disease transmission, as the duration and intensity of an individual's contact with another person that is a sign of disease transmission (40).

Sensors for Body Temperature without Contact

Its limited use as a substitute for temperature monitoring was demonstrated by sensors. There was a negative association between the number of animals and the length of the monitoring period. Comparing the accuracy of infrared thermometers with rectal temperature as the gold standard for body temperature measurement yielded similar results. A variety of environmental factors, including stocking density, barn and pen layout, sunshine, air circulation and ambient temperature, affect the accuracy of infrared thermometry for determining pig body temperature (41).

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 10 October 2023; Revised: 23 November 2023; Accepted: 17 December 2023

PLF Technology Developments and Needs for Pig Welfare Evaluation

Reliable information on the health of farmed animals is required to promote the openness of animal farming. Despite all, the animals stand to benefit from the information that is used correctly. It is possible to assist manufacturers and consumers in making choices based on information. Animal welfare and health conditions are closely monitored by producers for the benefit of the animals and the effectiveness of their output (42). Therefore, these two distinct strategies one focused on minimizing negative effects and the other on maximizing good effects produce quite different results. A different approach to consider the amount of a resource is required to maximize a favorable welfare result. To investigate the impact of increased straw allocation on pig's exploratory behavior and found that there was an inflection point at around 250 g/pig/day, beyond which more straw availability had a declining influence on exploratory behavior as shown in Figure (5).

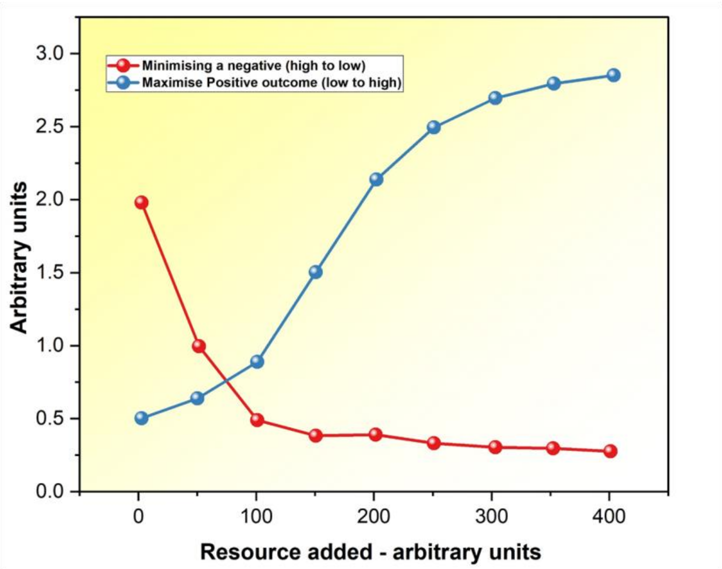

Figure (5). Pig welfare improvements (Source: Author)

To assist them in differentiating between improved welfare friendly products, prospects were requesting accurate data regarding wellbeing of agricultural animals. Recent developments in sensor technology make it possible to monitor several indicators that give details of welfare condition for livestock on farms with an automated to systematic manner. Labeling is created from this data to provide customers with helpful information (43). The PLF technology is used physiological along with behavioral variables to provide continuous well-being information. The result in a continuous and systematic evaluation of various phases of the animals' lives along with the future, which was able to transform animal welfare, is evaluated. These make it possible to look into specific variations from normalcy, resulting in a welfare assessment that is less reliant on environmental indications.

CONCLUSION

A comprehensive review of the PLF method for assessing animal wellbeing presents relevant details regarding the technology and animal welfare interface with pig farming. An accomplished method for managing, optimizing and keeping updated on many aspects of pig welfare is made possible by the combination of PLF methods, data analytics and modern sensors. Assessing significant metrics including behavior, health and environmental state underscores PLF's capacity to transform conventional pig farming methods. Furthermore, the degree of welfare improvement depends on whether management practices are modified using the PLF data to minimize unfavorable effects and whether steps are taken to address the underlying causes of the problems rather than treating their symptoms. This evaluation is an asset for stakeholders that desire to support the effective and humane management of pig farming systems as the industry develops. The review discusses the many technologies and approaches used in precision pig farming and emphasizing their capacity to monitor that enhances the welfare of pigs. The assessment method become more complicated due to the changing nature of animal welfare and the subjectivity of certain welfare indices. Subsequent advancements will focus on enhancing sensor technology to provide even more precise data on animal behavior and health.

REFERENCES

1. Albernaz-Gonçalves, R., Olmos Antillón, G., & Hötzel, M. J. (2022). Linking animal welfare and antibiotic use in pig farming—A review. Animals, 12(2), 216.Doi: 10.3390/ani12020216
2. Delsart, M., Pol, F., Dufour, B., Rose, N., & Fablet, C. (2020). Pig farming in alternative systems: strengths and challenges in terms of animal welfare, biosecurity, animal health, and pork safety. Agriculture, 10(7), 261.Doi:10.3390/agriculture10070261
3. Albernaz-Gonçalves, R., Olmos, G., & Hötzel, M. J. (2021). My pigs are ok, why change?–animal welfare accounts of pig farmers. Animal, 15(3), 100154.Doi:10.1016/j.animal.2020.100154
4. Pol, F., Kling-Eveillard, F., Champigneulle, F., Fresnay, E., Ducrocq, M., & Courboulay, V. (2021). Human–animal relationship influences husbandry practices, animal welfare and productivity in pig farming. Animal, 15(2), 100103.Doi:10.1016/j.animal.2020.100103
5. Racewicz, P., Ludwiczak, A., Skrzypczak, E., Składanowska-Baryza, J., Biesiada, H., Nowak, T., ... & Ślósarz, P. (2021). Welfare health and productivity in commercial pig herds. Animals, 11(4), 1176.Doi:10.3390/ani11041176
6. Stygar, A. H., Chantziaras, I., Toppari, I., Maes, D., & Niemi, J. K. (2020). High biosecurity and welfare standards in fattening pig farms are associated with reduced antimicrobial use. Animal, 14(10), 2178-2186.Doi:10.1017/S1751731120000828
7. Hockenhull, J., Main, D. C., & Mullan, S. (2019). 'Would it sell more pork?'Pig farmers' perceptions of Real Welfare, the welfare outcome component of their farm assurance scheme. animal, 13(12), 2864-2875.Doi:10.1017/S1751731119000946
8. Tzanidakis, C., Simitzis, P., Arvanitis, K., & Panagakis, P. (2021). An overview of the current trends in precision pig farming technologies. Livestock Science, 249, 104530.Doi:10.1016/j.livsci.2021.104530
9. Väärikkälä, S., Hänninen, L., & Nevas, M. (2019). Assessment of welfare problems in Finnish cattle and pig farms based on official inspection reports. Animals, 9(5), 263.Doi:10.3390/ani9050263
10. Schukat, S., von Plettenberg, L., & Heise, H. (2020). Animal welfare programs in germany—an empirical study on the attitudes of pig farmers. Agriculture, 10(12), 609.Doi:10.3390/agriculture10120609
11. Leeb, C., Rudolph, G., Bochicchio, D., Edwards, S., Früh, B., Holinger, M., ... & Dippel, S. (2019). Effects of three husbandry systems on health, welfare and productivity of organic pigs. Animal, 13(9), 2025-2033.Doi:10.1017/S1751731119000041
12. Godyń, D., Nowicki, J., & Herbut, P. (2019). Effects of environmental enrichment on pig welfare—a review. Animals, 9(6), 383.Doi:10.3390/ani9060383
13. Pietrosemoli, S., & Tang, C. (2020). Animal welfare and production challenges associated with pasture pig systems: A review. Agriculture, 10(6), 223.Doi:10.3390/agriculture10060223
14. Remus, A., Hauschild, L., Methot, S., & Pomar, C. (2020). Precision livestock farming: real-time estimation of daily protein deposition in growing–finishing pigs. animal, 14(S2), s360-s370.Doi:10.1017/S1751731120001469
15. Diana, A., Carpentier, L., Piette, D., Boyle, L. A., Berckmans, D., & Norton, T. (2019). An ethogram of biter and bitten pigs during an ear biting event: first step in the development of a Precision Livestock Farming tool. Applied Animal Behaviour Science, 215, 26-36.Doi:10.1016/j.applanim.2019.03.011
16. Witte, J. H., Gerberding, J., Melching, C., & Gómez, J. M. (2021, July). Evaluation of deep learning instance segmentation models for pig precision livestock farming. In Business Information Systems (pp. 209-220). Doi:10.52825/bis.v1i.59
17. Gómez, Y., Stygar, A. H., Boumans, I. J., Bokkers, E. A., Pedersen, L. J., Niemi, J. K., ... & Llonch, P. (2021). A systematic review on validated precision livestock farming technologies for pig production and its potential to assess animal welfare. Frontiers in Veterinary Science, 8, 660565.Doi:10.3389/fvets.2021.660565

18. Maes, D. G., Dewulf, J., Piñeiro, C., Edwards, S., & Kyriazakis, I. (2020). A critical reflection on intensive pork production with an emphasis on animal health and welfare. Journal of animal science, 98(Supplement_1), S15-S26.Doi:10.1093/jas/skz362
19. Sandøe, P., Hansen, H. O., Rhode, H. L. H., Houe, H., Palmer, C., Forkman, B., & Christensen, T. (2020). Benchmarking farm animal welfare—A novel tool for cross-country comparison applied to pig production and pork consumption. Animals, 10(6), 955. Doi:10.3390/ani10060955
20. Peden, R. S., Akaichi, F., Camerlink, I., Boyle, L. A., & Turner, S. P. (2019). Pig farmers' willingness to pay for management strategies to reduce aggression between pigs. PloS one, 14(11), e0224924.Doi:10.1371/journal.pone.0224924
21. Argemí-Armengol, I., Villalba, D., Tor, M., Bertolín, J. R., Latorre, M. A., & Álvarez-Rodríguez, J. (2020). Effects of dietary roughage on organic pig performance, behaviour and antioxidants accretion in perirenal adipose tissue. Livestock Science, 241, 104255.Doi:10.1016/j.livsci.2020.104255
22. Mkwanazi, M. V., Ncobela, C. N., Kanengoni, A. T., & Chimonyo, M. (2019). Effects of environmental enrichment on behaviour, physiology and performance of pigs—A review. Asian-Australasian journal of animal sciences, 32(1), 1.Doi:10.5713%2Fajas.17.0138
23. Andersen, H. M. L., Kongsted, A. G., & Jakobsen, M. (2020). Pig elimination behavior—A review. Applied Animal Behaviour Science, 222, 104888. Doi:10.1016/j.applanim.2019.104888
24. Diana, A., Snijders, S., Rieple, A., & Boyle, L. A. (2021). Why do Irish pig farmers use medications? Barriers for effective reduction of antimicrobials in Irish pig production. Irish Veterinary Journal, 74(1), 1-14.Doi:10.1186/s13620-021-00193-3
25. Little, S. B., Crabb, H. K., Woodward, A. P., Browning, G. F., & Billman-Jacobe, H. (2019). Water medication of growing pigs: sources of between-animal variability in systemic exposure to antimicrobials. Animal, 13(12), 3031-3040. Doi:10.1017/S1751731119001903
26. Toya, R., Sasaki, Y., Uemura, R., & Sueyoshi, M. (2022). Optimizing antimicrobial use by improving medication adherence among pig producers. Animal Science Journal, 93(1), e13713.Doi:10.1111/asj.13713
27. Vandael, F., Filippitzi, M. E., Dewulf, J., Daeseleire, E., Eeckhout, M., Devreese, M., & Croubels, S. (2019). Oral group medication in pig production: characterising medicated feed and drinking water systems. Veterinary Record, 185(13), 405-405.Doi:10.1136/vr.105495
28. Arulmozhi, E., Bhujel, A., Moon, B. E., & Kim, H. T. (2021). The application of cameras in precision pig farming: An overview for swine-keeping professionals. Animals, 11(8), 2343.Doi:10.3390/ani11082343
29. Pandey, S., Kalwa, U., Kong, T., Guo, B., Gauger, P. C., Peters, D. J., & Yoon, K. J. (2021). Behavioral monitoring tool for pig farmers: Ear tag sensors, machine intelligence, and technology adoption roadmap. Animals, 11(9), 2665.Doi:10.3390/ani11092665
30. Guo, Q., Sun, Y., Orsini, C., Bolhuis, J. E., de Vlieg, J., Bijma, P., & de With, P. H. (2023). Enhanced camera-based individual pig detection and tracking for smart pig farms. Computers and Electronics in Agriculture, 211, 108009. Doi:10.1016/j.compag.2023.108009
31. Yeo, U. H., Lee, I. B., Kim, R. W., Lee, S. Y., & Kim, J. G. (2019). Computational fluid dynamics evaluation of pig house ventilation systems for improving the internal rearing environment. Biosystems engineering, 186, 259-278.Doi:10.1016/j.biosystemseng.2019.08.007
32. Cheng, D., Ngo, H. H., Guo, W., Chang, S. W., Nguyen, D. D., Liu, Y., ... & Chen, Z. (2021). Evaluation of a continuous flow microbial fuel cell for treating synthetic swine wastewater containing antibiotics. Science of the Total Environment, 756, 144133.Doi:10.1016/j.scitotenv.2020.144133
33. Secco, C., da Luz, L. M., Pinheiro, E., de Francisco, A. C., Puglieri, F. N., Piekarski, C. M., & Freire, F. M. C. S. (2020). Circular economy in the pig farming chain: Proposing a model for measurement. Journal of Cleaner Production, 260, 121003Doi:10.1016/j.jclepro.2020.121003
34. Hu, J., Wen, J., Li, H., Duan, W., Fan, S., Xiao, H., & Chen, S. (2022). Experiment and numerical simulation on the fine particle migration behaviors for the collection efficiency enhancement of a wire-plate electrostatic precipitator in pig house. Computers and Electronics in Agriculture, 199, 107145.Doi:10.1016/j.compag.2022.107145
35. Morris, B. K., Davis, R. B., Brokesh, E., Flippo, D. K., Houser, T. A., Najar-Villarreal, F., ... & Gonzalez, J. M. (2021). Measurement of the three-axis vibration, temperature, and relative humidity profiles of

commercial transport trailers for pigs. Journal of Animal Science, 99(2), skab027. Doi:10.1093/jas/skab027

36. Wang, S., Jiang, H., Qiao, Y., Jiang, S., Lin, H., & Sun, Q. (2022). The Research Progress of Vision-Based Artificial Intelligence in Smart Pig Farming. Sensors, 22(17), 6541.Doi:10.3390/s22176541
37. Shen, W., Ji, N., Yin, Y., Dai, B., Tu, D., Sun, B., ... & Zhao, Y. (2022). Fusion of acoustic and deep features for pig cough sound recognition. Computers and Electronics in Agriculture, 197, 106994.Doi:10.1016/j.compag.2022.106994
38. Stukelj, M., Hajdinjak, M., & Pusnik, I. (2022). Stress-free measurement of body temperature of pigs by using thermal imaging–Useful fact or wishful thinking. Computers and Electronics in Agriculture, 193, 106656.Doi:10.1016/j.compag.2021.106656
39. Dalla Costa, O. A., Dalla Costa, F. A., Feddern, V., dos Santos Lopes, L., Coldebella, A., Gregory, N. G., & de Lima, G. J. M. M. (2019). Risk factors associated with pig pre-slaughtering losses. Meat Science, 155, 61-68.Doi:10.1016/j.meatsci.2019.04.020
40. Brown-Brandl, T. M., Adrion, F., Maselyne, J., Kapun, A., Hessel, E. F., Saeys, W., ... & Gallmann, E. (2019). A review of passive radio frequency identification systems for animal monitoring in livestock facilities. Applied Engineering in Agriculture, 35(4), 579-591Doi: 10.13031/aea.12928) @2019
41. Zhang, Z., Zhang, H., & Liu, T. (2019). Study on body temperature detection of pig based on infrared technology: A review. Artificial intelligence in agriculture, 1, 14-26. Doi:10.1016/j.aiia.2019.02.002
42. Cruz, V., Rico, J., Coelho, D., & Baptista, F. (2022). Innovative PLF Tool to Assess Growing-Finishing Pigs' Welfare. Agronomy, 12(9), 2159.Doi:10.3390/agronomy12092159
43. Nan, J. I., Yanling, Y. I. N., Weizheng, S. H. E. N., Shengli, K. O. U., Baisheng, D. A. I., & Guowei, W. A. N. G. (2022). Pig Sound Analysis: A Measure of Welfare. Smart Agriculture, 4(2), 19.Doi:10.12133/j.smartag.SA202204004